

A LITERATURE REVIEW ON MITIGATION STRATEGIES FOR ELECTRICAL COMPONENT OBSOLESCENCE IN MILITARY-BASED SYSTEMS

R.M. Rust^{1*}, A.Elshennawy¹ & L. Rabelo¹

ARTICLE INFO

Article details

Submitted by authors 11 May 2021
Accepted for publication 17 Jan 2022
Available online 06 May 2022

Contact details

* Corresponding author
ryanrust18@gmail.com

Author affiliations

¹ Department of Industrial Engineering and Management Systems, University of Central Florida, Florida, United States of America

ORCID® identifiers

R.M. Rust
0000-0001-9829-6679

A.Elshennawy
0000-0003-1245-7692

L. Rabelo
0000-0001-6833-8612

DOI

<http://dx.doi.org/10.7166/33-1-2519>

ABSTRACT

The aim of this research is to conduct an all-inclusive investigation on past studies of obsolescence, the issues involved, and tactics for mitigation in military-based systems. This research investigates four categories: 1. Obsolescence Consequences, 2. Life Cycle Stages and Strategies for Life Cycle Management, 3. Design for Obsolescence and Cost Optimisation, and 4. Management and Tools. A quantitative approach was used to determine the key topics of the 55 articles used in this literature review. A keyword and topic matrix was used to determine the six main areas of concern in current research, and then broken down further into the four categories discussed in this paper. A deep dive into the literature shows that the main areas of concern for obsolescence are cost optimisation, obsolescence management, system life cycle, design/system refresh planning, architecture/open systems, and end-of-life (EOL) predictions. In the EOL predictions category, only one article proposed the idea of machine learning as a forecasting method. This effort suggests a need for a more streamlined management approach to tackling obsolescence. Newer research shows an interest shift from system life cycle management towards forecasting techniques and looking towards future proactive management improvements. This study demonstrates opportunities and challenges for entities dealing with component obsolescence and methods for minimising the issues that go along with it. This paper identifies current practices for obsolescence management, and points to areas for further research development.

OPSOMMING

Die doel van hierdie navorsing is 'n allesomvattende ondersoek oor vorige studies van veroudering, sowel die betrokke kwessies en taktiek vir versagting in militêre stelsels. Vier kategorieë word ondersoek: 1. Verouderingsgevolge, 2. Lewensiklusstadia en -strategieë vir lewensiklusbestuur, 3. Ontwerp vir veroudering en koste-optimering, en 4. Bestuur en gereedskap. Met behulp van 'n kwantitatiewe benadering is die sleutelonderwerpe van 55 artikels in die literatuuoroorsig bepaal. 'n Sleutelwoord- en onderwerpmatriks is gebruik om ses hoofareas van kommer in huidige navorsing te bepaal, en is dit verder afgebreek in die vier kategorieë wat in hierdie artikel bespreek word. 'n Detail analise in die literatuur toon dat die hoofareas van kommer vir veroudering koste-optimering, verouderingsbestuur, stelsel-lewensiklus, ontwerp /stelselvernuwingsbeplanning, argitektuur/ oop stelsels en lewensduur voorspellings is. In die lewensduur-voorspellingskategorie het slegs een artikel masjienleer as 'n voorspellingsmetode voorgestel. Dit dui op 'n behoefte aan 'n meer vaartbelynde bestuursbenadering om veroudering aan te pak. Nuwer navorsing toon dat belangstelling verskuif van stelsellewensiklusbestuur na voorspellingstegniese en proaktiewe bestuurverbeterings. Hierdie studie demonstreer geleenthede en uitdagings vir entiteite wat te doen het met komponent-veroudering en metodes om die kwessies wat daarmee gepaardgaan, te minimeer. Hierdie artikel identifiseer huidige praktyke vir verouderingsbestuur, en identifiseer areas vir verdere ontwikkeling

1 INTRODUCTION

Obsolescence is a costly phenomenon that has the greatest impact on technologies with long system life cycles. The United States military has termed this issue ‘diminishing manufacturing sources and material shortages’ (DMSMS). These long life cycle products include airplanes, ships, industrial equipment, medical equipment, and military systems, which are slow to implement new technology and leading-edge technology – often because of the expense and the length of time that accompanies the development of a new product [1]. According to Underwood [2], since the 1970s ever-expanding commercial markets have surpassed the needs of the military, and companies have no longer manufactured military-specific components. This has forced the military to use commercial off-the-shelf (COTS) parts, and so they are at the mercy of the demand of the electronics market. In 1975 the military controlled around 17% of the electrical component market share; by 1995 it controlled less than 1% [3].

This research explores the various consequences, mitigation strategies, management techniques, and possible future areas of research in the field of obsolescence for military systems. These systems typically have a longer life than most commercial products and require a well-structured sustainment protocol during their life cycle. A deep dive into the literature, as shown in Figure 1 below, shows that the main areas of concern for obsolescence are cost optimisation, obsolescence management, system life cycle, design/system refresh planning, architecture/open systems, and end-of-life predictions. It should be noted that, in the end-of-life (EOL) predictions category, of the six articles, only one proposed the idea of machine learning. This followed an exhaustive search for any article related to obsolescence in military systems or systems with long life cycles. These areas of interest will be covered in each of the following categories below.

1. Obsolescence consequences
2. Life cycle stages and strategies for life cycle management
3. Design for obsolescence and cost optimisation
4. Management and tools

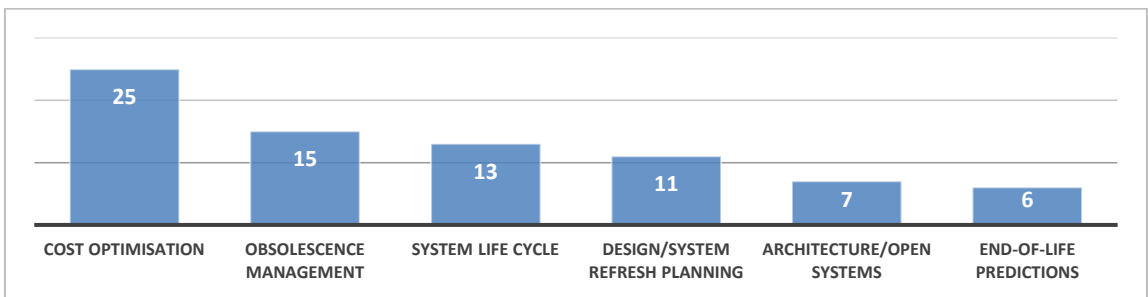


Figure 1: Literature keywords and main topics

Of the 55 articles reviewed, 45% came from the academic sector, 35% from the industry sector, and 20% from government sources. While most of the articles from all three sectors emphasised life cycle or obsolescence management and minimising costs, the academic sector had many articles focusing on forecasting techniques and looking towards future improvements. Some of these topics were forecasting design refresh points and predicting obsolescence dates. Figure 2 below shows the sectors of the literature reviewed, with the number of articles for each.

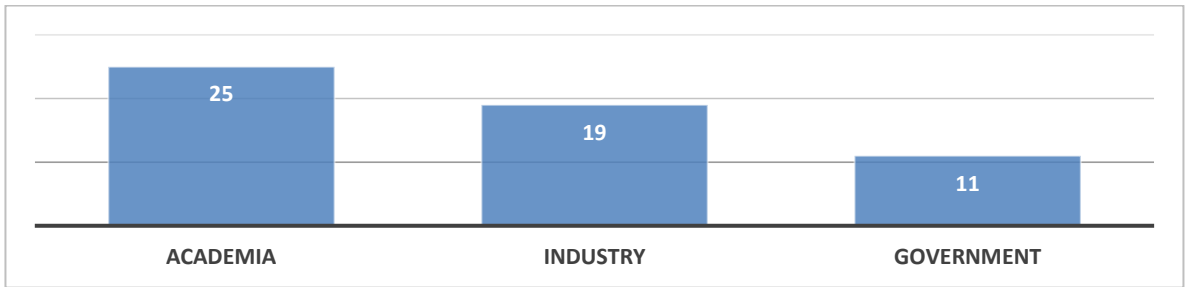


Figure 2: Sectors of literature reviewed, with numbers of articles

2 OBSOLESCENCE CONSEQUENCES

Electronic component obsolescence is one of the largest technical risks a system can face in its operational uptime and maintainability [4]. Various mitigation techniques can be implemented, but they all affect the reliability, maintainability, and cost of a system [5]. When selecting new components for redesign because of obsolescence, their reliability and maintainability must be taken into consideration. When left unchecked, obsolescence can put entire product lines out of commission owing to an inability to manufacture new products or repair existing ones; and this has an excessive impact on business continuity and the maintainability of a system [6]. The following examples paint a picture of the financial risk and impact of component obsolescence on various sectors in the military and related environments:

- “Obsolescence is also very expensive, costing the US Navy (USN) hundreds of millions of dollars each year” [4].
- “The Deputy Under Secretary of Defense for Logistics (USA) indicates that the average cost to redesign a (single) circuit card to eliminate obsolete components is \$250,000” [4].
- “The [US] Air Force is reprogramming \$81 million for the F-22 program to purchase obsolete or soon-to-be out-of-production parts and to redesign assemblies to accept commercial parts” [4].
- “An avionics manufacturer for the commercial airlines spent \$600,000 to replace an obsolete Intel chip” [4].
- “The F-16 program has spent \$500 million to redesign an obsolete radar” [4].

Not every one of these situations could have been avoided; but overlooking DMSMS issues for too long only makes the problem worse. In any programme, one of the main goals is to minimise costs. This is where having a robust obsolescence management team in place can be used to avoid these extra expenses. Complicating the issue even more is that most military-based systems require the use of five-volt logic devices, while the commercial industry is quickly moving away from five-volt logic and towards 3.3 volts and lower [7]. According to Tomczykowski [5], as technology continues to advance, digital designers can create higher densities at faster speeds with lower voltages. The main benefits include lower operating temperatures, speed, and size in low-power commercial products; but this movement will catalyse a further increase in obsolescence for the US Department of Defense (DoD), airlines, and others. Before the year 1999, the procurement life for these components was decreasing as industry shifted to components of 3.3 volts and lower. However, as seen in Figure 3 below, five-volt components introduced into the market since 1999 have seen slight increases in procurement life, as the manufacturers of these parts seek platforms that are either slowly transitioning or not moving at all towards applications that use lower voltages [1].

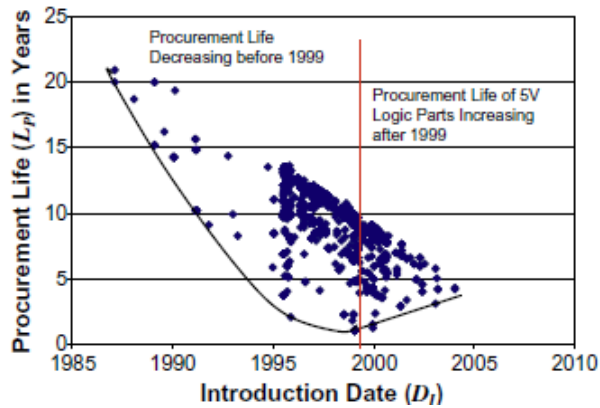


Figure 3: 5V bias logic parts [1]

Obsolescence can also have an impact on the reliability and maintainability of a system, because availability is a function of reliability and maintainability. The Government-Industry Data Exchange Program (GIDEP) is a voluntary data exchange agreement between the US Government and industries that provide critical DMSMS information that impacts system reliability and life-cycle cost [2]. Tomczykowski [5] states that, if not proactively managed, and if certain mitigation solutions are not thoroughly investigated and implemented, DMSMS could lead to higher operational downtime and decreased reliability. When incorporating a new component into the system, the mitigation solutions that require the most reliability and maintainability research are reclamation, aftermarket, and emulation owing to potential defects or variations in manufacturing processes.

3 TITLE LIFE CYCLE STAGES AND STRATEGIES FOR LIFE CYCLE MANAGEMENT

The components of these systems typically go through the six life-cycle phases of introduction, growth, maturity, decline, phase-out, and obsolescence [8]. Once a part is discontinued by a manufacturer, a product is no longer maintainable, and it is up to a company's DMSMS team to take a proactive approach to catch issues before a component's EOL is reached. Typically, a manufacturer will discontinue parts owing to a lack of market demand for that product line; or the company might have difficulty in finding raw material to build the component. Customers are then given a defined window of time to perform what is known as a last-time buy (LTB). They must then decide internally whether they would like to find a different supplier or determine whether an alternative part that still performs to all their requirements can be found. If neither of those options is available, then they must perform an LTB to purchase enough parts until they can redesign their product. Figure 4 below shows a product's life cycle-curve as used for forecasting.

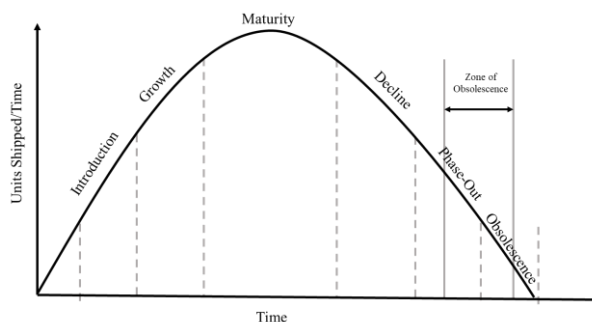


Figure 4: Life cycle forecast using Gaussian trend curve. Adapted and modified from [9].

Soloman [9] states that the introduction stage of a product's life cycle usually experiences high production costs that are caused by costly designs, poor yields, constant modifications, ever-changing rates in production, and the wrong production equipment. The growth stage shows an increase in sales that may validate the need to develop dedicated production equipment that would improve the rate of production. Maturity in the part life cycle is represented by a large volume in sales. Decline shows a slowing of demand and normally a decreasing profit margin. The phase-out stage is when the manufacturer sets a production discontinuation date for a component. The obsolescence phase is when the manufacturer completely stops production of the component. It is possible that the component will still be available for procurement if a production line has excess components left at an aftermarket source [9].

3.1 Mitigation techniques

A strong obsolescence management programme will consist of both reactive and proactive measures. These measures include decisions made after the part has become obsolete and actions taken before that point to minimise the risk or to get ahead of the issue altogether.

4 REACTIVE MEASURES

Much of DMSMS management today is reactive, which means that the management process starts only after discontinuance has occurred, using various mitigation techniques such as LTB, aftermarket sources, substitute parts, emulated parts, and salvaged parts [1]. Conventionally speaking, according to Zheng [10], efforts to mitigate the effects of DMSMS have been reactive in nature. This reactive DMSMS management method creates faster, but more expensive, solution paths with desirable short-term wins to avoid having an irreparable or unproductive system; but it overlooks the long-term solution paths that could prevent future DMSMS issues. Many mitigation solutions can be used in conjunction with one another.

4.1.1 Existing stock

When there are already enough parts in stock to last the remainder of a system's life, no further action is required to mitigate the obsolescence problem. If the amount of existing stock will only partially fulfill the required needs, an additional mitigation will be needed, such as a substitute part or LTB.

4.1.2 Reclamation

This is the use of a component from non-repairable systems or sub-assemblies, also known as cannibalisation. This option is not recommended by the Defense Reutilization and Marketing Service (DRMS), and should be used as a last resort because of potential reliability impacts from the re-use of components [5].

4.1.3 Alternative or simple substitute

This is the use of a different component that has the same form, fit, and function as the existing component. It can meet or exceed the requirements of the existing component in use that has gone obsolete. These components can also come from an aftermarket source when manufacturers are authorised by the original equipment manufacturer (OEM) to reproduce obsolete components using an existing wafer and die [5]. Counterfeit products can be an issue with new component selection, so thorough research and testing is imperative to avoid this issue.

4.1.4 Complex substitute

This is the replacement of the obsolete component with one that has different specifications and may require modification of the source product or the next-higher assembly (NHA) [10]. These components can also come through emulation, in which the component is replaced with another that emulates it [5]. This type of substitute must also be thoroughly tested.

4.1.5 last-time buy (LTB) and bridge buy

A LTB procures enough components to last until a system is no longer in service, while a bridge buy purchases enough components until a redesign can take place. With both solutions, the production and sustainment usage demand for the component must be taken into consideration to calculate the needed quantity properly. The shelf life and storage environment should be considered before performing an LTB.

4.1.6 Circuit board redesign – next higher assembly (NHA)

When no substitute components exist, or a new component cannot be used unless the circuit card is redesigned, an NHA redesign may be used. In this scenario, only the NHA is affected, and the new design will not result in any changes above this level [10]. A bridge buy is usually necessary to have enough inventory to last until the NHA redesign is complete.

4.1.7 Complex/system redesign

This redesign involves multiple changes to various parts of the system beyond the NHA of the obsolete component. This is the costliest mitigation option, and a bridge buy is usually necessary to have enough inventory to last until the system redesign is complete.

4.2 Cost avoidance

Each of the mitigation techniques mentioned above has an associated cost for its implementation. One of the principal metrics that an obsolescence management team (OMT), also known as a DMSMS team (DMT), tracks is cost avoidance. The cost avoidance of a solution relates to the cost difference between the solution being implemented and the next most feasible solution [10]. An example of this (shown in Table 1 below) would be if either a simple substitute or a complex redesign were determined to be the only two solutions; the cost avoidance for that case would then be \$10,473,148 - \$12,805 = \$10,460,343. Table 1 below shows the average cost associated with each resolution option. (The data comes from a 2014 US Department of Commerce survey of government and commercial DMSMS programmes [10].)

Table 1: Average cost associated with implementing each DMSMS resolution option [10]

Resolution option	Average ⁸⁵
Approved item	\$1,047
Life-of-need buy	\$5,328
Simple substitute	\$12,805
Complex substitute	\$25,867
Extension of production or support	\$25,930
Repair, refurbishment, or reclamation	\$66,185 ⁸⁶
Development of a new item or source	\$667,209
Redesign–NHA	\$1,112,528
Redesign–complex/system replacement	\$10,473,148

4.3 Proactive measures

There is no single catch-all solution that will proactively manage a system’s obsolescence issues. Key areas to focus on include having a robust supply chain, designing the system with obsolescence in mind, and planning for mitigating issues before they occur. It is essential that the supply chain has multiple sources and strong supplier relationships. The open system architecture allows for easier replacement of components as old ones are discontinued. Having an OMT that constantly tracks obsolescence cases is imperative for catching DMSMS issues. It will monitor current and past cases to make sure that part shortages do not occur. Figure 5 shows many different proactive obsolescence mitigation techniques.

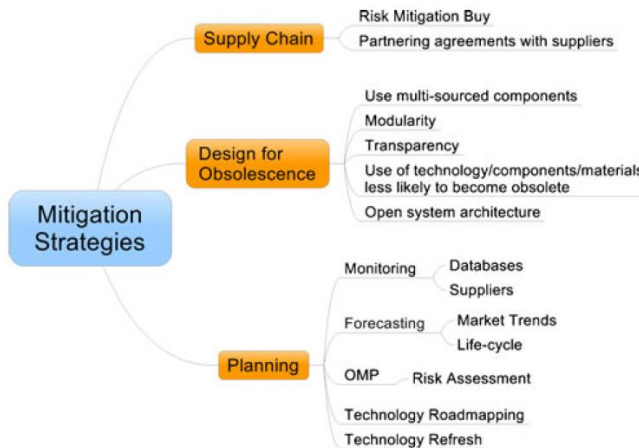


Figure 5: Proactive obsolescence mitigation strategies [8]

Proactive management entails forecasting and tracking obsolescence risk to the system’s components [11]. It includes a part criticality analysis, a spare stock posture, and maintenance planning [12]. Figure 6 below shows how early and proactive engagement will result in fewer obsolete components in a system over time.

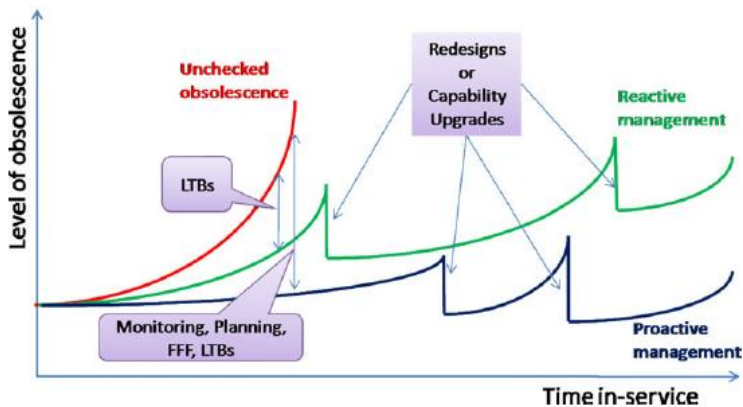


Figure 6: Levels of obsolescence based on the type of management [8]

Building in-design refreshes into a system’s life cycle is a form of proactive obsolescence management. Issues arise, however, with high costs and lengthy redesigns. High costs and initial investments often mean that they will only realise a return on investment if they can operate for a long time – sometimes 20 years or more; therefore, it is more desirable to keep working with older technology [13].

Research performed by Sandborn (2007) shows an obsolescence forecasting approach using a life-cycle curve forecasting methodology created by curve-fitting sales data for an electrical component. The first technique offers a way to make the life-cycle curve for the component family, with memory size being its primary attribute. The second method is a determination of electrical component obsolescence using vendor-specific windows from data mining historical last-order or last-ship dates. The combination of the life-cycle curve trends and the vendor-specific windows substantially improved the algorithm’s accuracy in forecasting flash memory obsolescence dates compared with the original algorithm of a fixed window [14].

A case study by Connor Jennings [15] revealed that machine learning could process large sets of obsolescence data with multiple variables and provide recommendations based on its results. Two forecasting methods were used, applying machine learning to increase accuracy and long-term usability over current forecasting methods. The first was obsolescence risk forecasting (ORML), where the output is the risk associated with a component being obsolete. The second method was life-cycle forecasting (LCML), by which a component discontinuation date was estimated. In this research, the case study was performed using more than 7 000 unique cell phone models with knowledge of the obsolescence status, release year and quarter, and other technical specifications such as screen size, weight, and camera resolution. The study by Jennings used the three machine-learning algorithms of artificial neural networks (ANN), support vector machines (SVM), and random forest (RF). When setting the RF model's training set to 100%, the algorithm correctly identified 98.3% of the cellphones as active or discontinued and had a test accuracy of 94.3% when the training size was set to 90%.

5 DESIGN FOR OBSOLESCENCE AND COST OPTIMISATION

Designing for obsolescence can include designing the physical architecture of a product to have multiple component replacement options and an overall management plan for combatting component discontinuance. These physical strategies include implementing open architecture, functional partitioning, and technology insertion, which need to be addressed during system engineering, detailed design, production, and product support [16]. One method is to divide the hardware into distinct partitions using modularity that is made possible by open architecture to split the system functionally into multiple platforms [16]. Many companies use the terminology of line replaceable module (LRM) or line replaceable unit (LRU). Often performance constraints supersede any obsolescence management concerns to use functional partitioning when designing a system, which can make this an unusable solution [17].

Having an open system architecture is one of the ways to break the dependence of systems on specific COTS technologies through 'loose' coupling between applications and the underlying infrastructure of the platform [18]. The military is the largest holder of long-term assets. Being the sector that is affected the most by obsolescence issues, the military has named this issue 'the DMSMS problem' [19]. Much of the defence industry produces systems or parts that have strict requirements and are proprietary to the company itself or are classified by the government, making open system architectures difficult to accomplish. Even though the United States Department of Defense has begun using open-system architecture in limited cases, more research is needed to protect against security concerns using strict interface definition and control [20].

A study by Feng [19] also looks at cost minimisation from an LTB perspective. He developed a tool called the 'life of type evaluation' (LOTE) to optimise LTB quantities. This tool looked at and compared demand distributions, holding costs, system downtime or unavailability penalties from the customer, and excess component disposal costs. The study determined that some companies may be placing too much emphasis on their contractual penalties for system unavailability and not enough on the procurement, holding, and disposal costs of conducting LTBs. As a result, they may be purchasing more components than necessary. However, this is completely dependent on the language of the contract, and for some situations, especially military systems, downtime is not an option. This means that having too many parts outweighs the consequences having too few.

Technology refreshes are a useful way to help mitigate obsolescence issues and minimise life cycle costs by building design refreshes into a system's life cycle. According to Zheng [21], there are a variety of ways to replace components at design refreshes. A component that is projected to be obsolete at a future time can be proactively substituted during any possible design refresh before it becomes obsolete, or it can be reactively replaced during the earliest design refresh once it has already become obsolete. Figure 7 shows the optimal design refresh plan for components with projected obsolescence dates. The chart shows that, even though planned designed refreshes can be put in place, reactive approaches will still be necessary when a component becomes obsolete between refresh cycles.

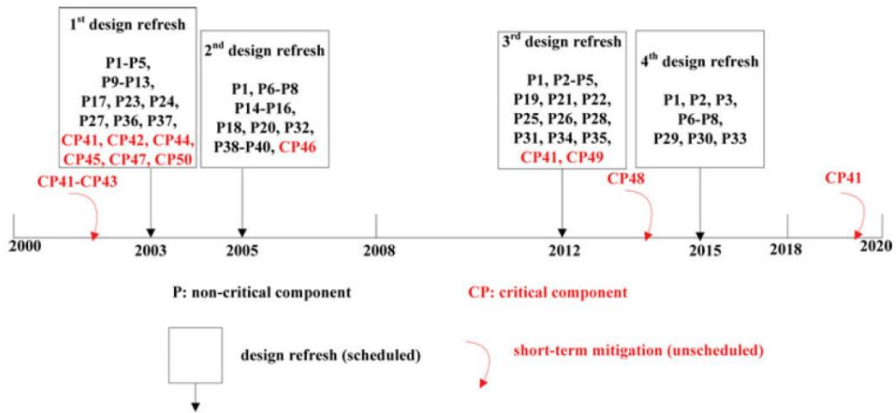


Figure 7: Optimal design refresh plan [21]

Herald (2012) also proposes two different models for system refreshes that focus on optimising the cost of the system during its lifetime. The two models are the system element life cycle cost (SELCC) and the obsolescence revision sequence (ORS). Figure 8 below shows the S-curve associated with the acquisition cost of a specific system element.

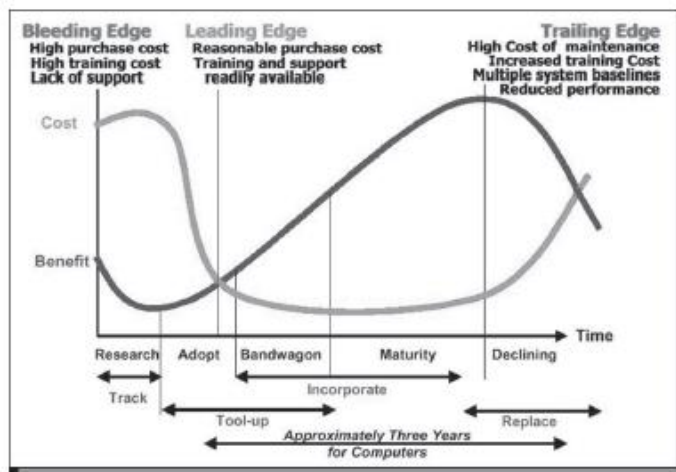


Figure 8: Market sales benefit S-curve vs support cost [22]

The bathtub type curve shows high costs at the bleeding edge and the lowest cost during the maturity phase of the component. There is a benefit to cost ratio intersection where a component should be purchased, called ‘the leading-edge point’, and then another point towards the end of the maturity phase where the component should be replaced to minimise total cost. The ORS model uses the inputs from the SELCC model and provides a mathematical representation to optimise the rate and sequence of system element revisions [22].

6 MANAGEMENT AND TOOLS

Current research shows that much obsolescence management today is reactive based, meaning that problems are managed once they occur using the various types of mitigation tactics described earlier in this paper. “At the earliest stages of a project, the project manager should produce and implement an obsolescence management plan (OMP)” [4]. Many companies have a DMSMS team that handles the entire obsolescence process from the product discontinuation notice (PDN) to the final resolution. Vendor surveys are a critical element of any OMP, as they keep the company up-to-date on any manufacturing changes from the sources that produce the system’s components [10]. However, once the part has become obsolete,

the main solutions are to find a substitute or to perform an LTB. There is no further opportunity to be proactive, which is what this research focuses on. The response must be purely reactive; but even that is an art form to be appreciated and having an extremely efficient reactive obsolescence mitigation process will always be crucial to the success of a company's product.

According to Sandborn [17], designing a management plan for obsolescence focuses on the problem of minimising the life-cycle cost of sustaining the system. Figure 9 below shows a hierarchy of design for involuntary obsolescence activities that can be implemented to help manage this issue.

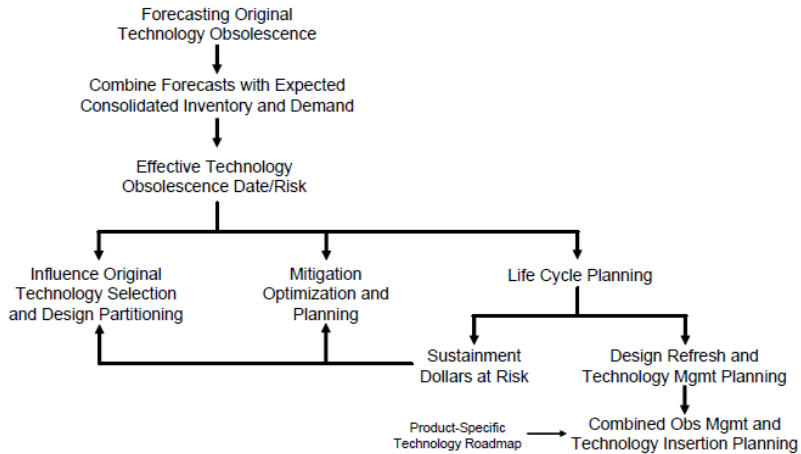


Figure 9: Hierarchy of design for involuntary obsolescence activities [17]

A big factor in the decision-making depends on the life-cycle stage of the product that a company has developed for its customer. The final solutions are going to be tailored differently for a product that is still in the design phase, in production, or in its sustainment phase. Typically, the product is in the production and/or sustainment phases, which are where obsolescence has the greatest impact. Figure 10 shows a basic current process for obsolescence management. Once the team identifies a component as obsolete, the best mitigation approaches are adopted and ultimately executed through management.

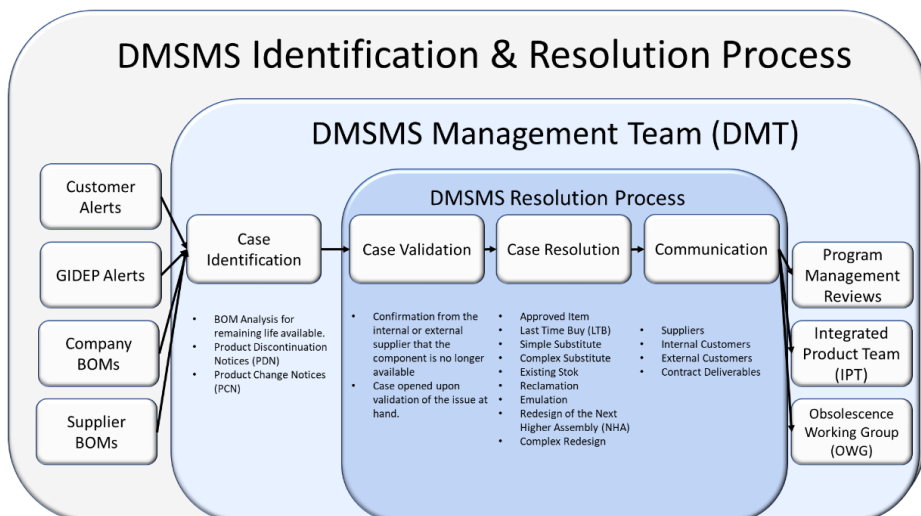


Figure 10: An obsolescence management process

When key obsolescence metrics are effectively communicated, leadership can make informed decisions and have a timeline for the steps that need to be taken to avoid the impact of obsolescence. Therefore, understanding the data early is vitally important for the full risk mitigation of an obsolescence issue. Typically, leadership buy-in is needed after all of the data has been collected and analysed. It is imperative to develop an effective and data-driven approach to communicating obsolescence impacts to the leadership to ensure the successful mitigation of obsolescence issues. The leadership needs to see their options in a quick, clear, and concise way that has the data analytics to back it up. Information is only valuable when it permits communication between those involved in decision-making so that constructive action can take place. More information is not necessarily better communication; so converting the information into a format that reduces its bulk and targets only the key aspects of an issue is important [23]. The team must be able to back up their answers and be able to model new solutions ‘on the fly’, based on management’s needs.

Figure 11 shows all the parties impacted by obsolescence, and the strong relationships that are needed between the DMSMS team and all those groups. If an individual sector is not on board, things can fall through the cracks and timelines can be missed, resulting in a missed LTB date. All parties are equally important; but properly communicating needs to suppliers is often overlooked and is sometimes the easiest route to resolving a company’s obsolescence issue.

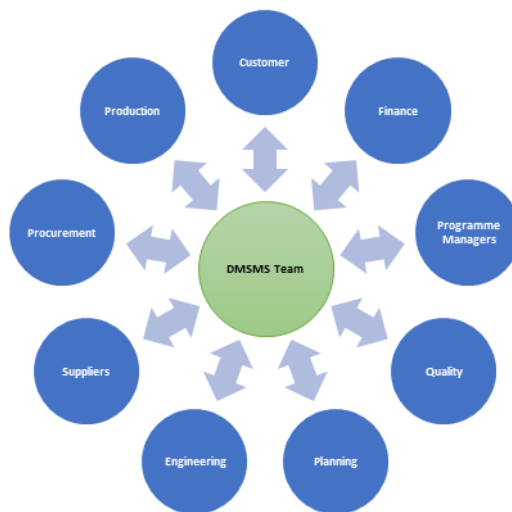


Figure 11: Parties impacted by obsolescence

The defence industry does not have a market share majority in the supply chain for COTS electronic components. COTS parts are becoming obsolete at a ever-faster rate, owing to rapid changes in technology. Therefore, it is desirable to partner with suppliers to ensure the continuous support and provision of critical components [8]. Achieving long-term system availability that leverages COTS technology requires having good relationships within the supply chain. A company must work closely with its suppliers to develop life-cycle management plans to keep its systems up to date with active components, instead of waiting for obsolescence events to happen [24].

On a component level, partnering agreements between two companies rarely exist, unless it makes financial sense for the manufacturer to continue building and selling a specific component to just a few companies. Is their purchasing volume going to be enough even to keep that product line profitable? Most likely not. However, it is still important to have a strong relationship with the suppliers: often – especially if the company does enough business with them in general – they can offer what is known as a lifeboat agreement. These are agreements that say that the manufacturer will continue to produce a component for a specified amount of time until the company can develop a redesign or secure funding to perform an LTB.

The management process for selecting new components in a design, and the development of a system, are complex matters, and should be done with an iterative process. According to Lebron [25], this process can

be broken down into the three stages of operational requirement analysis, COTS solutions for these requirements, and a COTS assessment. During the COTS assessment, the components are reviewed for performance, reliability, cost, and obsolescence risk. A system designed with open architecture is beneficial when a component becomes obsolete, because systems designed under completely closed and proprietary architecture typically require complex redesigns or new interfaces to incorporate new components. The iterative decision-analysis process occurs when there is need for a new design. Other management considerations that go into the component selection process should include critical material analysis (CMA) to check for hazardous materials and potential material shortages for a component selection, and contracting language that proactively sets customer money aside to resolve obsolescence issues that may occur in the future [10].

Rojo [8] reviews the three different approaches of forecasting, monitoring, and identifying alternative components, and mitigation strategy development. These software tools are Q-Star, MOCA, Obsolescence Manager, Parts Plus, CAPS BOM Manager, and a few others. Most of these tools are focused on BOM management and alternative component identification, but the MOCA tool is unique in that it attempts to predict the optimum technology insertion points to minimise obsolescence impacts on the system.

7 CONCLUSION

To conclude, this paper has presented the various opportunities and challenges that exist for those fighting the battle against DMSMS. It is a reality in manufacturing systems and supply chain environments, as many systems, especially in the defence industry, need to be sustained for several decades. This research effort suggests a need for a more streamlined management approach to tackling obsolescence. There are various proactive/strategic approaches to mitigating obsolescence and tools to help track and forecast cases. Some of these key areas of focus are funding for a robust DMSMS team, a strong supply chain, system design that factors in obsolescence risk, and strong communication with all parties involved. It is imperative to develop an effective and data-driven approach to communicating obsolescence impacts to leadership to ensure the successful mitigation of obsolescence issues. Solution funding could take time, especially if it is customer-funded, and time is often a limited commodity in the world of obsolescence.

Newer research shows an interesting shift from system life-cycle management towards future proactive improvements of forecasting techniques with EOL predictions and system design refreshes. One of the key findings in this study was that, of the 55 articles reviewed, only one proposed using machine learning for forecasting purposes. Today's best tools for forecasting obsolescence use traditional algorithms that analyse inputs using defined logic; but they are only as good as the logic provided. Machine learning takes inputs and outputs to create its own logic, and then uses this logic when analysing new data. This is an area of study that may need more research. The main benefit of having a strong understanding of obsolescence is that systems can be sustained for longer periods with reduced system life-cycle costs and downtime.

8 REFERENCES

- [1] P. Sandborn, V. Prabhakar and O. Ahmad, "Forecasting electronic part procurement lifetimes to enable the management of DMSMS obsolescence," *Microelectronic Reliability*, vol. 51, no. 2, pp. 392-399, 2011.
- [2] M. K. D. Underwood, "Minimizing the Risks of Diminishing Manufacturing Sources and Material Shortages: Evaluating Electronic Avionics Lifecycle Sustainment Strategies," 2011. [Online]. Available: <https://apps.dtic.mil/sti/citations/ADA546421>.
- [3] J. Bell, "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," MS thesis, AFIT/GLM/LAL/98-2, School of Logistics and Acquisitions Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH September 1998 (AD-B238919)1998.
- [4] A. Meyer, L. Pretorius and J. Pretorius, "A Management Approach to Component Obsolescence in the Military Electronic Support Environment," *SA Journal of Industrial Engineering*, vol. 14, no. 2, pp. 121-136, 2003.
- [5] W. J. Tomczykowski, "A Study on Component Obsolescence Mitigation Strategies and Their Impact on R&M," 2003. [Online]. Available: https://www.dfrsolutions.com/hubfs/DfR_Solutions_Website/Resources-Archived/Publications/2002-2004/2003_Obsolescence.pdf.
- [6] N. Verma and J. Smith, "Assessing Obsolescence - Evaluating and managing the risk of obsolescence across the enterprise can help manufacturers mitigate plant downtime and perform more timely systems upgrades.," 2015. [Online]. Available: <https://documents.pub/document/assessing-obsolescence-cognizant-defining-obsolescence-risk-obsolescence.html>.
- [7] T. Glum, "United States Department of Defense Initiatives for the Management and Mitigation of Microelectronics Obsolescence," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.

- [8] F. J. R. Rojo, R. Roy and E. Shehab, "Obsolescence management for long-life contracts: state of the art and future trends," *Int J Adv Manuf Technol*, vol. 49, pp. 1235-1250, 2010.
- [9] R. Soloman, "Electronic Part Life Cycle Concepts and Obsolescence Forecasting," *IEEE TRANSACTIONS ON COMPONENTS AND PACKAGING TECHNOLOGIES*, vol. 23, no. 4, pp. 707-717, 2000.
- [10] L. Zheng, J. Terpenny and P. Sandborn, "Design refresh planning models for managing obsolescence," *IIE Transactions*, Vol. 47, No. 12, pp. 1407-1423, 2015.
- [11] D. S. P. Office, "SD-22 - Diminishing Manufacturing Sources and Material Shortages (DMSMS)," 2016. [Online]. Available: <https://www.scribd.com/document/437205825/DMSMS-Guideboo>.
- [12] X. Meng, B. Thörnberg and L. Olsson, "Strategic Proactive Obsolescence Management Model," *IEEE TRANSACTIONS ON COMPONENTS, PACKAGING AND MANUFACTURING TECHNOLOGY*, vol. 4, no. 6, pp. 1099-1108, 2014.
- [13] A. Konoza and P. Sandborn, "Evaluating the End of Maintenance Dates for Electronic Assemblies Composed of Obsolete Parts," *Journal of Mechanical Design*, vol. 136, no. 031006-1, pp. 1-14, 2014.
- [14] J. Amankwah-Amoah, "Integrated vs. add-on: A multidimensional conceptualisation of technology obsolescence," *Technological Forecasting & Social Change*, vol. 116, pp. 299-307, 2017.
- [15] P. A. Sandborn, F. Mauro and R. Knox, "A Data Mining Based Approach to Electronic Part Obsolescence Forecasting," *IEEE TRANSACTIONS ON COMPONENTS AND PACKAGING TECHNOLOGIES*, vol. 30, no. 3, pp. 397-401, 2007.
- [16] C. Jennings, D. Wu and J. Terpenny, "Forecasting Obsolescence Risk and Product Life Cycle With Machine Learning," *IEEE TRANSACTIONS ON COMPONENTS, PACKAGING AND MANUFACTURING TECHNOLOGY*, vol. 6, no. 9, pp. 1428-1439, 2016.
- [17] D. Young, "New Approaches to Processor Lifecycle Management," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [18] P. Sandborn, "Designing for Technology Obsolescence Management," in *Industrial Engineering Research Conference*, College Park, 2007.
- [19] D.J.Jibb and J.B.Walker, "Avionics Architecture Standards as an Approach to Obsolescence Management," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [20] D. Feng, "Optimizing lifetime buy quantities to minimize lifecycle cost," 2007. [Online]. Available: <https://www.tc.faa.gov/its/worldpac/techrpt/tc15-33.pdf>.
- [21] J. L. Tokar, "An Examination of Open System Architectures for Avionics Systems - An Update," in The U.S. Air Force FACE™ Technical Interchange Meeting, Dayton, 2017.
- [22] T. E. Herald and J. E. Ramirez-Marquez, "System element obsolescence replacement optimization via life cycle cost forecasting," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 2, No. 8, pp. 1394-1401, 2012.
- [23] R. Sanderlin, "Information is not communication," *Business Horizons*, vol. 25, no. 2, pp. 40-42, 1982.
- [24] National Instruments, "Military/Aerospace Solutions for Obsolescence," 12 August 2019. [Online]. Available: <https://www.ni.com/en-us/innovations/white-papers/19/solving-obsolescence-management-with-system-design.html>. [Accessed 1 June 2020].
- [25] R. A. Lebron, Jr., R. Rossi and W. Foor, "Risk-based COTS systems engineering assessment model: A systems engineering management tool and assessment methodology to cope with the risk of commercial off-the-shelf (COTS) technology insertion during the system life cycle," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [26] NATO Research and Technology Organization, "Strategies to mitigate obsolescence in defense systems using commercial components presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [27] U.S.D.S.P. Office, Obsolescence management for Virginia-class submarines, Ft. Belvoir: Defense Standardization Program Office, 2010.
- [28] K. Shaffer, "Planned Obsolescence - The Ethical Aspect," 13 November 2015. [Online]. Available: http://www.academia.edu/21396146/Planned_Obsolescence-_The_Ethical_Aspect. [Accessed 10 May 2020].
- [29] F. Echegaray, "Consumers' reactions to product obsolescence in emerging markets: the case of Brazil," *Journal of Cleaner Production*, vol. 134, pp. 191-203, 2016.
- [30] S. M. Sait, "Novel design of heterogeneous automation controller based on real-time data distribution service middleware to avoid obsolescence challenges," *Journal of Circuits, Systems, and Computers*, vol. 25, no. 9, pp. 1-28, 2016.
- [31] C. Gao, X. Liu and X. Wang, "A model for predicting the obsolescence trend of FPGA," presented at 9th International Conference on Reliability, Maintainability and Safety Reliability, Maintainability and Safety (ICRMS), Guiyang, 2011.
- [32] A. Jain, "Learning by hiring and change to organizational knowledge: Countering obsolescence as organizations age," *Strategic Management Journal*, vol. 37, no. 8 pp. 1667-1687, 2015.
- [33] W. D. National Science Foundation, "Emerging Issues in Science and Technology, 1981. A Compendium of Working Papers for the National Science Foundation," ERIC, Washington, DC, 1981.
- [34] R. Lawlor, "Delaying obsolescence," *Science and Engineering Ethics*, vol. 21, no. 2, pp. 401-427, 2015.
- [35] F. Patriarca, "Time-to-build, obsolescence and the technological paradox," *Structural Change and Economic Dynamics*, vol. 23, no. 1, pp. 1-10, 2009.
- [36] L. Petersen, "The Use of Commercial Components in Defense Equipment to Mitigate Obsolescence A Contradiction in Itself," Research and Technology Organization, Heidelberg, 2000.
- [37] M. B. Szekely, "COTS in our air control system," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.

- [38] **W. A. Veitch**, "Commercial off-the-shelf software and simulation tools," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [39] **G. Gaillat**, "Generic tools and methods for obsolescence control," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [40] **B. B. M. F. G. Grabowski**, "Integrated modular avionics with COTS directed to open systems and obsolescence management," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [41] **M. Rothmaier**, "A modular signal processing architecture to mitigate obsolescence in airborne systems," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [42] **T. Dowling**, "Planning for change with a holistic view of the system," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [43] **R. Ellis**, "Management issues in the use of commercial components in military systems," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [44] **T. Dowling**, "Software COTS components - Problems, and solutions?," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [45] **T. Smith**, "Future initiatives for obsolescence mitigation strategies," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [46] **J. Schaff**, "Avoiding obsolescence with a low cost scalable fault-tolerant computer architecture," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [47] **F. J. Romero Rojo, R. Roy, E. Shehab, K. Cheruvu and P. Mason**, "A cost estimating framework for electronic, electrical and electromechanical (EEE) components obsolescence within the use-oriented product-service systems contracts," *Proceedings of the Institute of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 226, no. 1, pp. 154-166, 2010.
- [48] **K. Mulla, M. Dhanamjaya and V. Talawar**, "Citations in engineering doctoral dissertations: An obsolescence study," *DESIDOC Journal of Library & Information Technology*, vol. 33, no. 6 pp. 451-456, 2013.
- [49] **J. A. Fossum, R. Arvey, C. Paradise and N. Robbins**, "Modeling the skills obsolescence process: A psychological/economic integration," *Academy of Management Review*, vol. 11, no. 2, pp. 362-374, 1986.
- [50] **R. Sparrow**, "Enhancement and obsolescence: Avoiding an enhanced rat race," *Kennedy Institute of Ethics Journal*, vol. 25, no. 3, pp. 231-260, 2015.
- [51] **L. Zheng, R. Nelson III, J. Terpenney and P. Sandborn**, "Ontology-Based Knowledge Representation for Obsolescence Forecasting," *Journal of Computing and Information Science in Engineering*, vol. 13, no. 1, pp. 1-8, 2013.
- [52] **T. G. Pobiak, T. A. Mazzuchi and S. Sarkani**, "Creating a proactive obsolescence management system framework through the systems engineering continuum," *Systems Engineering*, vol. 17, no. 2, pp. 125-139, 2013.
- [53] **F. del Rio and A. Sampayo**, "Obsolescence and productivity," *Portuguese Economic Journal*, vol. 13, no. 3, pp. 195-216, 2014.
- [54] **M. Emsermann and B. Simon**, "Optimal control of an inventory with simultaneous obsolescence," *Interfaces*, vol. 37, no. 5, p. 445-454, 2007.
- [55] **E. Cernko, D. Jäger and R. Manser**, "Consequences for the design of military aircraft systems due to integration of commercial electronic components in avionics," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [56] **M. Barré and P. Butel**, "Methodological guide to ASIC design with durability management," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [57] **P. Lacomme and V. Baret**, "Minimizing the software re-design in obsolescent radar processors with functional radar simulation and software workshop," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [58] **M. Buratti and D. D. Brusco**, "The obsolescence management based on a "pro-active" approach in conjunction with a 'pre-planned' technology insertion route," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [59] **M. Gangkofer, H. Kader, W. Klöckner and C. White**, "Transitioning to integrated modular avionics with a mission management system," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [60] **R. Sabatini and M. Massari**, "MB-339CD aircraft development COTS integration in a modern avionics architecture," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.
- [61] **C. H. R. Lane, E. S. Beattie, J. S. Chita and S. P. Lincoln**, "Adopting new software development techniques to reduce obsolescence," presented at the Systems Concepts and Integration Panel (SCI) Symposium, Budapest, Hungary, 2000.