OBsolescence: A Systems Engineering and Management Approach for Complex Systems

By

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S.B. Aerospace Engineering with Information Technology
Massachusetts Institute of Technology, 2002

Submitted to the System Design and Management Program in partial fulfillment of the requirements for the degree of Masters of Science in Engineering and Management at the Massachusetts Institute of Technology

February 2010

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Obsolescence mitigation is an increasingly important aspect of large systems development & maintenance that has often only been considered once obsolescence is imminent. For long lifecycle systems, this has become a major concern as the lifecycles of the components that are encompassed within these systems are often far shorter – up to ten times shorter – than the overall system lifecycle. Many defense systems can be characterized in this manner and therefore require obsolescence mitigation approaches to ensure the continuing ability for the system to perform and evolve. Current system-level obsolescence mitigation practices make recommendations for designing new systems to slow the onset of obsolescence and make the system more flexible when change for obsolescence is required. However, currently fielded systems were often not designed with this in mind.

Other obsolescence mitigation techniques focus only on the approach to mitigating component-level obsolescence locally without examining the impact of the change on the system as a whole. This thesis combines the recommended approaches for obsolescence mitigation, the experience and lessons learned for obsolescence mitigation on a real-world case study system gained from interviews with key subject matter experts, along with systems engineering techniques for dealing with engineering change in systems to develop a robust systems engineering and management approach for obsolescence in large complex systems. The thesis provides the reader with a flow chart and a clustered DSM of the tasks along with a checklist that could be used with this obsolescence engineering and management approach.

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ACKNOWLEDGEMENTS

I would like to take this opportunity to thank those groups and individuals who made it possible for me to pursue the SDM program and those that supported me throughout the past two years.

First, thank you to my mentor Tim Carey who encouraged me to work towards my goals and apply to the SDM program. Tim pushed when a push was needed and I am very grateful. I would also like to thank the Advanced Studies Committee that provided me the opportunity to attend school while also working. While I cannot personally thank everyone who contributed to my success in this program I would like to thank my managers and IPT lead, Beverly LeClerc, Daniel Dechant and Chibl Nahas. I could not have completed the program without your understanding of my “crazy” schedule and the flexibility you provided.

At MIT I would like to thank Prof. Paul Lagace who introduced me to the SDM program. I have sincere gratitude for the entire SDM staff who could always find a way to help when there was an issue. I would like to thank all of my professors over the past two years, especially my thesis advisor, Prof. de Weck who introduced me to the topic of engineering change and provided much needed direction and encouragement as this thesis began to take shape. You have all challenged me to think in new and broader directions when facing a problem.

Finally, I would not have pursued this wonderful opportunity if it hadn't been for the support and encouragement of my family and friends. I would like to especially thank my parents who have always encouraged me to take the opportunities presented to me. To my fiancée Tom, thank you for taking care of me during the past two years – I owe you many dinners.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ΔE</td>
<td>Binary Change Propagation Matrix</td>
</tr>
<tr>
<td>BOM</td>
<td>Bill Of Materials</td>
</tr>
<tr>
<td>CDRL</td>
<td>Contract Deliverable</td>
</tr>
<tr>
<td>CIDS</td>
<td>Component Item Development Specification</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial-Off-The-Shelf</td>
</tr>
<tr>
<td>CPI</td>
<td>Change Propagation Index</td>
</tr>
<tr>
<td>DMEA</td>
<td>Defense Microelectronics Activity</td>
</tr>
<tr>
<td>DMM</td>
<td>Domain Mapping Matrix</td>
</tr>
<tr>
<td>DOD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>DSM</td>
<td>Design Structure Matrix</td>
</tr>
<tr>
<td>ECP</td>
<td>Engineering Change Proposal</td>
</tr>
<tr>
<td>FFF</td>
<td>Form, Fit, and Function</td>
</tr>
<tr>
<td>GFE</td>
<td>Government Furnished Equipment</td>
</tr>
<tr>
<td>GOTS</td>
<td>Government-Off-The-Shelf</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IMS</td>
<td>Integrated Master Schedule</td>
</tr>
<tr>
<td>MIL-SPEC</td>
<td>Military Specification</td>
</tr>
<tr>
<td>Legacy System</td>
<td>Existing, Fielded or In-Use System</td>
</tr>
<tr>
<td>MIL-STD</td>
<td>Military Standard</td>
</tr>
<tr>
<td>MOTS</td>
<td>Military-Off-The-Shelf</td>
</tr>
<tr>
<td>PIDS</td>
<td>Prime Item Development Specification</td>
</tr>
<tr>
<td>POD</td>
<td>Proof Of Design</td>
</tr>
<tr>
<td>POM</td>
<td>Proof Of Manufacturing</td>
</tr>
<tr>
<td>RJ</td>
<td>Registered Jack</td>
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</table>

~ 8 ~
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCAS</td>
<td>Traffic Collision and Avoidance System</td>
</tr>
<tr>
<td>TCP/IP</td>
<td>Transmission Control Protocol/Internet Protocol</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
</tbody>
</table>
1 THESIS OVERVIEW AND LITERATURE REVIEW

1.1 THESIS OVERVIEW

1.1.1 MOTIVATION

Many defense systems are manufactured in comparatively low quantities compared to mass produced items in the commercial world. These systems are often very expensive, built with state of the art technology for their time, and may be used beyond the original lifespan originally predicted. Design lifetimes in military systems are often on the order of 10-20 years but many systems, such as the B-52, are now used for 50 years or more. Examples of such systems include radars, missile systems, some types of aircraft, and submarines among others. As these systems evolve through their lifecycle, components may be upgraded in order to improve capability or to extend the systems’ mission or to compensate for design flaws that only became apparent after extensive use. In addition, components may be required to be replaced because the system outlives the lifespan of the component, or that over time there is a larger demand than was anticipated for a lifetime buy or the planned manufacturing level for that component. The likelihood of these types of changes increased with

"DOD Directive 5000.1 [which] prescribes a systems engineering approach throughout the entire life cycle of a system and categorizes the four basic types of acquisition in order of preference:

a. Modification of existing system
b. Procurement of a COTS item
c. Procurement of a non-developmental item
d. Development of a new system" (Lebron Jr., Rossi, & Foor, 2001)

because the reuse of existing systems and deployment of COTS into these existing systems outside the span of control of the original system development modifies established relationships and creates new relationships in a system for which it may not have been originally designed. This effort is further complicated by the constraints that the existing system places on a project that would not necessarily occur in a “clean-sheet” development of a new system. Two examples of systems that have evolved over time are the B-52 bomber which was modified for numerous missions including low altitude flight and electronic countermeasures (now in service > 50 years) and the Ohio Class submarine that has been retrofitted with different missiles and launch systems (to be in service for 25 years beyond the original planned retirement date).

While defense applications may have some unique attributes, large complex systems are becoming increasingly more common in the civil and commercial spaces (e.g. air traffic control, transportation systems, energy grid, etc.). These systems will also face obsolescence and will need an effective methodology for determining an appropriate mitigation approach. Thus, the
obsolescence problem is not unique to the defense world and the mitigation techniques proposed could have far wider application.

When obsolescence occurs, there are trades that must be performed. The first trade—including a cost-benefit analysis using program specific decision criteria (e.g. design cost, lifecycle cost, technical performance, safety, etc.)-- is to commission a replica of the original antiquated component (or module) or to replace it with a more modern component (or module) often with increased capability. Engineers must also examine the impact to system-level performance of these modifications and potential downstream impact (other components that may require a redesign due to a tight functional or structural coupling). Such changes apply to hardware and software components, as well as operational and maintenance procedures. Finally, the studies, trades, and other decisions must be managed and tracked to ensure that changes made to one part of the system are consistent with those made elsewhere. This type of problem requires a structured systems engineering and management approach. Without structure, important system impacts can remain missed or undiscovered until late in the development cycle, which negatively impacts budget and schedule.

1.1.2 Objectives
This thesis intends to examine the suitability and validity of existing approaches for addressing obsolescence in existing systems. It will focus on the context of a particular approach and application system that the author is familiar with but seek to generalize the conclusions. In addition, this thesis will evaluate some of the gaps in the existing approach and show how the use of certain techniques and a systematic systems engineering approach can improve the process for updating a real large, complex defense system subject to obsolescence.

1.2 Literature Review
A literature review was conducted in two primary areas: obsolescence and systems engineering techniques that may be useful when dealing with engineering change.

1.2.1 Obsolescence
1.2.1.1 Types of Obsolescence & Terminology
Slade's book "Made to Break: Technology and Obsolescence in America" looks at the various meanings of obsolescence in America from primarily the late 1800's to present day. His intent is to describe how America largely changed global culture from that with limited obsolescence to one that is economically dependent on obsolescence. His emphasis is on deliberate obsolescence and focuses on three major types "technological, psychological, or planned" (Slade, 2006). While Slade's focus is on cultural changes, he synthesizes historically how the influence of obsolescence has changed over time and compares and contrasts the language surrounding obsolescence as well.

Table 1 uses Slade's book as a foundation and supplements with other sources to define the different types of obsolescence.
TABLE 1: OBSOLESCENCE DEFINITIONS AND TERMINOLOGY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definitions</th>
<th>Similar Terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Obsolescence (1)</td>
<td>&quot;Here, when it is planned, a product breaks down or wears out in a given time, usually not too distant.&quot; (Packard, 1960)</td>
<td>Quality Obsolescence</td>
</tr>
<tr>
<td>Planned Obsolescence (2)</td>
<td>When obsolescence of components is expected and planned as part of a systems' lifecycle</td>
<td></td>
</tr>
<tr>
<td>Psychological Obsolescence</td>
<td>&quot;In this situation a product that is still sound in terms of quality or performance becomes &quot;worn out&quot; in our minds because a styling or other change makes it seem less desirable.&quot; (Packard, 1960)</td>
<td>Desirability; Obsolescence; Progressive Obsolescence; Dynamic Obsolescence; Style Obsolescence</td>
</tr>
<tr>
<td>Technological Obsolescence</td>
<td>&quot;due to technological innovation&quot; (Slade, 2006) &quot;In this situation an existing product becomes outmoded when a product is introduced that performs the function better.&quot; (Packard, 1960)</td>
<td>Functional Obsolescence</td>
</tr>
<tr>
<td>Human Obsolescence</td>
<td>&quot;human workers could be replaced by machines&quot; (Slade, 2006) When the skill sets of experienced workers become outdated due to specialization in technologically obsolete areas</td>
<td></td>
</tr>
<tr>
<td>Manufacturing &amp; Maintenance Obsolescence</td>
<td>When there is no need in the current application for a product with increased function, however the market demands do not support a supplier's continued production or support of the legacy component</td>
<td></td>
</tr>
</tbody>
</table>

1.2.1.2 Obsolescence Context for this Thesis

Commercial products are often driven by psychological obsolescence and planned obsolescence. Without psychological obsolescence, people would not continue to consume products that rely heavily on styling (clothes, cars, etc.) before the end of their physical life. Without quality obsolescence, there wouldn't be the demand for disposable goods like razors and plastic silverware that may not have optimal quality, but are designed for a much shorter lifespan than their more robust counterparts. Due to the non-commercial nature of the system of focus for this thesis, it is assumed that psychological obsolescence and quality obsolescence do not play a role as maintenance activities and capability growth are the primary engineering change drivers. The primary focus for this thesis will be the role of technological obsolescence and manufacturing and maintenance obsolescence. In some respects, there is a need to discuss how the systems approach helps mitigate some of the impacts of human obsolescence, but that will be a secondary focus. Also the exogenous drivers of obsolescence such as changing strategic and tactical threat assessments in
defense systems are outside the scope of the thesis, even though the importance of such drivers is clearly acknowledged.

In addition, this thesis will address mitigating obsolescence in a legacy system in both a reactive and proactive manner. To this point, the thesis will address how obsolescence affects the entire product lifecycle, and how those impacts are reflected in the systems engineering process. In addition, in defense systems, functional or technical obsolescence are not always products of new systems that are developed that provide improved performance; however, obsolescence of function is often driven by the threat environment in today's ever-changing world. In these cases, new functionality has to be developed, due to the high cost of these systems, new acquisition is cost prohibitive and therefore, legacy systems often need to be adapted to meet the new functional challenges presented to them. The degree to which such adaptation is feasible or expensive and complex depends on the functional gap between current capabilities and new requirements.

1.2.1.3 Reasons for Obsolescence
"The spectrum of obsolescence effects is broad. It encompasses not only advanced microelectronics, but also materials used in legacy systems for which there is no longer a MIL-Spec. nor a supplier; basic electrical piece parts for which the market has dwindled to the re-supply of military hardware; software which is no longer compatible, and is neither supported nor modifiable to meet today's requirements." (Lynch, 2001)

1.2.1.3.1 Use of Commercial-Off-The-Shelf (COTS)
Large complex and costly systems like those often developed for defense systems face a significant issue in terms of obsolescence. Defense Secretary William Perry proposed in 1994 that absolute adherence to military specifications was at times unnecessary and costly. He therefore encouraged, when appropriate, that commercial standards be accepted and that military specifications would only be required by exception. Since that time, there has been a push to use COTS components in newly developed systems for cost reduction. The benefits of cost reduction must be weighed against the technological concerns with using COTS components for military applications. Interestingly, an original goal of using COTS was to help mitigate parts obsolescence. Ultimately because of the speed of technological change in the COTS environment, use of COTS actually increased and effectively guaranteed that all new programs will have increased levels of parts obsolescence on their programs.

"Somewhat perversely, the rapidity of part unavailability is less for legacy systems designed in the 1970's and 1980's than in their replacements currently being deployed or under development." (Lynch, 2001)

This is partially due to the fact that now, instead of the standard setting luxury that these programs held when they were one of the only customers capable of procuring electronics and large software programs, defense programs no longer have the leverage over the development of new components. Defense programs lost this luxury when electronics, once very expensive, became common place and are now considered a commodity.
"The entire Defense industry share of the global microelectronics market is now only about 0.3%, so our influence on the component manufacturers is minimal." (Lynch, 2001)

As updates occur due to planned obsolescence commercially, the project may need to make many updates to their systems that need to be planned for in the original assessment of using a COTS system. Any individual customer is now only supported to the level required by the masses and does not have the power to request customization to the COTS product for their needs. Use of a COTS system implies an added dependency upon the COTS supplier. Once the supplier deems a product is obsolete, the product will not be supported at the level needed by some projects. Setting up custom production and support programs from such manufacturers is often prohibitively expensive.

1.2.1.3.2 Lifecycle Duration
While somewhat related to COTS, system lifecycles are an important reason why obsolescence exists. Unlike a cell phone, which is likely to be discarded in 2-3 years, the lifecycle expectations of large, expensive defense systems are significantly longer than most of the critical components that make up the system itself.

"Whereas the life cycles of our weapon systems have become increasingly longer and exceed in many cases 50 years, the introduction cycles of new commercial microelectronics families average approximately 2 to 4 years, for memory devices they are as short as 9 months. And the trend is continuing." (Petersen, 2001)

Not only is it a concern that the components within a system will need to be replaced many times over the lifecycle of a system, there is a more complex problem associated with the uneven update schedules. Since these systems are often deployed in various environments, upgrade maintenance time periods are often limited. In addition, if one item requires upgrade before the rest of the system, it can increase the number of configurations (instantiations) of a system. Multiple configurations make design, development, testing and logistics more complex and more costly.

1.2.1.3.3 Increase in use of Electronics
Electronic systems become obsolete faster than mechanical systems. Since many functions are now able to be executed through software for less initial cost, power, and weight, electronic systems running software have replaced components which executed these functions using analog and digital hardware. Utterback illustrates the growth in electronics through a simple example of typewriters. Using data from Engler, Utterback developed the chart shown in Figure 1 to illustrate how electronic typewriters replaced mechanical typewriters over time.
In addition, electrical systems are now able to perform functions that would have been too costly or impractical to create using mechanical means, increasing the overall capability able to be achieved with a given system. For all of the advances and gains, obsolescence is one of the primary drawbacks with increased use of electronic systems.

1.2.1.3.4 Supply

There are however unique challenges that defense systems often have to face in terms of needing systems that can operate under more extreme environmental conditions and with higher reliability as were defined by the MIL-STD, yet there are fewer and fewer suppliers of components in that space. Therefore, replacing parts that used to be designed to a MIL-STD with COTS or COTS-like components will require redesigns of other parts of systems to compensate for the COTS' shortcomings. A specific example of this is the use of commercial non-space qualified processors in satellites that do not meet radiation hardening requirements. Such processors can indeed be used but require supplemental shielding which adds weight and complexity as well as complex software routines to deal with the increased occurrence of single event upsets caused by cosmic radiation and charged particles in Earth orbit.
In addition, the past notion of developing a long-term or lifetime buy for a particular component has negative consequences in the current environment. For one, any errors in the part will occur in the entire batch of parts and there is less flexibility in the system over time. (Young, 2001) Even if the part met the overall system requirements at the time, the flaw could impact the ability of the part to be used in a modified way over the system’s lifespan. Systems will have to be designed to incorporate replacement parts with new designs over time. In addition, there are impacts to the supply chain, logistics, maintenance manuals, etc. because obsolescence lends to multiple configurations existing in the field. This requires careful recording of retrofit actions and specific configurations by serial number for each system instantiation (e.g. aircraft tail number, etc.). If with those modifications are differences in function, these differences will be even more difficult to manage.

1.2.1.3.5 Manufacturability
Manufacturing methods and standards change over time. As plants upgrade their facilities to stay relevant with advancements in technology, it may be difficult for them to maintain the facilities for the production of legacy components. It is for this reason that “lifetime buys” of certain components are done. There are a couple problems with buying a large supply of a particular component. As Young indicated, if there is a hidden defect in the component that is not discovered until after production, the entire batch of components will have this defect. (Young, 2001) Secondly, a component may for another reason become obsolete or require engineering change because of obsolescence in an adjacent component. As a result, an investment in the lifetime buy may not be prudent. On the other hand, if one does not purchase a reasonable supply of a component, the supplier may dictate the schedule for change and that change may be more frequent and at high cost. Estimating the right quantity for a lifetime buy is a challenging problem because it requires a probabilistic assessment of future failure rates, retirement schedules and upgrading scenarios amongst other factors. Despite efforts to develop techniques for calculating the appropriate levels of lifetime buys, external change can cause the part to become not only obsolete from a manufacturing and maintenance point of view, but also from a functional perspective. Avoiding obsolescence mitigation through lifetime buys can ultimately lead to a company housing significant levels of obsolete inventory that may or may not be able to be used. (Sandborn, 2008)

1.2.1.3.6 Changes in Environment
Changes in environment can occur in two ways for a given system. First, a system may be used in a fundamentally different physical environment than was anticipated during development. While the specifications may have requirements that cover the majority of environmental conditions, at times there are certain phenomena that only really emerge under these new conditions. These changes may cause a system to need modification in order to maintain performance and not become functionally obsolete. An example of this is the use of U.S. Navy airplanes such as the F/A-18 Hornet by small countries (e.g. Finland) with more severe flight spectra leading to premature metal fatigue induced cracks and failures. (Siljander, 2009) Secondly, defense systems that are fielded for decades must adapt and evolve to the changing threat environment. Dowling notes that it becomes possible that
“the environment in which the system acts has changed in such a way that it can no longer offer adequate performance.” (Dowling, 2001)

As a new threat emerges or an existing threat develops mechanisms to try to beat or evade the defense system, that system must adapt and evolve with new countermeasures to prevent functional obsolescence. For example, the Patriot Missile System was originally designed for the anti-aircraft mission and then was later redesigned provide capability against tactical ballistic missiles as the threat space had changed.

1.2.1.3.7 Management Approach
Katz and Allen propose that human obsolescence in engineering may actually be created because of a management perception that older engineers are only familiar with functionally obsolete technology and cannot contribute as much to the cutting edge technology. They believe that this perception can lead to a “self-fulfilling prophecy” in that managers will not provide these engineers with assignments that would keep them technically current.

“Recent research shows that instead of age being the cause of obsolescence, the failure of management to provide challenging work and to emphasize the need for technical currency are the more likely causes.” (Katz & Allen, 2004)

Ultimately, even unintentional actions can lead to human obsolescence and efforts will need to be taken to ensure that institutional knowledge is well documented for future engineers working on replacing an obsolete component while providing the current engineers with the appropriate learning experiences and tasking to ensure that they stay technically current.

1.2.1.4 Obsolescence Mitigation
This section is titled Obsolescence Mitigation and not Obsolescence Prevention as is impossible to prevent obsolescence entirely in these large complex systems. In fact multiple sources indicated that for systems using COTS hardware or software the obsolescence problem is far worse than it had been in the past because the design and support of those components is dependent on the supplier. In this section, we examine how the literature proposed obsolescence be mitigated in various aspects of a project from systems engineering, software engineering, test, prognostics and supply chain.

1.2.1.4.1 Systems Engineering
Typically, systems engineering is a front-end activity for a project that peaks early in the project life-cycle and then reduces in activity level as the project moves into development. Systems engineering is also important during the integration and test phases and then finally tapers down after system deployment. Obsolescence mitigation can be proactive or reactive, but in either case, to fully leverage a mitigation opportunity, a systems engineering approach should be used. An example of a basic systems engineering process is shown in Figure 2 below:
When being proactive in obsolescence management, part of the objectives or criteria may include obsolescence considerations in the initial implementation approach. If obsolescence occurs in a legacy system, alternatives still need to be evaluated, and this overall approach can still be applied. The key additional consideration, however, is how the obsolete parts of the system interact with the non-obsolete parts of the system. In other words, can obsolescence be addressed as a local problem affecting only single components or does the impact of obsolescence cross interfaces between components or even interfaces between sub-systems or the system as a whole and its environment?

Dowling addresses obsolescence as a form of engineering change and indicates that these changes can and should be planned for at the system level and not only the component level. He believes that obsolescence is bigger than the availability of a component from a supplier, but rather that there are many changes that can make a given system obsolete (e.g. miniaturization/personalization, scalability to number of users, changing threat environments) and for those changes that can be anticipated, a plan should be in place for how to deal with these different types of obsolescence. Dowling suggests a detailed examination of how the system may be used in the future and as well as the current needs of the system. Figure 3 shows how Dowling anticipates examining solving problems through system design. Dowling shows the importance of
evaluating the possible solution options against the problems and needs that are required. This step is typically performed in the basic systems engineering process. However, his process then continues to consider the future problems or requirements of a system and how those might manifest themselves in a solution space. Once those two efforts have been performed he hopes that a plan will be developed to evolve the current system into one that will meet the future requirements of the system, thus dealing with functional obsolescence. He proposes adding the following systems engineering artifacts to the typical systems engineering activities executed for a project: obsolescence management plan, change plan, future systems requirements, future system design, and future system simulations. (Dowling, 2001)

**FIGURE 3: DOWLING’S VIEWS ON A SYSTEMS ENGINEERING APPROACH WHEN ADDRESSING OBSOLESCENCE**

(SOURCE: (DOWLING, 2001))

1.2.1.4.1.1 Use of Standards and Specifications
Common standards help provide structure to an implementation design. In a proactive approach to obsolescence, use of common standards provides some stability in a changing technological environment.

"Interface standards generally have long lifetimes, some as long as 25 years, and can outlast any particular product, vendor or technology." (Smith, 2001)

If the technology must eventually be swapped out or modified, the new technology will likely be built to the same standard or a newer standard (backward compatible with old one but containing added functionality) for easier integration into the system. Often obsolescence mitigation activities attempt to minimize impact to interfaces in order to reduce the likelihood of change propagation as changes to interfaces almost ensure that some level of propagation will occur. The use of common standards supports this goal because the components that are interfaced to the one facing
Obsolescence will be less likely to be impacted as the standard interface will not need to be changed. Examples of common standards range from the Ethernet interface standard RJ-45, wireless Ethernet standard IEEE 802.11, USB 2.0, MIL-STD-1553 for a serial data bus for use in military applications, to the TCP/IP protocols.

Clear specifications with traceability from the system level to the component level requirements provide the context for reactive obsolescence mitigation activities. Specifications provide a context and constraints for implementing alternative design and verification planning. Without clear specifications, it may be hard to determine if a replacement part or component truly meets the capability of the old component. The new component may meet the memory and throughput capabilities of the old requirement, but there may be some aspect of the overall environmental design or another area that may be impacted by the changes that are proposed. Leveson notes that specifications are actually areas that can be re-used on a given project or product with limited changes without major impact as they are written at an appropriate level for re-use (unlike lower level software or design choices which are typically application specific or will require change due to technology updates) (Leveson, Intent Specifications: An Approach to Building Human-Centered Specifications, 2000).

1.2.1.4.1.2 Use of Open Architecture

The use of open architectures in the initial design of a system is recommended in order to help minimize the impact of future engineering change be it due to evolution of a system or due to obsolescence.

"DOD Directive 5000.2-R strongly encourages the design of open architecture for DOD-developed systems in order to ensure flexibility and scalability and to facilitate the insertion and integration of technology. In many cases, industry also has embraced open architecture in order to promote supportability, interoperability, and scalability as means of reducing production costs and gaining a competitive advantage." (Lebron Jr., Rossi, & Poor, 2001)

Young discusses obsolescence mitigation from the very beginning of systems engineering by planning for open architectures that will allow for technology insertion. Young is a supporter of using techniques of abstraction and introduction of middleware to help minimize the impact of hardware obsolescence on software. He also believes that newly developed components should be backwards compatible with other older technology so that technology refresh can occur at the convenience of typical maintenance. (Young, 2001)

Buratti and Del Brusco as well as Smith advocate the use of open architecture and standard interfaces as these architectures and interfaces change far less frequently than the hardware and software on which they are implemented. (Smith, 2001) Like Young, they believe that a plan must be in place for future technology insertion, and that backwards compatibility will help minimize the impact of that insertion. (Buratti & Del Brusco) These approaches are typically established at the beginning of a project such that the system is designed with modularity such integration of a new component or part for obsolescence mitigation can be performed smoothly.
While open architecture may be recommended for obsolescence among other reasons, proprietary solutions are often selected to gain a different type of competitive advantage. For a particular system, the designer of the proprietary system have the required knowledge to more easily make changes for these systems, thus positioning them for future maintenance and upgrade contracts. Open architectures make those future contracts more competitive as more companies possess the required knowledge. These competing concerns must be evaluated early in the product design such that whatever approach is chosen, the appropriate obsolescence strategy can be developed.

1.2.1.4.1.3 Monitor Obsolescence As Risk
Lebron, Rossi, and Foor developed a systems engineering and management approach for obsolescence by treating it as risk. They developed the Risk-Based COTS Systems Engineering Assessment Model to attempt to minimize the risk of COTS insertion throughout the system lifecycle. The model uses a cube to assess the various risks (criticality, complexity, and life-cycle cost) associated with the possible COTS alternatives presented. The tool can also be used to determine when COTS insertion should not be planned for and lifetime buys are a better lifecycle solution. (Lebron Jr., Rossi, & Foor, 2001)

![FIGURE 4: LEBRON, ROSSI, AND FOOR’S MEASURE OF OBSOLESCENCE AS RISK](source: (LEBRON JR., ROSSI, & FOOR, 2001))

1.2.1.4.1.4 Modeling and Simulation
Similar to Leveson’s goal of reusing aspects of specifications, Lacomme advocates for reusability of simulations that are built to be independent of the system hardware and can be used to test the system requirements. He believes that by mimicking some of these approaches in the embedded system software, it will also reduce software redesign when obsolescence occurs. (Lacomme, 2001)
1.2.1.4.2 Software Engineering
Rothmaier proposes developing modular domain specific software architectures to mitigate obsolescence. By doing this, he believes that libraries can be developed which would promote reuse and therefore reduce the qualification and test activities required. Rothmaier also advocates encapsulation and abstraction to help distance the software from potential changes in the hardware. (Rothmaier, 2001)

Lane, Beattie, Chita & Lincoln advocate a model based architecture development using the UML syntax, object-oriented design and automatic code generation to limit the impact of platform obsolescence to the code that needs to be developed. (Lane, Beattie, Chita, & Lincoln, 2001)
Theoretically, the model would only require an interface change to the new platform and then the entire code base could be automatically generated off of the same existing model. They also believe that the use of a model that ties out to the requirements will help bridge the communications gap between the systems engineering and software engineering development groups. Wherever possible they recommend re-use and design of a model with units that can be easily changed when functionality upgrades are required. In recent years this approach is also being extended to Systems Engineering in the Model Based Systems Engineering domain using various languages (e.g. OPM and SYSML) though it is not as mature.

1.2.1.4.3 Test
Obsolescence can affect test in multiple ways. New test methodologies may need to be developed to test the design changes that result from obsolescence. In addition, the fielded product may not be the only area experiencing obsolescence. The test harnesses and testing SW may also experience obsolescence and should be considered early in any activity where obsolescence is being managed. (Bach, 2001)

The COTS components costs are amortized over the many users; however, the testing is also only focused on the areas of the system most likely to be exercised by the majority of users. If the new projects application of a COTS component diverges from that of the masses or from the context of previously tested projects, specialized testing is still needed in order to reduce the likelihood that the difference in application of the COTS component could cause problems during use.

"Even with no explicitly defined operational distribution, testers usually have some information or intuition about how the software will be used and therefore emphasize, at least informally, testing of what they believe to be its central or critical portions. These priorities will likely change, however, if it is decided to incorporate the component into a different software system. The original system may commonly execute portions that the other never will, which makes much of the testing irrelevant to the new user in the new setting. Likewise, the new user may use parts of the component that correspond to extremely unlikely scenarios in the original system’s behavior, and these may have been untested or only lightly tested when the software was developed." (Weyuker, 1998)

Weyuker stresses the need for various levels of testing specifically in the software domain. She believes that at minimum unit testing, integration testing and systems testing are essential for a system and further types of testing such as feature testing, performance testing, load testing, stability testing, stress testing, and reliability testing may also be required. Weyuker points out that
when using COTS systems, the understanding of the lower levels of the system are often lost by those trying to integrate and test with COTS products and it is often easier for people to assume that the appropriate levels of testing have been performed by the COTS supplier than to fund and develop a robust testing program specific to the project's application. In order to mitigate some of these concerns with reuse of COTS components, Weyuker encourages maintaining the software specification whenever new functionality is added and maintaining traceability between the specification and detailed test cases that have been used to test the software. (Weyuker, 1998)

1.2.1.4.4 The Supply Chain

Monitoring the supply chain is an essential part of obsolescence identification and finding possible alternative solutions to an identified obsolescence issue. Young states that:

"there is much that can be done in partnership, between supplier, integrator and end-user to mitigate the effects. Reviewing the overall system architecture and designing for Technology Insertion, hardware abstraction and program/product synchronism hold great promise as methodologies for the future." (Young, 2001)

Young recognizes that for all of the planning and design that can initially be developed into a system, that coordination with the supply chain is essential in order to gain a coherent obsolescence mitigation approach. This coordination can begin with simply monitoring the supply chain for part availability to more proactive approaches that involve special supplier agreements to incentivize a supplier’s support of a particular product line or even acquisition of certain suppliers to ensure that the know-how and supply of parts will be ensured for a particular product.

In an alternative approach the Defense Microelectronics Activity (DMEA) is a government organization developed specifically due to the difficulties that military systems have sourcing the appropriate electronic products over their long life-cycles. The DMEA includes a number of specialized engineering facilities that can (when a reasonable commercial alternative does not exist) remanufacture the legacy electronic part for a system facing obsolescence. (Defense Microelectronics Activity)

Smith proposed a massive military product wide database containing relevant information on semiconductor devices including: Original Component Manufacturer, Parametric Information, Availability Information, International Parts Reference Numbers, and Possible Equivalents. This database would be paired with another tool that would trace where the semiconductor devices were implemented in various military platforms. Smith proposed a centralized obsolescence management center and a method that considers prognostics to predict when a component may become obsolete based on assessing the ability to source the part. Ultimately, while there have been similar localized implementations of a database system, the proposed common database concept never really came to fruition.

1.2.1.4.5 Prognostics

Prognostics is a developing field that extends the current state of the art in diagnostics system. Where diagnostics tell a maintainer of a system if a component is Go, No-Go or Degraded, a prognostics system aims to understand the physics of failure models for a system, sense changes
that could imply failure in the future and then predict future failure rates which could be used to predict when obsolescence (i.e. lack of product availability) may have an impact on a system (Smith, 2001). While the technology in this field has not been fully developed, new contracts are being issued with prognostics requirements and these systems should be developed with a look to how prognostics can help mitigate obsolescence issues in the field through improved logistics and supply chain planning.

1.2.1.4.6 Obsolescence Team
Buratti and Del Brusco proposed the establishment of an obsolescence team that includes members from component engineering, procurement, design engineering, project management, manufacturing and program management. This team would monitor the state of the components in a system for obsolescence and when obsolescence is discovered would characterize that obsolescence into the categories shown in Table 2 shown below:

TABLE 2: BURATTI & DEL BRUSCO'S OBSOLESCENCE CRITICALITY METRIC

(SOURCE: (BURATTI & DEL BRUSCO))

<table>
<thead>
<tr>
<th>Approach</th>
<th>Criticality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Replacement available, same footprint</td>
<td>Low</td>
</tr>
<tr>
<td>2. Replacement available, different footprint (new layout is required)</td>
<td>Medium</td>
</tr>
<tr>
<td>3. No direct replacement available, different functionality</td>
<td></td>
</tr>
<tr>
<td>- Design modification required</td>
<td>High</td>
</tr>
<tr>
<td>- New layout</td>
<td></td>
</tr>
<tr>
<td>- Software changes could be required</td>
<td></td>
</tr>
<tr>
<td>4. No direct replacement available, process/technology obsolete (ASICs)</td>
<td></td>
</tr>
<tr>
<td>- New component design</td>
<td>Highest</td>
</tr>
<tr>
<td>- Module redesign</td>
<td></td>
</tr>
<tr>
<td>- New layout</td>
<td></td>
</tr>
<tr>
<td>- Software</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: Footprint in this instance can be interpreted as a combination of Form & Fit

Once the criticality is established, obsolescence mitigation strategies are developed which may fit into the categories included in Table 3.
<table>
<thead>
<tr>
<th>No.</th>
<th>Strategy</th>
<th>Description</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FFF Equivalent</td>
<td>Replacement by a form, fit, function component</td>
<td>Multi-source component, change to different source, no real obsolescence, problems may occur if the same quality level is unprocurable a substitution shall be activated</td>
</tr>
<tr>
<td>2</td>
<td>Life-Time Buy</td>
<td>All components for the series production programme (including spares and repair stock) will be purchased at the start of production</td>
<td>High risk is present when a single source supplier is considered in the relevant Part List (typical for ASICs and Hybrids). This solution is to be avoided when possible, it can be applicable when a specific batch of items are in production and their life cycle is well known and agreed.</td>
</tr>
<tr>
<td>3</td>
<td>Last Time Buy</td>
<td>Upon obsolescence notification by the supplier, a purchase of components is initiated to cover all future demand for the programme including spares and repairs.</td>
<td>This solution is applicable to a mature equipment and on isolated events only, but not for new design/redesign. It is also acceptable only if all obsolete components on a module can be removed by last time buys, otherwise a redesign shall be considered.</td>
</tr>
<tr>
<td>4</td>
<td>Substitution</td>
<td>Replacement by a part with acceptable non-compliance</td>
<td>This solution is applicable when no alternative components are present and a deviation can be accepted by the Customer/Purchaser. No redesign activities shall be considered.</td>
</tr>
<tr>
<td>5</td>
<td>After Market Supplier</td>
<td>Purchase from a supplier who has purchased the rights and facilities to continue to manufacture the part from the original manufacturer</td>
<td>This solution is applicable to a mature equipment and on isolated events only, but not for new design/redesign</td>
</tr>
<tr>
<td>6</td>
<td>Emulation/Cloning</td>
<td>FFF redesign of the obsolete component using current technology</td>
<td>This is applicable to ASICs and other custom designed components as Hybrids</td>
</tr>
<tr>
<td>7</td>
<td>Redesign</td>
<td>Redesign of the entire module to replace obsolete components with current technology. Major objective is to remove and avoid future obsolescence.</td>
<td>This is applicable when bulk obsolescence can be predicted or when at the beginning of a new tranche the rules are out of last time buys conditions</td>
</tr>
<tr>
<td>8</td>
<td>Inventory Survey</td>
<td>Use of internet tools (such as TACTech's Lo-K-tor) to locate components, which have become obsolete and which are for sale as excess inventory</td>
<td>This is applicable when the LRUs/SKUs are out of production but still in service (last phases of the life cycle of the equipment)</td>
</tr>
</tbody>
</table>

Gaillat summarizes the work of two obsolescence working groups on obsolescence and also recommended the development of an obsolescence task force including purchasing experts, technical experts and a coordinator. The purpose of this task force is to monitor the state of the components in the database for a product, continually update the status of those components, and when obsolescence is identified find a solution to a given instance of obsolescence which can be in the following forms:
“1) searching for a strictly equivalent component,
2) searching for a more or less equivalent component,
3) creating a reserve stock,
4) buying stock available on the market,
5) sharing stocks between units,
6) negotiation with the supplier,
7) calling on after market companies,
8) producing a substitute component (ASIC or FPGA),
9) partial or total redesign of the card,
10) etc.” (Gaillat, 2001)

Annually this Obsolescence Task Force evaluates every part, tries to predict end of the commercial life for those parts based upon the supplier parts availability forecasts, and attempts update product sales forecasts to determine the next course of action in terms of obsolescence investigations.

1.2.2 Systems Engineering Techniques and Approaches for Engineering Change

There are many reasons for engineering change in a system after the design has been established. Errors are one cause, but not the only cause. System evolution and the need to mitigate hardware or software obsolescence are other reasons that engineering change may occur.

“The problems that design modifications frequently present to manufacturing managers, and the considerable cost implications, have given rise to the observation that the resulting EC [engineering change] are an evil, foisted on the manufacturing function by design engineers who probably made a mistake in the first place” (Wright, 1997)

Here Wright notes the perception that change is “evil.” Systems engineering techniques in support of engineering change is an important topic in relation to obsolescence because obsolescence implies change is needed in either the system or the manufacturing process in order to maintain the functionality of a legacy system; therefore, a change is only “evil” if it does not pertain to system growth. Because obsolescence mitigation often will lead to engineering change and that change can have impacts throughout the system, it is makes sense to use techniques applicable to engineering change in the obsolescence mitigation process.

There are a number of matrix based approaches, described in Section 1.2.2.1, that contribute to understanding the system relationships that are essential to evaluate the impact of engineering change. These approaches start from the foundation of the design structure matrix. These matrix techniques provide a formal and structured way to examine relationships between the system components that a typical system drawing does not capture.

In addition, Giffin et al., showed that a change propagation analysis can be applied to a legacy system in order to classify the system components as multipliers, carriers, absorbers or constants. (Giffin, de Weck, Bounova, Keller, Eckert, & Clarkson, 2009) These classifications can be used to identify which components are “hot spot” components that if change is required due to
obsolescence can have a ripple effect throughout the system. Section 1.2.2.2 discusses change propagation analysis in detail.

Finally, Section 1.2.2.3 discusses intent specifications. Intent specifications are one technique that can be used to help capture the rationale for the design decisions, and link that rationale to the specifications for the system. The benefit to this technique in engineering change is that the impacts of a proposed change can be more easily evaluated. For example, if a system needs to be modified to increase in capability, and that change would modify certain system assumptions, all of the requirements that are impacted by that assumption are linked to it and can therefore be evaluated to determine if changes would be required.

### 1.2.2.1 Matrix Based Approaches

#### 1.2.2.1.1 Design Structure Matrices (DSM)

Much of the literature review for this section involved a review of the 480+ abstracts of all the publications posted on the http://www.dsmweb.org webpage. The selected few articles are those that appear to hold the most promise for techniques that could be applied to engineering change in general and obsolescence in particular. The dsmweb.org site provides tutorials and background on the DSM method. As a general summary, a design structure matrix is a square matrix that shows relationships between entities in one domain. An example of a task based DSM is included below. The entities can be tasks, objects such as physical parts, parameters or people and organizational units, amongst others.

![FIGURE 5: EXAMPLE DSM](SOURCE: (DSMWEB.ORG: DESIGN STRUCTURE MATRIX (DSM)))

Each task is included on both the rows and the columns of the matrix. The diagonal represents where one task relates to itself and therefore must always be blank or populated with a zero. The upper right triangular half of the matrix represents tasks that feed forward into a subsequent task. The lower left triangular half of the matrix represents tasks that have a feedback mechanism to another task. (Note: The opposite nomenclature is also in use in some DSMs). There are a number of variants on the ways that DSMs can be used, but the basic purpose of a DSM is to represent relationships in a given domain. There are several categories of DSMs, for example: time-based and static. The task DSM is time-based. When a task-based DSM is not optimal, it can be re-sequenced to reduce the impact of feedback loops. DSMs mapping parameters to each other are sequence-based. Component DSMs are an example of a static DSM. These DSMs are representative of component connectivity and can be used to evaluate the architecture of a system. Team DSMs can be used to
map the relationships between individuals or groups in an organization. DSMs provide a highlystructured manner for evaluating domain relationships.

1.2.2.1.2 Domain Mapping Matrices (DMM)
Danilovic and Browning formally defined the concept of a Domain Mapping Matrix with respect to a DSM. The DMM is a rectangular matrix that relates the DSMs of two different domains as illustrated in Figure 6. For example, the specification DSM could be mapped to the component DSM through a DMM to show which specifications contain requirements that trace to a particular component. This type of relationship would be important to note if the specifications were changing as a result of functional obsolescence, as it may help predict if a component could be impacted. They noted that when issues in a project or product arose that the root cause was often a relationship that had been overlooked.

"The product or service to be developed (the deliverable) may be complex in its function, form, integration, technology, etc. The work required to develop it is often complex in its number of activities, people, teams, and organizations involved and their relationships. These areas are interwoven, creating a number of complexities and uncertainties for managers." (Danilovic & Browning, 2007)

DSMs and the added DMM provided an ability to capture those relationships in a structured form.

FIGURE 6: DANLOVIC & BROWNING'S "PERIODIC TABLES" PROJECT SYSTEM DOMAINS AND PRODUCT SYSTEMS
(SOURCE: (DANILOVIC & BROWNING, 2007))
1.2.2.1.3 Engineering System Matrix (ESM)

Bartolomei introduces a similar approach to the DMM called the Engineering System Matrix which is illustrated in Figure 7. The ESM works on the same principle of rectangular matrices that related DSMs in various domains, however the domain definitions of this approach are different. The most noticeable differences are the system drivers which show how external factors influence the system.

![Figure 7: Engineering System Matrix](source: (BARTOLOMEI, 2007))

1.2.2.2 Change Propagation Analysis

A change propagation analysis is a technique that can be used to help understand or predict how change in one part of a system can affect other parts of the system.

Eckert, Clarkson and Zanker developed a number of definitions surrounding change propagation for a given component as listed below:
- Constants: Not affected by change
- Absorbers: Absorb more change than they cause
- Carriers: Absorb a similar number of changes to that they cause
- Multipliers: Generate more change than they absorb
- Buffers: Minimize the effect a change (e.g. tolerance margins)
- Resistors/Reflectors: Components for which there is an engineering or business reason to minimize or eliminate change

They also noted that differing design strategies impact the likelihood of change propagation in a system. A highly optimized system leaves little margin in order to drive down cost or increase performance thus increasing the overall change that a change will propagate throughout the
system. However, systems built with added margin have included the option for future flexibility by introducing buffers into the system. Multiplier components would be good candidates to examine to determine if added margin can be developed into the initial design to reduce the impact of change to the overall system. In summary they noted that:

"successful change management needs to be informed by all of the following aspects of change and their relationships to each other:

- The source of the change and the underlying causes
- The interdependencies between parts and systems
- The types of propagation behaviour and their dependence on tolerance margins
- The consequences of change on product quality, cost, and time to market
- The state of tolerance margins on key parameters" (Eckert, Clarkson, & Zanker, 2004)

These points will become more important as we examine obsolescence mitigation approaches later in this paper.

In another paper, Suh, de Weck, and Chang developed a change propagation index (CPI) to help measure the degree of change propagation. The ΔE is a binary change propagation matrix. This matrix is developed by evaluating the impact of the ith element by a change to the jth element. The equation they developed is included below (Suh, de Weck, & Chang, 2007):

\[ CPI_i = \sum_{j=1}^{n} \Delta E_{i,j} - \sum_{k=1}^{n} \Delta E_{j,k} = \Delta E_{out,i} - \Delta E_{in,i} \]

- CPI > 0: Multiplier \( \rightarrow \) Add flexibility, split into sub-components or surround with buffers
- CPI = 0: Carrier \( \rightarrow \) Examine closely
- CPI < 0: Absorber
- If \( \Delta E_{out,j,} = \Delta E_{in,j} = 0 \): Constant
- Resistors are not identified mathematically, but should be through evaluation

Giffin’s thesis examined change propagation in large technical systems by evaluating engineering change requests for an established system. While the change propagation technique may be a helpful way of categorizing change propagation, her thesis showed that the predicted CPI was not always what occurred when actual engineering change occurred (Giffin, Change Propagation in Large Technical Systems, 2007). CPI may need to be re-evaluated on a project throughout its lifecycle. Changes can also propagate between components that are not directly connected in the system DSM.

1.2.2.3 Intent Specifications
Leveson introduces a technique called intent specifications which attempts to propose a technique for software specification development that improves designs by leveraging knowledge of how
humans think and interact with machines and integrating that into a system’s engineering approach. She notes that specifications should support the overall iterative system’s engineering process of evaluating alternatives and selecting one to move forward into design of the components and interfaces. The specifications should also support verification efforts. In order for a specification to support this approach she believes that:

“design decisions at each stage must be mapped into the goals and constraints they are derived from to satisfy, with earlier decisions mapped (traced) to later stages of the process, resulting in a seamless (gapless) record of the progression from a high-level system requirements down to the component requirements and designs.” (Leveson, Intent Specifications: An Approach to Building Human-Centered Specifications, 2000)

While her approach is somewhat particular to software specifications, she takes into consideration many of the levels of concern in systems engineering. Aspects of her approach could be extended to other disciplines in order to trace the system level requirements and context of a project or product to the components of that product.

Leveson cites Checkland that the:

“specification is required that defines the system boundary, inputs and outputs, components, structure, relevant interactions between components and the means by which the system retains its integrity (the behavior of the components and their effect on the overall system state), and purpose or goals of the system that makes it reasonable to consider it to be a coherent entity.” (Checkland, 1981)

She believes that in the final point regarding including the purpose and goals of a system are typically not included in current specification systems. Leveson then introduces intent specifications as a means to capture all of these aspects in order to support the systems engineering process.
FIGURE 8: LEVESON'S INTENT SPECIFICATION STRUCTURE

(SOURCE: (LEVESON, INTENT SPECIFICATIONS: AN APPROACH TO BUILDING HUMAN-CENTERED SPECIFICATIONS, 2000))

On the horizontal axis, intent specifications include relevant information about the system's environment, operators, and the decomposition of the system which can be helpful in grounding the context for the specification. The vertical dimension has 5 levels with the intention that a higher level provides the intent for the level immediately below it and these intents are appropriately mapped to each other to provide traceability from the system level requirements down to the requirements for the components. Each level provides the opportunity to look at a system from a different perspective. Below is an outline of an intent specification created for the TCAS system used in support of air traffic control. This outline gives some context for the type of information that would be included in each section of an intent specification.
While Leveson notes that intent specifications are a great approach for the initial specification of a system, she acknowledges that

"they may be even more important for the maintenance and evolution process."  (Leveson, Intent Specifications: An Approach to Building Human-Centered Specifications, 2000)
This is the case because the original designer of a system lives the process and has the knowledge of the rationale for the design decisions at the time. For those engineers trying to make change in a system, unless that background and rationale is captured in a structured way, the resources either may not be available (i.e. the original engineer has left the project) or time has diminished the ability for those who had the knowledge to pinpoint the rationale for a given decision. Intent specifications document the context and rationale in a structured and readable manner to allow engineers the best chance for being able to determine the impact of their design changes.

1.2.3 ASSESSMENT OF GAPS

Many of the resources on proactive obsolescence mitigation looked at techniques that could be applied first early in program development including open architectures, use of interface standards, model based architecture and looking at the potential of the future system requirements. A new system may be able to develop a fully systematic approach to obsolescence in the design phase and then deploy an obsolescence plan throughout the product lifecycle; however, a legacy system does not have that luxury. Legacy systems were often not designed with obsolescence considerations and therefore, while they may be able to deploy some of these techniques in the obsolescence mitigation solutions used, the overall system will likely still struggle. The reactive obsolescence mitigation papers tended to focus on obsolescence identification in the hardware through supply chain monitoring, classification of the obsolescence and developing a replacement solution, without fully acknowledging the impact of these choices on the rest of the project or the system. On the whole, there was little reference in the obsolescence papers to using techniques like DSM, DMM, and change propagation analysis that were developed for engineering change.

This thesis will look at obsolescence mitigation from the point of view of an already in-use, legacy system facing functional and manufacturing obsolescence. It will look to leverage recommendations made in the papers from the literature research as well as those developed by the case study organization. The goal will be to provide a resource for those planning an obsolescence mitigation approach that is not limited to identification and monitoring of obsolescence and the design of the new components to be more resistant to obsolescence, but also to assess the impacts of these changes to other aspects of the product itself and the project as a whole. Where appropriate, some engineering change techniques may be recommended to help overcome some of the difficulties acknowledged with using the original derived obsolescence mitigation process.
2 RESEARCH APPROACH

The goal of this thesis is to evaluate current methodologies used and proposed for obsolescence mitigation and determine if other systems engineering techniques could be applied to provide a more robust obsolescence approach. In order to determine the current methodologies used in obsolescence mitigation, the following research method was applied to a real-world case study of a system dealing with a large amount of obsolescence in the defense industry. This complex weapon/sensor system (per system development and production cost $1B) had been out of production for greater than ten years, had limited and localized hardware upgrades for particular customers leading to multiple system configurations, software had been maintained for these configurations with limited capability evolution, and the parts of the system that had not been upgraded had been maintained over the years with spare parts. A particular customer had a desire for more instances of this system and an effort was made to determine how these systems could be manufactured in today’s environment. The supply chain organization began with the Bill of Material lists for the system and started to ping the suppliers to determine if the legacy parts were available. It was at this point that large amounts of obsolescence were discovered. While certain components were faced with functional obsolescence due to the changing environment, most of the components identified for change faced manufacturing obsolescence in that they could no longer be purchased or manufactured in the same manner at reasonable time and cost. The technical and financial details of this system are abstracted in this thesis; however, it is fair to say that this system is a large, complex system that has high performance requirements. A system level depiction of this system is included in Figure 10. The lines depict physical connections for the system. The lightning bolts depict radio frequency communication. This picture of the system is a notional set-up selected to represent the different types of connectivity that are allowed between the different components. In reality, this system is scalable and the components have been designed to provide flexibility in the various deployment configurations. Typically the types of connections established are determined based upon distance. If the Command and Control Level 2 is close to the Command and Control Level 1, communication between the two would occur through a physical link. If the range is too far for the physical connection, communication would typically occur through an Antenna attached to each location, and if the distance required it, the communication could be received by an Antenna attached to a Relay that would transmit the signals over a longer distance.
In order to assess the planned systems engineering approach to help mitigate the found obsolescence, interviews were conducted with seven individuals involved in the update of the system to understand the systems engineering approach that was taken with respect to obsolescence.
TABLE 4: INTERVIEWEE INFORMATION

<table>
<thead>
<tr>
<th>Interviewee Number</th>
<th>Role</th>
<th>Overall Years of Experience</th>
<th>Years of Experience on Case Study System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Director of Systems Technology Refresh</td>
<td>&gt;20</td>
<td>&gt;5</td>
</tr>
<tr>
<td>2</td>
<td>Systems Engineering Cross Product Team Lead</td>
<td>&gt;20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>3</td>
<td>Systems Engineering Proposal Lead &amp; Sub-System Studies Lead</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Software Task Manager</td>
<td>24</td>
<td>&gt;7</td>
</tr>
<tr>
<td>5</td>
<td>Program Systems Engineering Lead</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Systems Engineering Requirements Lead</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>Author: Systems Engineer and Task Lead</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

In addition, any areas of “surprise” or difficulty were documented in order to identify improvements that could be made in the systems engineering or management process. The existing process was then evaluated to determine how it could have been improved by adding a few select systems engineering techniques (e.g. DSM/DMM and Intent Specifications). The research into a real world obsolescence mitigation approach in conjunction with recommendations from the literature review will help establish the foundation of a more robust systems engineering and management approach. The goal of this thesis is that the results of this research provide obsolescence management guidelines that could be used as a primer for those currently encountering obsolescence on a project or for those that want to prepare to mitigate future obsolescence concerns on an existing system.

2.1 SUBJECT MATTER EXPERT INTERVIEWS

2.1.1 INTERVIEW APPROACH

Seven interviews were conducted with people of varying roles on the project examined in our example case study in dealing with obsolescence. The goal of these interviews was to determine their approach to obsolescence and to gain insight into areas that were either surprising or required an additional approach compared to that of the original plan. Interviewees included the Director of Systems Technology Refresh, the Systems Engineering Cross Product Team Lead, one of the Systems Engineering Proposal Leads and Sub-System Studies Lead, the Software Task Manager, the Program Systems Engineering Lead, and the Systems Engineering Requirements Lead. In addition, the thesis author’s own observations were included as she had participated in some of the proposal and study efforts for the system.
2.1.2  **INTERVIEW QUESTIONS**

The following questions were asked as part of the interview process:

1. How were areas of obsolescence identified?
2. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?
3. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?
4. Was there any engineering change in an item required because of obsolescence in another item?
5. What approaches can be used to help deal with obsolescence?
6. What were the decision criteria used in the trades to determine what approach would be used on the project?
7. Where did the primary obsolescence manifest itself (Hardware, Software, Interfaces)?
8. What type of complications does obsolescence bring to the project/product lifecycle?
9. What engineering tasks were developed in the project that help address obsolescence?
10. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?

These questions were asked of the interviewees without providing them the information from the literature review in order to get their unbiased responses based upon what they experienced through the case study. The interviewees were provided with a partial list of the questions in advance in order for them to understand the context and intent of the interview. Handwritten notes were taken during the interviews to document the responses. The notes were then transcribed and are included in Appendix I: Interview Documentation.

2.1.3  **INTERVIEW CONCLUSIONS**

The conclusions yielded for each question have been summarized by question number in Table 5. An “X” in the table indicates that an interviewee addresses a given conclusion in their interview. In some cases, a particular interview may have addressed the comment for one question in their response to another question. In those instances, the conclusions was listed only once in Table 5 with the most appropriate question number. Column 7 was shaded as these were responses known to have been relevant to the case study, but provided by the author to give context to the interviewee about the intent of the question.
**TABLE 5: SUMMARY OF INTERVIEW CONCLUSIONS**

<table>
<thead>
<tr>
<th>Interview Question</th>
<th>Interview Assessment</th>
<th>Interviewee #</th>
</tr>
</thead>
<tbody>
<tr>
<td>How were areas of obsolescence identified?</td>
<td>HW obsolescence primarily identified when there is an inability to purchase parts on the BOM lists from known suppliers.</td>
<td>XX XX</td>
</tr>
<tr>
<td></td>
<td>Suppliers going out of business or no longer supporting a product line are the primary reasons for obsolescence.</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Determine what level the replacement should occur based upon the percent of obsolescence at lower levels: part, component, assembly, subsystem, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Movement to COTS increases occurrences of future obsolescence but minimizes some of the impact.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The documentation of a system can also experience obsolescence.</td>
<td>XX</td>
</tr>
<tr>
<td>Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?</td>
<td>There was a perception of more obsolescence than was eventually identified.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stale supply data in relation to the BOM lists was the primary reason for the discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified.</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Document obsolescence was identified later and impacted some of the design mitigation activities.</td>
<td></td>
</tr>
<tr>
<td>If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?</td>
<td>An assumption that what was acceptable before will be acceptable now is a false assumption that will often lead to an underestimation of the work that may need to be performed.</td>
<td></td>
</tr>
<tr>
<td>Was there any engineering change in an item required because of obsolescence in another item?</td>
<td>Obsolescence caused engineering change in areas other than those impacted by obsolescence alone.</td>
<td>XX XX</td>
</tr>
<tr>
<td></td>
<td>Impacts like this can be minimized by maintaining existing interfaces.</td>
<td>X</td>
</tr>
<tr>
<td>What approaches can be used to help deal with obsolescence?</td>
<td>Use existing spares-Delay obsolescence problem.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Desktop Replacement - Same part from another vendor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Desktop Validation - Same part from different manufacturer requiring validation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Build-to-Print/Maintain Form, Fit, Function.</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Replace part with functional equivalent.</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Functional Reallocation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Replace part with COTS/MOTS.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Redesign Part.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consolidate several parts into one part.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Migrate hardware to software.</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Use of common and standard interfaces.</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Design Cost.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lifecycle Cost.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Risk.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Schedule.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feasibility.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flexibility.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintainability.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reliability.</td>
<td></td>
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<tr>
<td></td>
<td>Ability to maintain Form, Fit &amp; Function.</td>
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<td></td>
<td>Adherence to contract.</td>
<td></td>
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<tr>
<td></td>
<td>Backwards Compatibility.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Future Growth.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Impact to Interfaces.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintain current capability.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>End-of-Commercial-Life Date.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vendor/Supplier Stability.</td>
<td></td>
</tr>
</tbody>
</table>

~ 39 ~
<table>
<thead>
<tr>
<th>Interview Question</th>
<th>Question</th>
<th>Interview Assessment</th>
<th>Interviewers #</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Where did the primary obsolescence manifest itself (Hardware, Software, Interfaces)?</td>
<td>Hardware was the primary driver of obsolescence in the system. COTS increases dependency on vendors; may not be able to get features wanted in a particular release</td>
<td>1234567</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For systems that will be used in multiple locations, certain country specific considerations need to be designed into the mitigation strategy</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Managing multiple configurations of a system is one of the primary types of complications that can occur because of obsolescence; impacts design, integration, system stability, backwards compatibility, different standards and requirements</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Short COTS lifecycle requires repeated technology insertion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>When gaps arise between the approach and the specification, waivers or additional design may be required</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>What type of complications does obsolescence bring to the project/product lifecycle?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>What engineering tasks were developed in the project that help address obsolescence?</td>
<td>Identify obsolescence Other Obsolescence Mitigation Approaches: Trade Studies, Determine how the changes affect key system parameters, Evaluate regulatory implications of the changes, Evaluate the impact on the factory test equipment, Ensure that the system continues to meet the system level specification: test to the technical performance measures, Identify gaps in system documentation and identify people who have the required knowledge, Establish required requirements traceability, Identify required changes to the requirements specifications based upon new regulations, Make required updates to documentation, Early integration activities, Design artifacts for systems integration, Designed verification test plans, Development of ECP, Determine the future supply chain decisions: lifetime buys, supplier partnerships, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Team Training</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?</td>
<td>Align future design activities to vendor roadmaps, Assess part availability by “pinging” the supply chain more regularly, Consolidate number of vendors, Develop a team or mechanism to align engineering, supply chain and operations for obsolescence mitigation, Find suppliers that support other industries with longer lifecycles &amp; similar requirement needs, Increase term of vendor agreements, Increased use of COTS, Increased visibility for obsolescence strategies in program reviews, Maintain system documentation, Need to improve requirements and rationale traceability, Provide suppliers incentives to continue support, Obsolescence mitigation activities provide opportunities to improve on established procedures, Obsolescence mitigation can enable future system growth, Obsolescence must be continually monitored, Migration to COTS can lead to a lack of in-house expertise, If a replacement part does not meet the original specification, must evaluate whether other actions must be performed to meet the systems needs.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Other Items</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

~ 40 ~
All of the interviewees who were involved with the discovery of obsolescence on the project agreed that most of the obsolescence started in the hardware. There was a general understanding that obsolescence is identified by “pinging” the supply chain in order to determine if a particular component could still be purchased from an established set of suppliers. In many circumstances, suppliers either no longer supported a particular part or product line or the supplier had gone out of business.

In response to question 2, there was a varying response as to the perceived level of obsolescence at the beginning of the project versus that discovered at the end of the project. This difference typically represented one of two things: 1) what phase the interviewee came onto the project and 2) which sub-system they interviewee was most familiar with. In the sensor sub-system, functional obsolescence had been identified and planned for replacement for a number of years. Therefore, those familiar with this sub-system were not surprised by the level of obsolescence in that sub-system. Those involved at the very beginning of the process, knew about a certain level of obsolescence; however, they were using the stale supply chain data (only 30% current). Once the full parts list was checked against the supply chain, there was a substantial increase in the number of obsolete parts. If the interviewee came on after this point, there was a certain level of obsolescence reduction as alternative vendors and suppliers were found that could supply some of the parts previously tagged as “obsolete”.

Everyone acknowledged that obsolescence could cause engineering change in other components that were not obsolete; however, one respondent emphasized that a goal within the project was to minimize the impact to the interfaces to try to reduce the level of these changes.

The biggest complication that results from obsolescence was unanimous – managing multiple configurations of the system. This is because an increased number of configurations affects all aspects of the development and deployment lifecycles.

Many of the interviewees brought up the necessity of vendor coordination moving forward. They look at “technology refresh” and future “technology insertion” activities as opportunities to enable capability growth within the system. They recognize that the increased pace of technology change requires coordination with vendor roadmaps and with the customers maintenance and upgrade plans.

The interviews provided areas that could be improved and lessons learned. The following research approach using DSM artifacts was chosen because the DSM has some properties of structure that should help mitigate some of the difficulties that were experienced in the original approach.

2.2 DSM ARTIFACTS
The use of the Design Structure Matrix (DSM) methodology as a potential addition to the systems engineering approach for obsolescence was evaluated to hopefully address some of the gaps that exist in the current methodologies. In order to perform some of this analysis a baseline DSM representing the system architecture was required. The system architecture was translated into a DSM showing each of the components as well as their physical, energy-, mass- and information-flow related interactions (mass-flow interactions were omitted from the provided diagrams as they were
not applicable to the evaluated sub-system). The Design Structure Matrix methodology when applied to the system's architecture can provide a highly structured analysis and communications tool that can be used by both engineering and management to help determine where trades are needed and the relevant status that should be reported to management. Section 4 will show examples of how certain DSM representations and techniques may be applied to the systems engineering process while dealing with obsolescence.

2.2.1 BASELINE DSMs & DMM

For large systems, it is often difficult to represent all of the interrelated components in one DSM. In these cases, one can leverage the option to represent the system in multiple hierarchically related DSMs. A description of hierarchical DSMs can be found at DSMweb.org. (DSMweb.org: Building and Creating a DSM) The benefit of using a hierarchical DSM is that system level relationships can be shown in a smaller DSM for overall understanding. Then each sub-system can have their own DSM relating the internal components of that sub-system. In addition a few rows can be added to the sub-system DSM to show which components of the sub-system provide the interfaces to the rest of the system.

As Figure 6 illustrates, there are numerous different DMM representations that can be examined. As an example, the specification to product DSM shown below in Figure 12 has been selected.

2.2.1.1 System Level

Figure 11 shows the system-level structural DSM for the case study system introduced in Figure 10. Though this DSM has not been clustered, it shows the relationships established between the different sub-systems of the case study system. This DSM omits the mass-flow relationship type as it is not applicable to the system at this level. In addition, this system can operate with multiple instances of each of the prime item level components. For clarity, each of the prime item level components are included once; however, since the Antenna & Relay components of the sensor system can interface with other Antenna & Relay components, they have been divided into their transmit and receive capabilities to develop a representative DSM. The system level DSM was developed through review of various system documents and was then reviewed by multiple system experts for accuracy. This DSM provides a baseline view of the system, and can be used to help identify which areas should be evaluated for potential obsolescence impact.
FIGURE 11: SYSTEM LEVEL BASELINE STRUCTURE DSM

This system level DSM is symmetrical because it only considers if the relationship between two components exist. It does not consider directionality of the relationship. If directionality were particularly important in the system, one could have a non-symmetric DSM where the component on the rows could be on the receiving end of the relationship where the component on the column would be the providing component. In the case of Row 3 (Power 2), Column 1 (Command and Control Level 2) the relationship would be 1 as the Command and Control Level 2 is physically connected to Power 2, but it does not provide power to Power 2. Then Row 1, Column 3 would

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remain a 4 as Power 2 is not only physically connected but also provides power to Command and Control Level 2.

In addition, this system is build with multiple means of communicating between certain components. A 3_5 relationship indicated that information may either be transmitted over a physical connection or it may be transmitted via a radio frequency alone. At the system level, the system is quite modular as might be expected from the system diagram in Figure 10. The Antenna Sub-system is used in a variety of relationships. In addition Power 2 can be used to independently support the Relay or the Command and Control Level 2.

This DSM shows that Command and Control Level 1 is the most connected component at the system level with 6 out of 10 connections. This makes sense as Command and Control Level 1 controls and processes the information from the Sensor and coordinates that information with the Weapons Platform. It then conveys any relevant information via the communications network (either a physical connection to Command and Control Level 2 or via the Antenna or Relay to another Command and Control component).

The benefit to using the DSM rather than a generic system diagram is that the DSM makes the creator question each possible relationship between components. A system diagram may be reviewed for accuracy; however, it is often possible to forget or lose relationships that are possible in the system because many systems do not only have one possible configuration for operation. While the system diagram may technically be correct for a given configuration, it may not capture other possible configurations.

Figure 12 is one example of a DMM that shows the relationships between each of the prime item level components and the system specification (SYS) and prime item level specifications (PIDS#). For this particular system, MIL-STDs are often used as part of the specification. For simplification purpose all relevant MIL-STDs are included in a generic category labeled MIL-STD. For legacy systems, the specification list has been established, and it is important to know which requirements documents contain requirements pertaining to the prime item level components. For each component facing obsolescence, the relevant specifications need to be evaluated to determine if the requirements are sufficient, still applicable, and if the proposed obsolescence mitigation activities impacts the requirements in the specification. It is important that for each component there is at least one specification that provides the requirements for the component. If one of the columns did not have a corresponding specification, further investigation would need to take place to determine where the relevant requirements for that component are contained. One or more specifications may need to be updated or possibly created if necessary. While this DMM does provide helpful information, it does not currently give enough information on the impact of these documents on the interfaces between each of the components.
FIGURE 12: SYSTEM LEVEL DMM COMPARING SPECIFICATIONS TO PRIME-ITEM LEVEL OBJECTS

An obsolescence evaluation is essential in a system that faces any level of obsolescence. Figure 13, shown below, shows how the baseline system-level DSM can be used as a communication tool to which prime item elements are facing obsolescence. By identifying these components in the DSM, one can examine which interfaces may be impacted by the obsolescence occurring in the system. In the next section, a sub-system DSM is described. The system level status would be the roll-up of the status at the sub-system level.
It is important to ensure that each sub-system, component, and eventually part is evaluated for obsolescence. By taking this approach, one can have an easily understandable visual representation of the status of that activity.
2.2.1.2 Sub-System Level

Figure 14 expands the DSM view of the Command and Control Level 1 Prime Item Level down to the component level. The shaded region (below the square DSM) shows how the sub-system components interface to the other prime item level components, thus capturing which sub-system components are actually involved in the interfaces shown in Figure 11. In this instance, only one component, Component A which represents the Shelter, provides the interface with all of the external components. This means that if any interface changes are required at the system-level, it will likely impact this component. In addition, the sub-system level is much less modular than the system level. Component A and Component X are connected to many of the components. Therefore changes to either of those components would likely have an effect on other components, and vice versa. The same exercises using the DMM for specification relationships and identification of obsolescence can also be performed at this level of the DSM hierarchy. It is recommended that the baseline versions of these DSMs are performed for all the systems sub-systems in advance of obsolescence identification. When obsolescence is then found, the baseline DSM for that sub-system will be readily available for analysis.
FIGURE 14: COMMAND AND CONTROL LEVEL 1 SUB-SYSTEM LEVEL BASELINE STRUCTURE DSM

Legend

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Connection</td>
</tr>
<tr>
<td>1</td>
<td>Physical Connection Only</td>
</tr>
<tr>
<td>2</td>
<td>Power Connection Only</td>
</tr>
<tr>
<td>3</td>
<td>Information Connection Only</td>
</tr>
<tr>
<td>4</td>
<td>Physical and Power Connection</td>
</tr>
<tr>
<td>5</td>
<td>Physical and Information Connection</td>
</tr>
</tbody>
</table>
3 RESULTS

3.1 CASE STUDY REASONS FOR OBSOLESCENCE
The case study interviews provided some concrete real-world examples surrounding the reasons for obsolescence. Much of the obsolescence faced by the case study system originated in hardware, as the software used in the system was often proprietary and maintained by the company since the project’s inception. This paradigm is changing during the technology refresh activities. While many items are being addressed as build-to-print, others are being addressed by new hardware solutions which often make use of COTS or GOTS products, which include COTS application software or at minimum a COTS operating system that the software will run on are often part of the COTS system. For hardware and software obsolescence, there are a number of factors that can influence obsolescence.

3.1.1 FUNCTIONAL AND TECHNOLOGICAL OBSOLESCENCE
This exists in the case study system for a couple of reasons. First, this defense system exists in a changing threat environment. The baseline system did not need to address the threats that will need to be addressed in the future. In order to evolve the system, there are larger data processing requirements that must be addressed in the system to provide the required performance enhancements. Therefore, an updated system is required in order for the entire system not to become obsolete in the new or evolving environment. Secondly, there are many electronic parts and sub-systems in this system. Given the exponential rate of growth in this field, the use of newer parts can give many times the performance for far less cost. The older electronic parts are functionally obsolete and where possible are updated in order to provide the option for future evolutionary growth.

In the case study the Software Task Manager explained the term “obsolescence” was rarely used as there is a negative psychological connotation with the term that implied that the system was old and no longer useful. Since the system was still capable, but certain key components were becoming obsolete, the term “Technology Refresh” was used to indicate a system upgrade that would address the obsolescence in the system, but provide for future capability growth. (Software Task Manager, 2009)

3.1.2 MANUFACTURING AND MAINTENANCE OBSOLESCENCE
In this case study, there were a few reasons that manufacturing and maintenance obsolescence occurred. First, a few select components were reaching a threshold for functional obsolescence. In the investigation for mitigation plans, it was found that the upgraded hardware could support the functions of adjacent hardware as well, thus removing the need for large numbers of cables and connectors. This consolidation of function increases reliability and maintainability while providing a cost benefit compared to finding a manufacturer that would create replicas of the legacy electronic components and cabling. However, it also makes the system more integral which may or may not have implications on future change propagation. Secondly, the system had been out of production for years. The system was being maintained and upgraded for existing customers. Some
major end items were showing increased demand as customers developed new ways of using the system, but there had not been a major new sale to a customer for many years. A few customers expressed interest in additional units of the system. In order to determine how to proceed, the supply chain organization investigated which suppliers could still provide the required number of parts for the new development including considering maintenance of all the systems into the future. Many of the parts had not been purchased for some time and therefore the supplier/vendor data in the list was out of date. Some suppliers were no longer in business and others no longer supported that part or product line. Through this activity much of the obsolescence in the system was discovered.

3.1.3 **ENGINEERING CHANGES CAUSED BY OBSOLESCENCE**

For functional, technical, or manufacturing and maintenance obsolescence, the changes required to mitigate the obsolescence will likely have an impact beyond one part or component because of the interfaces that are identified in the baseline DSMs. The reason for change can be direct or indirect and either can have a profound impact on the system as a whole. Obsolescence and its effects can require redesigns of substantial parts of an existing system. The amount and impact of obsolescence was not entirely known at the beginning of the project. From observation in the case study, obsolescence in a system will be identified in a few high profile parts and mitigation plans will begin to form in isolation thus leading to a “surprise” when additional impacts of obsolescence are later discovered in the obsolescence mitigation approach. Many of the results of this case study point to the fact that obsolescence identification and mitigation may occur at a lower level, however, their impact should always be evaluated at the system level to help ensure overall success in the mitigation approach.

3.1.3.1 **Direct Effects**

Direct effects often occur when an interface change is made. For example, when the network of computing components changed from a serial interface to an Ethernet interface, the components could no longer communicate with some of the peripheral units like the printer. The printer itself was designed to meet the higher environmental requirements that defense systems often have to meet, and in itself was not obsolete. In this case either an adapter for the interface or an addition of an Ethernet interface would be required to make the printer work with the rest of the system.

3.1.3.2 **Indirect Effects**

Indirect effects are more difficult to identify but it is important to try and anticipate these effects. If they are not found until later in the effort, modifications could be more costly. Indirect effects are usually caused by hidden or undocumented relationships. For example, in the case study, many electronic parts were consolidated into one. In the original design, these parts were only part of the system allocation for weight, temperature, etc. Many calculations like center of gravity were performed to ensure overall system success. Making modifications of this kind can affect these parameters. Unless the requirements and documentation were detailed with appropriate design rationale, making a change could lead to unintended consequences. For example, the environmental controls may have been established assuming a certain amount of heat generation from the electronics. Once many components are removed, the heat generation may be reduced but
the environmental controls may not be able to adjust and could cause the environment to become too cool, as the A/C cycles rather than running consistently which can cause issues.

Also, while it may seem feasible and simple to remake a part "as is," new governmental regulations or laws may prohibit it. An evaluation must be done as soon as possible to determine which items must be developed to new standards and for which it may be possible to obtain a waiver. An example provided by the Systems Engineering Requirements Lead is lead paint. When some systems were established, it may have been acceptable to use lead paint. Since there are laws and regulations prohibiting this today, lead paint can no longer be used. A remedy to this may be using a different type of paint that had tin content, however, tin can develop "whiskers" which can effect grounding. Because lead is now obsolete, new requirements for coating, cleaning or maintenance may need to be established to mitigate the performance concern of using tin. In addition he pointed out that when many of these defense systems were first established, women were not often the primary operators of the systems and therefore the human factors design did not take women's proportions into consideration. Upon an upgrade to the system, these gaps may need to be addressed. (Systems Engineering Requirements Lead, 2009)

Software algorithms are another area that may experience indirect effects. Whether the interface remains the same or is slightly modified, certain parameters used in the system may be tuned to the system's hardware (and it may be an adjacent piece of hardware, not the one on which the software is running). When changes are made to these areas in the hardware, the software must also be modified. In addition, since many of the items being replaced were specialized hardware running proprietary software, the software had to be translated and re-hosted onto a COTS piece of hardware running a COTS operating system. While this investment and modifications may lead to opportunities in the future, it exposes the company to dependencies on other vendors (e.g. feature configurations in a particular release) which had up to this point been within their control.

3.2 CASE STUDY SYSTEMS ENGINEERING PROCESS FOR OBsolescence

Based upon the case study interviews, the following systems approach to addressing obsolescence in existing systems was established. This approach assumes that some level of obsolescence in a system is known and that there is a need for mitigating the obsolescence.

3.2.1 DETERMINE THE TYPE AND THE LEVEL OF OBsolescence IMPACT

If the obsolescence that the system, sub-system or component is facing is functional obsolescence, it is important to gain an understanding of which functions are now obsolete and if these functions need to be replaced or if the system functionality needs to be enhanced with new capability. In either case, the future needs of the system will need to be determined in order to facilitate the development of obsolescence mitigation alternatives. These future needs should be integrated into the system documentation as described in 3.2.5. In the case study, there were multiple instances of capabilities that required hardware and software modifications. In this instance, the benefits of functional obsolescence alone did not tip the decision to modify the system. However, many of the same components were about to face manufacturing and maintenance obsolescence which then opened the system to the possibility of upgrading the system to meet those needs as well as set the foundation for the addition of future capability. It is important to know what the future needs of a
system may be even if manufacturing and maintenance obsolescence are the primary concern as changes to these systems are typically discouraged due to the expensive costs of developing, testing and integrating hardware changes into an existing system; therefore, if the opportunity to make change for one reason arises, one may want the change to be as efficient and effective in enabling all of the needs to the future system even if they are not initially implemented at the time of the hardware change.

To assess the level of manufacturing and maintenance obsolescence, the supply chain organization was consulted to gather the systems' parts lists or Bill of Materials (BOM) for the product family tree. These lists were maintained by the supply chain organization. Each time a part is purchased, the lists are updated with information from the vendor about anticipated timelines for the continued production and support of that part. These lists were used as a baseline to determine which parts would be needed and then to ping vendors and determine which parts were currently able to be purchased. Because of the smaller part orders and less frequent purchasing that exists in the defense industry compared to that of the commercial industry, it was found that many of these lists contained stale data. In some instances, vendors had gone out of business or no longer sold the part in question. An up-to-date BOM list is an essential first step to determine the impact that obsolescence could have on the overall system.

In addition, it is important to get an initial assessment of the impact the obsolete parts could have on the overall system. The existing specification tree can then be extended and linked down to the pieces and parts level providing requirements traceability wherever possible.

If there is a lot of obsolescence in a particular component or assembly, a part by part replacement may not be the most appropriate approach. In some cases, a component level or assembly level replacement may be more appropriate. This should be considered as part of the trade study for obsolescence mitigation discussed below. At this point, the percentage of obsolescence in each area should be determined to assist in the decision for the type of replacement later.

3.2.2 IDENTIFY OTHER POSSIBLE SOURCES FOR A PART OR COMPONENT
If initial assessment is that a part or vendor is not available, an investigation should be performed to indentify other possible sources for the part. If another source exists, one should evaluate that vendor for future support as well to slow future obsolescence issues. In a difficult economic environment, small niche companies may find it hard to thrive. Ideally, entering into a longer term contract with an established supplier who has other customers for similar components will likely increase the chance that a supplier will be able to support the part or product line and will survive certain economic downturns.

3.2.3 DETERMINE THE DECISION CRITERIA FOR OBSOLESCENCE RELATED TRADES
There are a number of ways to mitigate issues of obsolescence. In order to determine the “best” approach, certain decision criteria need to be established and prioritized. These criteria may differ based on the type of project. For example, if a new capability is cutting edge, but it is a “must have”, performance may top the decision criteria list and cost may be less of a concern. It is usually a good idea to establish top decision criteria and priorities before evaluating trades for two reasons. First, one will have determined what is of value and each team will have common criteria for discussing
and assessing each of the trades. Secondly, the trades will not be influenced by a “favorite” solution that does not support the true project criteria. The following list includes some of the possible decision criteria including those found during the case study (note: this list is not intended to be complete, nor are all of these criteria required for a given project):

- **Costs**:  
  - Design  
  - Manufacturing (per unit hardware cost to the manufacturer)  
  - Kit (per unit hardware & installation cost to the customer)  
  - Lifecycle  
- **Schedule**:  
  - When will the product be able to be purchased or manufactured  
  - Planned End-Of-Life of product vs. Product Line Upgrade Schedule  
- Performance Requirements  
- Adherence to contract  
- Do-No-Harm to current capability (Risk)  
- Backwards compatibility to a common hardware baseline (enables new parts to be used as spares for systems built with legacy parts)  
- Reliability (driven by parts count)  
- Flexibility (example: hard switch vs. software user interface)  
- Maintainability  
- Safety  
- COTS/MOTS (May help maintain backwards compatibility and transition to upgrades faster in the future)  
- Future growth capability  
  - Ability to increase capability without additional hardware change  
  - If hardware must change, ease of technology insertion  
- Impact to number of product configurations  
- Adherence to current regulations and standards  
- Vendor Considerations  
  - Compatibility with the vendors product roadmap and level of commitment of the vendor to support desired product  
  - Other users of the same product from the same or other vendors  
  - Number of vendors who can supply the part

### 3.2.4 Project and Team Management

As with all projects, management will play an important role. First, one must assign the team needed to perform the initial obsolescence evaluations. This may or may not be the same team as those that will later perform the obsolescence mitigation trades, design and development work. Based upon the required schedule, the size of the team will need to be established. An evaluation of institutional knowledge should also be conducted. Who at the company knows/understands the ever important and often not documented design decision rationale? Is it possible to have those
people work on or consult for this effort? If there are gaps in institutional knowledge, what skill sets and domain expertise will help fill these gaps? Are their people who have the required knowledge who have retired and could be brought back on a part or full time basis to support these activities? A decision must be made to either find resources within the company that have most of those needed qualities, or to hire externally. In addition, if this project is not in line with their typical job skill set, it may be required to provide some technical training for the team in areas that will help them address the challenges of the obsolescence mitigation tasks.

Organization is also a major concern. If this project has an existing team and organization working, will that same team and organization fit the needs of the obsolescence task? Does the existing team have other commitments it must continue to meet? Often times a strategy and a balance must be developed between the existing maintenance needs on a legacy system and the use of people with knowledge of the system to perform evolutionary change on the system and in this case, obsolescence mitigation. If the new project required a new organizational construct, the organization must not only consider the new deliverable, but also on how to execute to existing program commitments. The organization chart and description of how decisions are and should be made should be flowed down to all the team members with adequate explanation so that it is clear how the new organization will operate.

In addition, especially when a legacy system already exists, time is of the essence. In order to reduce the time prior to delivery, certain activities may need to be performed in via concurrent engineering. These activities should be taken into consideration while developing the Integrated Master Schedule (IMS) and the milestone at which the concurrent engineering will end and all the required decisions that need to be made are clearly indicated. In addition, the teams performing the concurrent engineering work should be highly integrated to ensure that one team does not end up "surprised" by a discovery close to the milestone due to insufficient communication.

### 3.2.5 Update Project Documentation

When a project involves updating a system for primarily obsolescence, documentation may be one of the last thoughts. There will probably be more time spent determining where one might be able to procure the needed parts and if those parts will meet the established needs of a system. It is tempting when dealing with obsolescence to work "backwards" by finding a solution and documenting it afterwards. There a few big reasons not to proceed in this manner which will be illustrated below.

#### 3.2.5.1 Identify Specifications and Documentation and Update to Current Configuration Management Standards

First, it is important to assess what documentation is available. If the system has been established for a long time, the hardware upgrades that have been developed may not have been updated in all of the documents needed. These documents may include specifications and architecture documents that will be used in the development of the integration and verification test plans. It is recommended to evaluate all the existing documentation in order to make an assessment. In the instance of the case study, many of these documents were in a company archive on microfiche. An effort was made to translate these documents into a modern electronic version in Word and then
was ported to the DOORS tool which houses the modern requirements specifications. This DOORS version became the baseline for each specification moving forward. It is important to determine the date of the document that each baseline refers to as some specifications may have been updated asynchronously from others.

3.2.5.2 Find All References Made in the Specifications to MIL-STD, Handbooks, or Interface Standards, Design Handbooks, Procedures and Internal Methods

For many defense systems, specifications and other documentation may refer to a MIL-STD or other documentation. These references may have changed versions since this last update. This alone could have a massive impact on the obsolescence mitigation project and should be performed before the obsolescence mitigation trades are conducted to determine if regulations or requirements have changes that would make a chosen approach unacceptable. In order to do this, one must identify what version of a standard was used for each specification, determine what the latest standard is and evaluate the differences between those versions. The differences must then be considered for an obsolescence trade, and may be placed into three categories:

- Must Change: Regulations and Laws require it and there will be no allowances
- Can't Change: While the standard may have become more restrictive, there are no laws prohibiting the old design which can either still be sourced or re-developed using the legacy requirements and changing the design would be cost prohibitive or will negatively impact the project in another manner.
- Like to change: Can comply with the new requirements of the standard easily because many vendors work to the new standards

By using these categories, the project will still have some flexibility in its solution set (the entire system may not be required to redesign if it doesn’t meet the current standards); however, it may make for a system that references many different versions of standards for different components. This makes configuration management, integration and verification more complex.

3.2.5.3 Update Documentation to Current Systems Engineering Standards

If there are new methods and standards for maintaining the documentation for a system (e.g. if microfiche will not allow for automated metric calculations or requirements traceability) the documentation should be updated to today’s standards for ease of use and maintenance into the future. In addition, based upon the contract in place, the customer may have assumed that they would receive updated CDRLs, and therefore would need to be performed in order to be compliant.

3.2.5.4 Ensure that Traceability Exists Between the Systems Specification and the PIDS

If the requirements in the PIDS document are all traced to requirements in the system specification, this step may not be required; however, a review of this tracing may be informative for those working on the possible obsolescence mitigation approaches. If this has not been done, it is important to perform this step to ensure that there are no “hidden” or undocumented relationships. For example, if the PIDS document has a requirement that does not clearly map to the system
specification, is it truly a requirement, is it a company imposed requirement but not a customer requirement, is the system specification incomplete? These questions should be answered before proceeding in order to ensure that the proper relationships are maintained in the mitigation approaches. In addition, any requirements in the PIDS document that are affected by the versions of the standards should be at minimum flagged for evaluation or modified as appropriate.

In the case of this system, while functional analysis was performed at the time of design, the current systems engineering processes for traceability did not exist and therefore these relationships were not captured in the PIDS documents. Much of the "legacy knowledge" had been lost with employee turnover/retirement but the decisions in many cases were captured in memos and other analysis documents. If recreating full traceability is not possible, efforts should be made to make the design memos available to the engineers currently working on the project. When explanation for design rationale is discovered the engineers should at a minimum reference the relevant memo in the requirements database.

3.2.5.5 Ensure that Traceability Exists between the PIDS and the CIDS
This effort may need to occur in a concurrent engineering effort with the obsolescence mitigation design as the design options will often have an impact on the CIDS documentation. As these requirements become clearer, there may be impact at the PIDS level that should be documented. The necessary adjustments should be made and traceability established to ensure that the CIDS requirements are traced through to the system specification. If this effort is being conducted in a concurrent engineering effort, it is imperative that the changes are tied out and frozen by a particular milestone and that the teams working on each effort are in frequent communication to minimize surprises.

3.2.6 Determine the Obsolescence Mitigation Approach Through Trade Studies Using the Relevant Decision Criteria
There are numerous obsolescence mitigation approaches that can be considered for a given part, component, assembly or sub-system. In this section, the terms part/component/assembly or sub-system may be used interchangeably as it the mitigation approaches are similar for either as long as the appropriate level of obsolescence mitigation has been chosen as described in Section 3.2.1. Those listed in the sections below are to be used as considerations while developing the mitigation alternatives that will be used in the obsolescence trade studies. Each of these alternatives may score differently depending on the decision criteria established in Section 3.2.3. Once the alternatives have been evaluated against each of the decision criteria, an approach can be selected and development can begin.
<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Obsolescence Type</th>
<th>Obsolescence Status</th>
<th>Description</th>
<th>Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Buys</td>
<td>Lifetime Buy</td>
<td>Manufacturing &amp;</td>
<td>Anticipated</td>
<td>Buy all anticipated part needs at initial order.</td>
<td>If future system needs and configuration are stable, engineering change due to technology insertion is not required.</td>
<td>Cannot address functional obsolescence. If part must be replaced, obsolete inventory may be maintained. If predictions are incorrect, obsolescence can still occur.</td>
</tr>
<tr>
<td></td>
<td>Last Time Buy</td>
<td>Manufacturing &amp;</td>
<td>Anticipated</td>
<td>Buy all future anticipated part needs once obsolescence is anticipated for the part.</td>
<td>If future system needs and configuration are stable, engineering change due to technology insertion is not required.</td>
<td>Cannot address functional obsolescence. If part must be replaced, obsolete inventory may be maintained. If predictions are incorrect, obsolescence can still occur.</td>
</tr>
<tr>
<td></td>
<td>Use Existing Spares</td>
<td>Manufacturing &amp;</td>
<td>Anticipated</td>
<td>Delay obsolescence until critical to make change</td>
<td>No impact to program if spares supply is deemed sufficient for projected future demand.</td>
<td>Cannot address functional obsolescence. If part must be replaced, obsolete inventory may be maintained. If predictions are incorrect, obsolescence can still occur.</td>
</tr>
<tr>
<td>Same Part/ New Vendor</td>
<td>Same Part/ New Manufacturer</td>
<td>Manufacturing &amp;</td>
<td>Former vendor no longer supports or has gone out of business; Other vendors available</td>
<td>Purchase part from new vendor. No extra validation is required.</td>
<td>Parts available in short term</td>
<td>Cannot address functional obsolescence.</td>
</tr>
<tr>
<td>Same Part/ New Manufacturer</td>
<td>Manufacturing &amp; Maintenance Functional</td>
<td>Manufacturing &amp; Maintenance</td>
<td>No vendors for products from original manufacturer; Other manufacturer available</td>
<td>Purchase part from aftermarket supplier; Requires additional validation.</td>
<td>Parts available in short term</td>
<td>Cannot address functional obsolescence.</td>
</tr>
<tr>
<td>Same Part/ Excess Inventory</td>
<td>Manufacturing &amp; Maintenance Functional</td>
<td>Manufacturing &amp; Maintenance</td>
<td>The part is no longer manufactured, but other users of part have excess inventory that they are willing to sell</td>
<td>Purchase same part from other users who carry excess inventory</td>
<td>Parts are currently available</td>
<td>Cannot address functional obsolescence.</td>
</tr>
<tr>
<td>Build-to-print</td>
<td>Manufacturing &amp; Maintenance</td>
<td>The part is no longer manufactured, but firms can be commissioned to manufacture based upon prior designs and drawings</td>
<td>Commission exact replica</td>
<td>Maintains FFF</td>
<td>Cannot address functional obsolescence; Time is required to remanufacture the part; May not be able to be made per the legacy requirements if government regulations have changed.</td>
<td></td>
</tr>
<tr>
<td>Emulation/Cloning</td>
<td>Manufacturing &amp; Maintenance</td>
<td>The part is no longer manufactured, and the legacy design is not conducive to being manufactured and therefore a redesign is required</td>
<td>Redesign to meet FFF requirements</td>
<td>Maintains FFF</td>
<td>Cannot address functional obsolescence; Time is required to remanufacture the part; May not be able to be made per the legacy requirements if government regulations have changed.</td>
<td></td>
</tr>
<tr>
<td>Substitution</td>
<td>COTS</td>
<td>Manufacturing &amp;</td>
<td>Accept differences in a COTS type product</td>
<td>Gain benefits of COTS and COTS Standards; May allow for addressing functional obsolescence;</td>
<td>Cannot address functional obsolescence; May not meet original specification; May imply modifications to Form, Fit &amp; Function.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Replace with Functional</td>
<td>Manufacturing &amp;</td>
<td>Need for redesign exists either because of functional obsolescence or the level of manufacturing &amp; maintenance obsolescence</td>
<td>Replace with part that provides the same function, but may have a different form/fit</td>
<td>May allow for addressing functional obsolescence.</td>
<td>Increased Design Costs; May be more likely to cause engineering change to other components.</td>
</tr>
<tr>
<td></td>
<td>Equivalent</td>
<td>Maintenance Functional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consolidation of Multiple</td>
<td>Manufacturing &amp;</td>
<td>Need for redesign exists either because of functional obsolescence or the level of manufacturing &amp; maintenance obsolescence</td>
<td>Combine functions of multiple parts into one part</td>
<td>May allow for addressing functional obsolescence; Increases Reliability</td>
<td>Increased design costs; Creates a more integrated system.</td>
</tr>
<tr>
<td></td>
<td>Parts to One Part</td>
<td>Maintenance Functional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Migration of hardware to</td>
<td>Manufacturing &amp;</td>
<td>Need for redesign exists either because of functional obsolescence or the level of manufacturing &amp; maintenance obsolescence</td>
<td>Rehost hardware functionality in software</td>
<td>May allow for addressing functional obsolescence; May reduce power, weight, etc.; Reduces manufacturing costs</td>
<td>Increased design costs; Software functionality increases the level of testing required. Increases risk and likelihood of impact to other parts of the system.</td>
</tr>
<tr>
<td></td>
<td>software</td>
<td>Maintenance Functional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete Redesign</td>
<td>Manufacturing &amp;</td>
<td>Need for redesign exists either because of functional obsolescence or the level of manufacturing &amp; maintenance obsolescence</td>
<td>Redesign the whole: component, assembly, sub-system, etc.</td>
<td>May allow for addressing functional obsolescence; Near Clean State Flexibility; Move to modern standards; Mitigate future obsolescence</td>
<td>High Development Costs; Increases risk and likelihood of impact to other parts of the system.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance Functional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 15: SUMMARY OF THE TYPES OF OBSOLESCENCE MITIGATION APPROACHES**
3.2.6.1 Maintain Form, Fit, and Function (FFF)
In the instance of the case study, unless the functional obsolescence of a component was a major impedance to future growth, it was desirable to limit the number of changes that the system would encounter. Therefore, it was a goal to maintain the form, fit, and function of a part in as many instances as possible. Not only does maintaining form, fit and function reduce the level of design that needs to go into a component, it can substantially reduce risk and minimizes the levels of testing that need to be performed as the part has previously been tested in the legacy configurations and limit the probability of change propagation. The following options are possible ways to maintain form, fit, and function:

- Delay the obsolescence problem: use remaining spares for as long as possible
- Desktop Replacement: same part from another vendor
- Desktop Validation: same part from a different manufacturer requiring validation
- Build-to-Print: for customized parts, manufacture the part to the same drawings and specifications using manufacturing methods that do not impact the overall design
  - Note: Build-to-print components may be impacted by the changing standards or regulations described in Section 3.2.5.2 and therefore the ability to get an exception to current regulations needs to be determined.

3.2.6.2 Limited Redesign of Components
When it is not possible or does not make sense to maintain the form, fit and function of a component, it may make sense to limit the redesign of a component by trying to maintain some of these characteristics. The following is a list of possible approaches that involve a limited redesign of the components:

- Replace part with functional equivalent
- Functional Reallocation by consolidate multiple parts into one part (provides an increase to reliability)
- Move hardware functionality to software thereby eliminating the hardware
  - One should ensure that the redesign does not negatively impact design criteria such as reliability and safety. Reliability and safety in software are not designed in the same way as in hardware. Leveson’s paper on the Therac-25 illustrates an example where physical safety constraints were removed from a previous configuration of a product and were replaced with software checks. In the end,

    "the FDA concluded that the accidents demonstrated that the software alone could not be relied upon to assure safe operation of the machine.“ (Leveson, Medical Devices: The Therac-25, 1995)

3.2.6.3 Redesign the System
At the opposite end of the spectrum from maintaining form, fit, and function is attempting to redesign the entire system in order to address any obsolescence issues. This approach entails large design, development, and testing expenses in both time and money. For smaller systems, however, facing great issues in obsolescence, this option may have some merit. The redesigned system would
have to meet the system level specifications and maintain the interfaces to external systems if applicable.

3.2.6.4 Other Considerations for all Obsolescence Mitigation Alternatives
For all of these possible approaches to developing an obsolescence mitigation alternative, there are a number of other considerations that should be examined to help develop the details of each alternative that will then be evaluated by the decision criteria. Some of these considerations are listed below:

- Make vs. Buy Trades
- Lifetime buys vs. Planned evolution of parts
- Maintain interfaces vs. upgrade to a common interface standard: If the interfaces are changed, an adapter may need to be developed to minimize redesign of other components or software
  - Minimize interface changes that involve third-parties
- Design for reduction of future obsolescence
  - Use of a common and standard interface
  - Open/Modular Architecture

3.2.7 Determine the Impact of the Obsolescence Mitigation Approach
In conjunction with selecting an obsolescence mitigation approach, the following impacts should be checked to determine if there are any unplanned consequences of the chosen approach that may be eliminated by the choice of another alternative. If another alternative is not optimal, these impacts need to be worked into the product development plan.

- Configuration management of the product line: does this solution increase the difficulties associated with configuration management of the system
- Ensure that local changes do not negatively impact overall system performance: Identify and monitor technical performance measures throughout the development of the system
- Regulatory implications of modifications to the system: e.g. export regulations
- Required test equipment changes
- Specification gaps when using COTS/GOTS: Look for the absence of new requirements due to multiple order "knock-on" effects
- Interfaces with adjacent equipment: Minimize impact unless the update facilitates future growth or adherence to a common standard. When change must occur consider the use of adaptors and choose industry standards which lead to the creation of technology to help adapt to the standard
- Test plans that address the multiple configurations the existing and newly developed system will require
- Software algorithms that have been tuned to the existing hardware
- Simulations may need to model the new hardware or be adapted for any software modification that were needed
• Design development plan: since system design and development timelines may still exceed the lifecycle for a particular component it may necessitate the use of multiple versions of hardware or software throughout development
• Perform a delta failure mode analysis to determine if the systems capabilities or sources of failure are dramatically different between the mitigation approach and the original component

3.2.8 **Look for Opportunities to Add Efficiencies To Other Processes in the Product Development Process**

At times, obsolescence mitigation approaches allow for taking a radical look at existing design and development approaches for ways to find efficiencies. One should examine if they can optimize any existing procedures, implement some concurrent engineering techniques, or develop innovative integration and test strategies. For example, when concurrent engineering is required, existing organizational teams may not be setup to appropriately handle the pace of decisions that need to be made. In this instance, special integrated teams may be formed to facilitate the concurrent engineering activities.

3.2.9 **Develop Integration & Verification Test Plans**

Based upon the updated requirements documentation, the obsolescence mitigation approach chosen, and the overall project development plan develop the integration and verification test plans. Where possible look for ways to reduce overall system risk. The case study example used and integration approach that takes a proven baseline and integrates individual POD or POM parts at early stages separately prior to system test. This enables the engineers to get an “early” evaluation of their design in the context of the system. The results of these activities can reduce the likelihood of integration difficulties when full systems integration gets underway as there will be fewer “surprises.”

3.2.10 **Outline the Future Plans for Dealing with Obsolescence for a Product Line**

Many of the difficulties surrounding the obsolescence mitigation arose from the fact that the level of obsolescence was not known at the outset of the project and that a solution oriented approach followed by some of the other systems engineering activities lead to some surprise discoveries in compliance. Moving forward with an increased level of COTS components, as described in the literature review, increases the likelihood and frequency of future obsolescence. Based upon these facts, a plan should be put into place to address future obsolescence.

First, as mentioned earlier, the designs of obsolescence mitigation approaches should at least consider if the proposed approach reduces the extent or frequency of future obsolescence or increases it.

Secondly, there are a number of techniques that can be applied to vendor relationships that will likely reduce the level of future obsolescence:

• Evaluate vendors and secure long-term agreements with vendors that are established, have a product line roadmap that extends into the future to support the products being purchased
• Establish relationships with vendors that work in industries with similar requirements. The defense industry has more stringent safety and environmental requirements compared to many commercial industries. However, the automotive industry typically also has more restrictive requirements. Vendors that work effectively in the automotive industry have a greater likelihood of being able to meet the needs of the defense industry as certain specifications, methods and validation approaches are already utilized and are more closely tuned to the needs of the industry. In addition, by using vendors that are supported by multiple industries the long term viability of a given vendor is increased especially during a given industry lull. In addition, these vendors may be accustomed to supporting products for longer lifecycles.

• Try to consolidate parts purchasing to a few select vendors in order to increase the number of parts in a purchase to leverage price negotiations as well as supporting the vendors that are essential to long term obsolescence planning

• When possible, work with vendors to understand their product roadmaps and then align future product upgrade plans with these roadmaps. This can only be achieved when working with vendors that are forthcoming with their product strategies, but when those relationships are established they can help develop true obsolescence strategies moving forward.

3.3 AREAS OF IMPROVEMENT TO THE SYSTEMS ENGINEERING PROCESS FOR OBsolescence

These following sections discuss specific areas that the interview process identified as areas that could be improved in the future, or if had been performed would have eased the obsolescence mitigation effort.

3.3.1 DEVELOPMENT OF AN OBsolescence TEAM

The Director of Technology Refresh indicated that “obsolescence is a living thing and has to continually be monitored.” (Director of Systems Technology Refresh, 2009) Many of the initial surprises in the process for dealing with obsolescence stemmed from the fact that the true amount of obsolescence in the system was not understood. This was likely due to the fact that supply chain updated the BOM lists with part availability only when purchases were made and only for the purchased part resulting in stale data. Supply chain can be more proactive by “pinging” vendors more frequently for the availability of the items on the parts lists. If it is too cumbersome to check every part, perhaps “hot spots” can be checked for items that meet certain metrics for example those that are deemed multipliers when a change propagation analysis is performed. In addition, in the past, there has been no established obsolescence plan or strategy in place. Section 3.2.10 lists a number of ideas for future obsolescence mitigation; however, there should be an official plan for obsolescence monitoring and planning in place with people responsible for its maintenance. These people should include an integrated team including people from engineering, supply chain and operations leveraging any enterprise-wide tools available that can help assist with obsolescence. The Director of Technology Refresh stated that “by tying engineering, supply chain and operations together at the hip we develop an exchange of information that turns data into knowledge.” (Director of Systems Technology Refresh, 2009) This team should develop the obsolescence
strategy on a program and when addressing manufacturing or maintenance obsolescence the approach "should also be looked at as an opportunity to enable the future" which will help address future functional obsolescence in the system. This team should also be the eyes and ears of the program organization to use relationships with COTS suppliers to help predict the direction of the technology in the future.

3.3.2 DOCUMENTATION IMPROVEMENTS FOR OBSOLESCENCE
In addition, there are a number of items that could have helped reduce the difficulty in implementing the obsolescence mitigation approaches. First, the system could have a developed product line architecture model to proactively assess the impact of future obsolescence in system performance, timing implications, etc. The requirements and design documentation could be sufficiently detailed, traceable and provide appropriate rationale so the impact of change due to obsolescence can be accurately determined. This information must be readily archived, readable and understandable to a non-expert as institutional knowledge alone cannot be relied upon for long lifespan systems. This documentation should be adequately maintained as a suite of documents and each configuration should clearly be traceable to the appropriate documentation with version number. In the instance of the case study it was found that some of the documentation required was either never created or not controlled (was not a deliverable to the customer). Institutional knowledge was often relied upon in these gaps. It was hard to recreate the specifications based upon old performance data and institutional knowledge in order to develop a robust verification and validation approach for those components. In addition, all of the system interfaces should be well documented. If there is not a unique specification for each interface, it is important to determine if all of the interfaces are addressed to ensure that there are not any gaps. Finally, while documentation may seem like a task that can be performed after the obsolescence mitigation trades have occurred, the obsolescence in the documents themselves may lead to surprises which may have a negative impact on the design activities. It is important to maintain the documents to identify when a system is "out of date" with respect to a particular specification or standard and track that delta through the obsolescence team or to update the documents and identify gaps in the standards prior to making the decision on an obsolescence trade.

3.3.3 DESIGN IMPROVEMENTS FOR OBSOLESCENCE
All architecture choices and design efforts should evaluate the possibilities of future obsolescence and design choices should take those considerations into account. At times, a more costly initial approach may save money down the line by reducing unique configurations when functional obsolescence necessitates change. An example of these choices could include using a more expensive processor or a larger chassis that exceeds existing requirements in anticipation that future requirements would require expansion. Overall architecture changes can also result in new failure modes that may require additional requirements. A failure mode analysis should be performed to ensure that when a system fails where it has been changed the anticipated outcomes are acceptable and understood.
3.3.4 Configuration Management and Obsolescence

Unless a complete refresh of fielded systems is performed for a particular piece of obsolescence in a system, obsolescence mitigation tends to increase the number of systems configurations in use. An overall configuration management plan must be in place. This plan would address all aspects of having the multiple configurations of the system including testing, documentation and the required ECP bundling to try and minimize the number of possible configurations. This plan should also be worked with the various system owners to develop an ultimate migration plan to a common configuration. The configuration management plan should address both hardware and software and should use a proper and common language such that all parts of the organization can discuss a given configuration with clarity and no confusion. At times, politics may influence the language surrounding the required changes and upgrades, and therefore it makes it difficult to settle on a common terminology. The case study experience would indicate that the faster this terminology and language is established the better the communication between the customers, suppliers, and various teams within the organization.

3.3.5 Management Improvements for Obsolescence

The status of obsolescence and the results of the work of the obsolescence team should be routinely and formally monitored and regularly presented to the program management. This attention will foster immediate communication between all of the stakeholders for any obsolescence issues as they arise and ensure that an appropriate strategy is developed and communicated and ultimately implemented in accordance with the product line roadmap.

In addition, organization and team development may need to take place. The organization should facilitate an integrated coupling between the supply chain, engineering and development teams. Training should occur where required to ensure that all stakeholders recognize the possible impacts of obsolescence on their program. Training may also be required for COTS components. When in-house development occurred for components, expertise was developed alongside the product. With the increase use of COTS, in-house expertise in a component or approach may need to be actively sought through training and relationship building with the vendor.
4 APPLICATIONS

4.1 A SYSTEMS ENGINEERING AND MANAGEMENT APPROACH FOR ADDRESSING OBsolescence IN LARGE COMPLEX SYSTEMS USING SYSTEMS ENGINEERING TECHNIQUES

4.1.1 Procedure and Task Descriptions
In order to develop the overall systems engineering and management approach for obsolescence mitigation, the tasks from the established procedure in the case study were combined with aspects from Section 3.3 to create the following list of tasks. These tasks are put into a task-based DSM (shown in Figure 16) to determine the optimal ordering of tasks. An entry of 1 below the diagonal indicates a feed-forward relationship (i.e. the change propagation analysis uses the output of determining the baseline system architecture). An entry of 1 above the diagonal represents a feedback relationship (i.e. when project documentation is updated a standard may be found to be out of date which would influence which obsolescence mitigation approach would ultimately be selected). The goal of DSM partitioning is to reduce the level and length of reach of feedback by re-ordering tasks. The reordered task list shown in Figure 17 was generated using the DSM_Program_V1.0 from MIT found on the dsmweb.org website (MIT). The benefit of the DSM technique is that the optimal order of tasks may not seem clear until an assessment of the possible points of feedback is performed.
<table>
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<th>11</th>
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<td>Perform a change propagation analysis</td>
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<td>Determine the type and level of obsolescence</td>
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<td>Determine the decision criteria needed for obsolescence trades</td>
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<td>0</td>
<td>5</td>
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<td>Establish the project and team management plan</td>
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<td>Update project documentation</td>
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<td>Evaluate alternative obsolescence mitigation approaches and select an approach</td>
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<td>1</td>
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<td>Determine the impacts of the selected obsolescence mitigation approach</td>
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<td>Execute obsolescence mitigation approach and all additional required changes</td>
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<td>Develop configuration management plan</td>
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<td>0</td>
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<td>1</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Determine improvements to established procedures</td>
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<td>0</td>
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<td>1</td>
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</tr>
</tbody>
</table>

FIGURE 16: PROPOSED SYSTEM ENGINEERING PROCESS FOR OBSOLESCENCE
Once the refined process has been identified, certain blocks of tasks should be performed recognizing that iteration may be required. These blocks are illustrated in the flow chart shown in Figure 18.
4. Monitor the System for Obsolescence

Assess the Obsolescence and the Obsolescence Strategy:
4. Type & Level of Obsolescence
5. Decision Criteria for Mitigation
6. Develop Project Team and Management for Mitigation
7. Identify Obsolescence in Documentation

Obsolescence Identified?

Y

Tasks Prior to Obsolescence Evaluation:
1. Develop Baseline System Architecture Artifacts
3. Establish Obsolescence Team
2. Conduct Change Propagation Analysis

Start/Finish

Obsolescence Mitigation Activity:
8. Evaluate Alternatives
9. Determine the impacts of the Alternatives
11. Develop Configuration Management Plan
12. Determine improvements to established Procedures
10. Execute Chosen Approach
14. Develop future obsolescence plans
13. Develop Test Plan for Chosen Approach

FIGURE 18: SYSTEMS ENGINEERING & MANAGEMENT FLOWCHART FOR OBSOLESCENCE

Once all of the blocks have been completed the updated system may become the new baseline for the future system; thus, closing the loop back to the start of the process.

4.1.1.1 Develop Baseline System Architecture

Any method for developing a baseline system architecture which provides key information regarding the overall structure and connectivity of the system can be helpful. In this example, a structural DSM was developed as shown in Figure 11 & Figure 14. Ideally, these matrices will be developed for the overall system & all sub-systems prior to identification of obsolescence. If however, obsolescence has already been identified, these baseline DSMs should be developed as soon as possible because they will help inform other aspects of the obsolescence mitigation process.

4.1.1.2 Establish an Obsolescence Team

An integrated team with members from the supply chain, engineering, operations and program management should be created. This team should be responsible for continuously monitoring the state of obsolescence in the system and reporting that obsolescence through the appropriate program tracking methods. The team should also look for opportunities for the program through relationships with suppliers by looking for synergies between anticipated technologies and planned growth capabilities for a program. Once obsolescence is identified, the obsolescence team should
work with all of the relevant teams to determine possible mitigation approaches to ensure that strategies for multiple instances of obsolescence are in alignment with each other.

4.1.1.3 Perform a Change Propagation Analysis
As described in Section 1.2.2.2 a change propagation analysis can be performed using a modified version of a DSM. Use the baseline structural DSMs as a guide while making the ΔE Matrix. The ΔE Matrix is a binary change propagation matrix. This matrix is developed by evaluating the impact of the ith element by a change to the jth element. For more information on this technique, please review (Suh, de Weck, & Chang, 2007). Once the ΔE Matrix has been created, calculate the CPI of each component. The designation of a particular component as a multiplier, carrier, absorber or constant can be added to the baseline DSMs for review while determining the obsolescence mitigation approach. This creates a basis for assessing the extent of indirect impacts of obsolescence mitigation strategies that involve some amount of redesign at the component or assembly level.

This technique can also be used to determine the impact of standards and specifications on each other. If a change propagation matrix developed to show how changing a given standard or specification affects another standard, the standards and specifications can be labeled as multipliers, carriers, absorbers or constants as well.

The change propagation analysis does not mathematically determine which items are resistors, but knowing which components are likely multipliers of change, may influence some of the decision criteria for the obsolescence trades.

4.1.1.4 Determine the Type and Level of Obsolescence
If a system is facing functional obsolescence, an evaluation of the future needs of the system must occur. This is similar to what Dowling recommends as depicted in Figure 3.

Many of the sources advocated for some type of automated obsolescence screening based upon databases tied to the supply chain vendors. This analysis should be performed on a regular basis to give substantial time to develop a mitigation approach. Once obsolescence has been identified, it can be characterized by a method similar to that of Buratti and Del Brusco as shown in Table 2. Based upon the level of obsolescence in a given area or component, a decision should be made on at what level (part, component, assembly, sub-system) the obsolescence shall be mitigated.

4.1.1.5 Determine the Decision Criteria Needed for Obsolescence Trades
Section 3.2.3 describes the need to define decision criteria and provides a list of potential decision criteria that could be evaluated in an obsolescence trade. It is likely that either priorities or weights may be placed on these decision criteria so that they can be used to trade various mitigation approaches. This technique is a common step in a basic systems engineering approach to a problem.

4.1.1.6 Establish the Project and Team Management Plan
The importance of project and team management is discussed in Section 3.2.3. Katz and Allen emphasized the need for keeping experienced engineers technically current in order to reduce human obsolescence. Placing engineers with experience on an existing system in the effort to
determine obsolescence mitigation can keep those engineers current with new technologies while leveraging their institutional knowledge.

In addition to any organizational procedures in place to evaluate the team skill-sets and training and to establish the task plan and execution plan for the project the steps outlined in this paper should be considered as possible tasks. A team-based DSM may be created to show the possible interactions that will likely need to be established. This can be influenced by the structural DSMs. If obsolescence is occurring in particular areas, the types of interactions expected will likely be influenced by the type of interface between the components. A purely physical interface will likely use mostly mechanical engineers, where a physical & informational interface may use mechanical, electrical, systems and software engineers. A task based DSM can be created and partitioned to help determine the “optimal” ordering of tasks to reduce the impact of rework on a project. The results of this analysis can be flowed into the overall schedule and project plan. A team/task based DMM may be helpful to illustrate to which teams have responsibility for which aspects of the project.

### 4.1.1.7 Update Project Documentation

In this section, the recommendation to develop a full or partial intent specification (as described in Section 1.2.2.3) prior to the need for updating a system for obsolescence is proposed. If that is not possible, if the opportunity for modifications to project documentation presents itself, reverse engineering an intent specification could help to understand the impact of an obsolescence mitigation approach. Intent specifications

> “provide mapping (tracing) of decisions made earlier into the later stages of the process. Design decisions at each level are linked to the goals and constraints they are derived to satisfy. A seamless (gapless) progression is recorded form high-level system requirements down to component requirements, design, and implementation.” (Leveson, Intent Specifications: An Approach to Building Human-Centered Specifications, 2000)

By having this type of specification, rationale for a particular design decision can be traced to the assumptions and requirements from which it was derived. This is especially important in legacy systems facing future obsolescence especially when there may not be sufficient institutional knowledge or when the team working the job is unfamiliar with past design decisions. In addition, when functional obsolescence occurs and certain system requirements must be changed, it will provide a means for quickly examining the design decisions that are tied to that systems requirement. It is important to note that for legacy systems whose design documentation has not been updated in a long time, this effort could be very difficult, time-consuming and costly. If it is not possible to develop the intent specification, controls should be put in place to help document and trace the rational of the new design decisions resulting from the obsolescence mitigation efforts.

In addition, baseline DSMs can be used as a structured foundation for various other efforts including updating the project documentation. When the component-based DSM is non-directional (i.e. it represents relationships without concern for the direction of the flow of mass, power, or information) the matrix is symmetric about the diagonal (i.e. all of the relevant information can be
contained in below the diagonal). It is proposed to use the DSM for communication between engineering and management. In the example used below in Figure 19, the information in the upper portion of the diagonal is removed and cells with a 0 (indicating no relationship) are blackened as an interface does not exist between those sub-systems or components. For the items on the diagonal, or the cells not blackened above the diagonal, some determination needs to be made as to where the relevant documentation resides for the requirements about the sub-system/component or for the interfaces between sub-systems or components. A typical “stop-light” theme was used to indicate the status for management. The information contained in the cells are the relevant pieces of documentation that will need to be referred to in the obsolescence mitigation activity and that may need to be updated as a result of that activity. By resolving this chart with the system and PIDS level specification to product DMM shown in Figure 12, it is clear that most of the interfaces between components are not addressed. This tells us that more investigation is needed to determine where the interfaces are specified such that the impact of a change to those interfaces can be appropriately evaluated. In her paper on Intent Specifications Leveson cites that

"cognitive psychologists have determined that people tend to ignore information during problem solving that is not represented in the specification of the problem." (Leveson, Intent Specifications: An Approach to Building Human-Centered Specifications, 2000)

This means, that when some information is present, people tend to ignore gaps in what has been presented. By looking at the existing specification list alone, the team may have assumed that all the relevant information for design was contained in the published and controlled specifications. By using this DSM method, it becomes clear that there are gaps that need to be investigated further.
FIGURE 19: MODIFIED USE OF DSM FOR DOCUMENTATION UPDATE STATUS
As described in Section 3.2.5, the following steps should also be taken to update the project documentation:

- Identify Specifications and Documentation and Update to Current Configuration Management Standards,
- Find All References Made in the Specifications to MIL-STD, Handbooks, or Interface Standards, Design Handbooks, Procedures and Internal Methods,
- Update Documentation to Current Systems Engineering Standards,
- Ensure that Traceability Exists Between the Systems Specification and the PIDS,
- and Ensure that Traceability Exists between the PIDS and the CIDS

4.1.1.8 Evaluate Alternative Obsolescence Mitigation Approaches and Select an Approach

Once the decision criteria have been developed decisions can be made based on the obsolescence mitigation approach. Possible alternative solutions need to be identified and then evaluated in a trade study by measuring how the decision criteria stack up against the decision criteria. Developing a delta DSM can be an effective way of representing the changes that are made in the architecture by a proposed obsolescence mitigation approach. This view can help all the stakeholders communicate about the changes involved in a mitigation approach. Figure 20 shows an example of a delta DSM. In this example, all highlighted components exhibit a change. This type of diagram must be used in comparison with the corresponding baseline DSM shown in Figure 14. The component highlighted completely indicates a new component. The numbers included in the highlighted fields represent the type of interface that the change represents. In this instance, component 2 is removed and all of the previous interfaces were zeroed.
A delta DSM should be created for each proposed mitigation approach. By comparing the delta DSMs, discussions could occur among the technical teams about the impact of each approach upon the system as a whole. A better understanding of the system impacts will also enable a better evaluation of the approach vs. the relevant decision criteria.

4.1.1.9 Determine the Impact of the Selected Obsolescence Mitigation Approach
Section 3.2.7 describes a number of considerations that need to be made when choosing an obsolescence mitigation approach. The type of approach will often dictate the level of impact that a change may have (e.g. a FFF replacement will yield far fewer effects than a redesign). These evaluations are critical for appropriately scoping the total efforts required for the obsolescence mitigation.
4.1.1.10 Develop a Configuration Management Plan
Configuration management affects everything from the documentation of a system, design of components, maintenance & logistics chain of fielding a system, to training of users of a system. It is generally acknowledged that the more configurations of a product, the more complexity is added to each of these aspects of the system. A robust plan should be agreed upon by the customers, suppliers, and the teams in the development organization and should be in place early in the design/implementation process to help minimize confusion and divergent approaches by the various stakeholders. Use of delta-DSMs described in Section 4.1.1.8 in conjunction with the baseline DSM would make a nice physical representation of the various configurations maintained in the system.

4.1.1.11 Execute Obsolescence Mitigation Approach and All Other Required Changes
Once the obsolescence mitigation approach has been chosen and all impacts have been evaluated, the approach must be designed and developed in order to be implemented. This activity would include any updates to the system documentation required by the change, the actual design activity, procurement or manufacturing of the replacement component, and integration of the component into the system.

4.1.1.12 Determine Improvements to Established Procedures
A legacy system has a benefit compared to a new system in that there are many procedures in place that need not be modified. However, there is often opportunity for improvement. In instances that experience makes one believe that there are efficiencies to be found a task based DSM may be used to find a more "optimal" ordering of tasks. In addition, there may be tasks that may have to be performed in a certain way with a new system, but may be able to be modified for efficiency for a legacy system (e.g. performing integration testing with POD or POM component replacements prior to overall system integration with all of the new components). These opportunities should be identified and leveraged.

4.1.1.13 Develop Future Obsolescence Plan
The obsolescence team should have a strategy on minimizing future obsolescence. This is the opportunity to be proactive instead of reactive to obsolescence. They can emphasize this consideration during the selection of the obsolescence mitigation approach in order that the design choices minimize the impact of future obsolescence. In addition, they can work to develop communication and alignment with vendors to establish a product roadmap that aligns with the vendors’ plans for component upgrades and support timelines.

4.1.1.14 Develop the Test Plans
The updated specifications and an understanding of the areas impacted by the obsolescence changed (perhaps through the delta DSMs) are necessary for the development of test plans appropriate for evaluating the modifications made due to obsolescence.
### 4.1.2 Checklist for Systems Engineering & Management Approach to Obsolescence

**Table 6: Checklist for Obsolescence Mitigation**

<table>
<thead>
<tr>
<th>Section</th>
<th>Task</th>
<th>Checklist Item</th>
<th>Complete?</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1.1</td>
<td>Develop Baseline System Architecture</td>
<td>Develop a DSM or other structured architecture model available that contains the relevant system &amp; sub-system level relationships.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.2</td>
<td>Establish an Obsolescence Team</td>
<td>Identify appropriate stakeholders to serve on the obsolescence team.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.2</td>
<td></td>
<td>Ping the supply chain routinely for parts obsolescence. Prioritize based upon the results of the Change Propagation Analysis.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.2</td>
<td></td>
<td>Maintain a watchlist of possible functional obsolescence that could occur in the system</td>
<td></td>
</tr>
<tr>
<td>4.1.1.2</td>
<td></td>
<td>Routinely report obsolescence status to Project Management.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.3</td>
<td>Perform a Change Propagation Analysis</td>
<td>Use the Baseline DSM as a foundation to create a change propagation matrix. Then calculate the Change Propagation Index of Each Component. Higher CPI components &gt; 0 should have priority in attempting to identify obsolescence.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.4</td>
<td>Determine the Type and Level of Obsolescence</td>
<td>When obsolescence is identified, it should be classified as manufacturing &amp; maintenance or functional obsolescence or both. Assess how much obsolescence exists in a given component, assembly, &amp; subsystem to determine the at what level the mitigation strategy should be pursued.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.5</td>
<td>Determine the Decision Criteria Needed for Obsolescence Trades</td>
<td>See Section 3.2.3</td>
<td></td>
</tr>
<tr>
<td>4.1.1.6</td>
<td>Establish the Project Team and Management Plan</td>
<td>Based upon the type and level of obsolescence discovered, determine the appropriate team who has the required levels of expertise. Determine if any special training programs need to be initiated for the team. Attempt to align team and schedule with the task grouping depicted in Figure 18 to account for the dependancies between tasks.</td>
<td></td>
</tr>
<tr>
<td>4.1.1.7</td>
<td>Update Project Documentation</td>
<td>Identify all relevant existing system documentation - component and interface (may use DSM representation depicted in Figure 18). Identify any difference in terms of current standards vs versions used in the baseline system. Identify the modified requirements. For any gaps identified, attempt to find or recreate the needed information based on documentation that is available. Are their new government laws or regulations that prohibit or discourage the original design? If so, are waivers able to be obtained from the customer? Update documentation to quality required for new release. Perform traceability analysis through the specifications where possible. Focus on the impact of any requirements that have changed or may change as a result of the obsolescence (possible use of intent specification). Identify design rationale relevant to the baseline system in the area where changes may be made (possible use of intent specification).</td>
<td></td>
</tr>
<tr>
<td>4.1.1.8</td>
<td>Evaluate Alternative Obsolescence Mitigation Approaches and Select and Approach</td>
<td>Use Figure 15 as a guide to identify all possible obsolescence mitigation alternatives that are available. Develop detailed descriptions of the alternative mitigation approaches (possible use of Delta DSMs). Attempt to understand the impact of each approach as described in Section 4.1.1.9. Weigh each option against the decision criteria selected in Section 4.1.1.5 in a Trade Study. Select the obsolescence approach.</td>
<td></td>
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</tbody>
</table>
4.2 APPLICATION TO NON-DEFENSE SYSTEMS

While much of this thesis has focused on a case study involving a defense system with very strict performance requirements and among other restrictions, the issues surrounding obsolescence can be extended to other large systems with longer lifecycles that may face obsolescence. The same techniques can be used to identify and determine an obsolescence mitigation approach; though for some industries the restrictions in place for a system may be far lower and less formal than those for defense systems. While the process for evaluating obsolescence mitigation approaches would be the same, the weight placed on various decision criteria would likely be different than that of the defense industry. Overall, this approach should be applicable for any system that would typically face obsolescence; however, the importance and benefits of performing a given task at each step should be evaluated for the project at hand.
5 SUMMARY

This thesis performed a literature review that resulted in a summary of the reasons that obsolescence occurs and various proposed approaches for dealing with obsolescence issues. It was determined through the review that the proposed proactive obsolescence mitigation techniques including design of open architectures, use of interface standards, model based architecture and looking at the potential of the future system requirements are typically appropriate for a system undergoing initial design and are not geared for a legacy system. The reactive obsolescence techniques focused on obsolescence identification in the hardware through supply chain monitoring, classification of the obsolescence and developing a replacement solution, without fully acknowledging the impact of these choices on the rest of the project or the system. The obsolescence research did not seem to acknowledge research in engineering change despite the fact that obsolescence is a common cause of engineering change.

This thesis examined an existing approach for addressing functional, manufacturing and maintenance obsolescence in legacy system. Seven interviews were conducted with subject matter experts on a case study system undergoing an update due to obsolescence. These interviews yielded insights that support the need for traditional systems engineering activities in conjunction with obsolescence mitigation approaches. The primary reason for this need is that engineering change for obsolescence within a system can have a ripple effect on other areas of the system. As there are often multiple possible obsolescence mitigation approaches available, the different impacts of each approach should be evaluated prior to the selection of the final approach. The interviews also found a number of lessons learned that could help inform the current obsolescence mitigation efforts on a project and help prepare programs dealing with obsolescence:

- An obsolescence team involving stakeholders from the various areas of a corporation (engineering, operations, program management, etc.) should be developed prior to the identification of obsolescence on long life-cycle projects to monitor the system for impending obsolescence and to develop and communicate the obsolescence mitigation strategy.

- Rationale for design decisions, institutional knowledge, and program documentation should be consistently maintained and evaluated for impact from obsolescence such that there are fewer "surprises" when obsolescence mitigation activities are required.

- The implementation strategy should be evaluated for unintended impact on the overall system and to also evaluate if it will reduce or increase the likelihood of future obsolescence. Additionally, choices that align with common standards and other techniques that can help mitigate future obsolescence concerns should be selected.

- Clearly define the configurations that will be supported by the program to help bound the impacts on design, test, and logistics. When developing a FFF replacement component for new systems, ensure that component will be backwards compatible, when possible, with the legacy components.
The thesis evaluated these lessons learned from the case study experience and studied the areas of difficulty that occurred while using the existing approach. The intent of that examination was to look for opportunities to leverage a number of systems engineering techniques and existing engineering change techniques to close some of the gaps in the original approach. This examination shows that integrating DSM/DMM techniques as well as aspects of intent specifications into the systems engineering and management approach for obsolescence mitigation can help to close some of the gaps in the existing process. The use of these techniques helps support a rigorous systems engineering approach to obsolescence that leverages knowledge from research in specifications and engineering change.

In the end, it is the hope that this thesis provides the background and context as well as a sound systems engineering and management approach for dealing with obsolescence in a real large, complex system that can be used as starting point for others in their obsolescence mitigation endeavors. This systems engineering and management approach has been consolidated into a flow chart, a clustered task DSM, a checklist, and description of the activities that could be performed in support of the obsolescence mitigation activities on a project. Future work in the area of improving the systems engineering and management approaches for obsolescence include the following:

- the establishment of clearly quantifiable metrics, such as the fraction of functions and/or parts obsolete in various sub-systems, and decision analytic models that could be utilized for making obsolescence decisions in a repeatable way,
- performing additional case studies against large, complex obsolete systems that may be revived or mimicked for various reasons (e.g. nuclear power plants, legacy automobile designs, Apollo program, etc.) using this new approach to look for possible improvements to the process
- the development of a technique to more clearly determine the effect of engineering change on non-adjacent components in a system
- and, developing a more robust strategy for dealing with future obsolescence issues in these legacy systems.
6 WORKS CITED


(2009, 12 8). Director of Systems Technology Refresh. (J. Devereaux, Interviewer)


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(2009, 12 8). Software Task Manager. (J. Devereaux, Interviewer)


7 APPENDICES

7.1 APPENDIX I: INTERVIEW DOCUMENTATION

7.1.1 DIRECTOR OF SYSTEMS TECHNOLOGY REFRESH
(Director of Systems Technology Refresh, 2009)

I. How were areas of obsolescence identified?
   - Obsolescence is a living thing
   - At the component level, supply chain manages lists with all of the relevant vendors. These lists are used to anticipate obsolescence at various time intervals (1yr, 2yrs, 3yrs, etc.)
     - These lists are often incomplete and they rely on the vendor being proactive and forthcoming with their plans for obsolescence
   - At the parts level, supply chain uses manufacturing requirements planning lists which contain information about lead time, time of last buys, inventory levels, etc.
     - These lists are refreshed at each buy
       - Defense systems tend to purchase at reduced numbers of parts and at extended intervals compared to commercial, which often leads to stale data
   - Start at the parts level and identified the %parts obsolescence, if too high, looked at the assembly level to determine if an obsolescence approach should be taken for the entire assembly→ might try to redesign a part or parts out (could sometimes examine the next higher assembly as well)

II. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?
   - Yes, but this was mainly due to stale data in the maintained lists
     - Some small companies had gone out of business
     - Only ~“30%” of the parts had current data

III. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?
   - N/A

IV. Was there any engineering change in an item required because of obsolescence in another item?
   - Whole circuit cards were redesigned if enough parts were obsolete
V. What approaches can be used to help deal with obsolescence?

- Desktop Replacement → Find the exact part from another vendor
- Desktop Validation → Same part from different manufacturer requiring validation
- Replace the part with a pin for pin functional equivalent
- Consolidate several parts into one part
  - Benefits of doing this are it can dramatically reduce the total part count (directly related to reliability) and the number of unique parts (drive to reduce number of SKUs because it reduced management effort and increases the volume of the parts that are purchased which helps when negotiating deals for buying parts)
- Perform a complete redesign e.g. from analog to digital
- Use another part → aim for a COTS or MOTS equivalent
- Move HW into SW wherever possible
- Need to consider Make/Buy (always not just for obsolescence) → examples: power supplies and cables made more sense to purchase than to manufacture in house as there were established suppliers for these components
- Future Growth

VI. What were the decision criteria used in the trades to determine which approach would be used on the project?

- Reliability → is part count reduced significantly
- Flexibility → e.g. Hard switches vs soft switches
- COTS/MOTS → moving more to these as they typically increase capability at faster rates and USUALLY maintain backwards compatibility
- Design Cost
- Lifecycle Cost
- Ability to meet Schedule

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?

- HW
  - Try to keep interfaces the same as much as possible, but sometimes will upgrade a proprietary interface to a COTS standard
  - Try not to impact any third parties who interface with the system

VIII. What type of complications does obsolescence bring to the project/product lifecycle?

- Multiple configurations outside of the baseline SW & HW
  - Should try to minimize
- Need to consider country specific needs such as communications

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IX. What engineering tasks were developed in the project that helped address obsolescence?
- Ensure that the system continues to meet the system level specification
  - Monitor technical performance measures throughout development
- Evaluate regulatory implications → Example: export criteria
- Evaluate impact on factory test equipments
- Determine the Supply Chain Decisions: e.g. Lifetime buys?

X. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?
- Consolidate vendors and try to engage in longer term agreements
- Look for ways to incentivize their support of the products we purchase to prevent loss of suppliers
- Design to vendor roadmaps
  - Try to anticipate design (this is a challenge as vendors are not always upfront with this information)
- Supply Chain can be more proactive with vendors to minimize surprise due to “stale” data
- Piggy-back off industry that has similar constraints → for Defense look to Automotive
  - Typically longer lifecycles than commercial
  - Environmental Specs are similar especially in the safety domain: fire, police etc.
- Engineering, Supply Chain, and Operations in an organization need to work closely together “be tied at the hip”
  - Develop enterprise wide tools to help facilitate this effort

XI. Other items?
- COTS/MOTS items often not designed to meet the original specifications of the original parts
  - Leads to first and second order effects
    - Instead of building specialized part, may redesign other aspect of systems to meet needs: Example: environmental conditions.. if multiple parts cannot meet the specification it may be more effective to just enclose those parts and control the environment
- “Obsolescence is a living thing and has to continually be monitored”
- “Mitigating obsolescence should also be looked at as an opportunity to enable the future”
- “By tying engineering, supply chain and operations together at the hip we develop an exchange of information that turns data into knowledge”
- Look to improve processes to increase efficiencies
I. How were areas of obsolescence identified?
   - Looked to determine if we could fabricate the product with the same list of components

II. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?
   - Unsure

III. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?
   - N/A

IV. Was there any engineering change in an item required because of obsolescence in another item?
   - Could perform formerly analog processing within digital processing.
   - Consolidated components

V. What approaches can be used to help deal with obsolescence?
   - Functional Reallocation \(\rightarrow\) More integrated HW
   - Rehost function into SW
   - Replace with equivalent part

VI. What were the decision criteria used in the trades to determine which approach would be used on the project?
   - Do not harm to current capability
   - Backwards compatibility to a common HW baseline

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?
   - HW

VIII. What type of complications does obsolescence bring to the project/product lifecycle?
   - Integration more difficult, System Stability, Compatibility equivalence
IX. What engineering tasks were developed in the project that helped address obsolescence?

- Designed Verification Test Plans
- Developed Integration tools → schematics documenting the updated baseline
  - Can be used as a foundation to integration and for troubleshooting the new baseline
- Internal training for technical staff to develop obsolescence mitigation

X. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?

- Develop a product line architecture model which will show the cause & effect of future obsolescence in terms of system performance, timing implications, etc.

XI. Other items?

- N/A
I. How were areas of obsolescence identified?

- N/A

II. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?

- No \( \rightarrow \) from one sub-component point of view

III. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?

- N/A

IV. Was there any engineering change in an item required because of obsolescence in another item?

- SW algorithms were tuned to the HW \( \rightarrow \) these had to be updated
- Functional Obsolescence also addressed by update, but new capabilities have to be incorporated still
- Simulations needed to be modified
- Interfaces were impacted \( \rightarrow \) some for functional obsolescence mitigation in the future

V. What approaches can be used to help deal with obsolescence?

- For this sub-system we redesigned the HW and improved the SW design to provide future benefit in capabilities

VI. What were the decision criteria used in the trades to determine which approach would be used on the project?

- Costs
- Adherence to contract
- Schedule
- Maintainability
- Reliability
- Future Growth “eye on the future”

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?

- HW but the interface changes increase the effect to other areas
VIII. What type of complications does obsolescence bring to the project/product lifecycle?

- Multiple configurations
  - Have to maintain designs that work in all configurations
  - Testing becomes more complicated

IX. What engineering tasks were developed in the project that helped address obsolescence?

- Trade Studies
- Identify how changes to the components effect the key parameters
- Determine if the system level effects of those changes are appropriate

X. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?

- Need to improve requirements and rationale traceability
- Unaware of formal planning being performed

XI. Other items?

- There is a need to have proper design documentation at each level → if you cannot find the rationale for a given design decision, if something becomes obsolete, you may not be able to determine how to change it without negative consequences
- Movement toward COTS products brings a technical concern since in-house expertise no longer there and increased reliance on the vendor
I. How were areas of obsolescence identified?
- Reasons for obsolescence: Can’t get parts, the company goes out of business or is bought by someone else
- For proprietary parts, we maintained the SW so less chance of obsolescence until we move to COTS
- Evaluate the Bill of Materials from supply chain → includes information about the vendor for each part number
- Determine how much cannot be procured anymore

II. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?
- Yes, prior to investigation, obsolescence was perceived to be much smaller than it ended up being
- Remember there were two paths here → increasing capability for the future and ability to manufacture

III. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?
- N/A

IV. Was there any engineering change in an item required because of obsolescence in another item?
- Changes in HW influenced SW parameters
- An old printer that met environmental specs was not obsolete and planned to be re-built, however the computer it was interfacing with did not have the legacy serial interface. The printer had to be redesigned to have an Ethernet interface.
  - This also applied to other peripherals: since no SCSI, move to Ethernet → goal to move to a common standard, which in long term is good, but did not immediately need to be changed except for obsolescence elsewhere

V. What approaches can be used to help deal with obsolescence?
- Find a way to rebuild the original design
- Try to consolidate components
- Use common and standard interfaces
- Purchase new HW & redesign to meet existing function
- Understand the vendors product roadmap (will they be supporting this product line in 5 years?) and purchase from well established vendors
VI. What were the decision criteria used in the trades to determine which approach would be used on the project?

- Planned End of Life for the product
- Are there other users or other buyers of a particular product? How about from this vendor? Are there multiple suppliers?

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?

- All in the HW but it drove SW Changes

VIII. What type of complications does obsolescence bring to the project/product lifecycle?

- Short COTS lifecycle affects the design (multiple versions before fielding) and the logistics chain
- COTS HW & SW drives dependency on vendors unlike what was experienced with proprietary designs
- Due to the nature of COTS for high performance systems – often on cutting edge
  - Assumed basic functionality which was not offered in the version the rest of the system had been designed around
  - Required much rework because instead of updating the current version we were forced to the next version → see dependency on COTS suppliers
- Supporting multiple configurations
  - Try to bundle certain ECPs or make certain items a pre-requisite for others
  - Increases SW maintenance costs and testing

IX. What engineering tasks were developed in the project that helped address obsolescence?

- Identify where there is a lack of documentation – what information is “passed from person to person through Subject Matter Experts”
- Test the new designs against the Technical Performance Measures at various levels of the system

X. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?

- In our reviews, obsolescence strategies are being requested
- COTS “Catch-22” trying to take advantage of the benefits but also change and become obsolete fast
- See # 5 with respect to vendor strategies and architecture development

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XI. Other items?

- Noted psychological implications of the term obsolescence. Program approaches these issues from a technology refresh and update point of view
7.1.5  **Program Systems Engineering Lead**  
(Program Systems Engineering Lead, 2009)

I. **How were areas of obsolescence identified?**

- Pull the Bill of Materials (BOM) and the product family trees
- Extend the specification trees down to the pieces and parts level
- Ping the supply chain system to see if it can be bought
- Look to determine if it will be a piece part replacement, new assembly, or new component (bottoms up approach)

II. **Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?**

- After the initial supply chain ping for obsolescence, some items actually went from red to green enabling large portions of the system to be a complete build to print
- Bottoms up approach helped this effort
- Current economic status is a concern: Vendor could be green for a part and then go out of business

III. **If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?**

- N/A

IV. **Was there any engineering change in an item required because of obsolescence in another item?**

- Tried to minimize this by keeping interfaces unchanged
  - Make adaptors at connector ends (e.g. USB to Serial)
  - Sometimes opt to use legacy interfaces for technical reasons

V. **What approaches can be used to help deal with obsolescence?**

- Keep to industry standards because industry also creates solutions that help adapt to the standards
- Maintain design documentation so it does not get out of date
  - Were able to find most of the specs that were created, but there were a few that were either never created or possibly created but not controlled
  - It is hard to recreate these specs primarily from test documentation
VI. What were the decision criteria used in the trades to determine which approach would be used on the project?

- Design Cost
- Schedule
- Bundle technology upgrades for future growth
- Interface impact: Keep them clear of change or upgrade to a common standard

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?

- HW \(\rightarrow\) didn’t help that the manufacturing line was cold for 10+ years

VIII. What type of complications does obsolescence bring to the project/product lifecycle?

- Maintaining Multiple Configurations across in development and fielded systems
  - Language is an important component of this, difficulties can arise if you don’t properly name a configuration
  - Want a common language that can be applied across the product line such that products can be combined into systems and it can be clearly communicated
  - Sometimes politics can influence these naming conventions

IX. What engineering tasks were developed in the project that helped address obsolescence?

- The integration approach: Take GFE baseline equipment and pull out and exchange a component with a POD or POM and then do comparison performance runs
  - Helps mitigate schedule risk because does not require all components to be complete at the same time to do integration
- Specification Efforts: Concurrent Engineering
  - Pull the specifications from microfiche, convert to an electronic file in work and then port into DOORS for an initial baseline
  - Trace the Systems Specification to the PIDS
    - Learned you cannot treat build-to-print the same way as new development as the build-to-print might be out of date with respect to the current version of the specification and thus cannot be held to the latest standards which results in requirement exception requests
  - Update the CIDS \(\rightarrow\) in accord with the component design efforts
  - Perform PIDS to CIDS trace (merge the top-down and bottoms-up approach) to evaluate the system for compliance to the specifications (in this merge, requirements may be pushed upwards from the CIDS level)
  - Team communications are critical in concurrent engineering need to build relationships
X. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?

- *Supply Chain continues to perform single point of failure assessments*
- *Need to ensure that these assessments are tied back to engineering such that the product line plans are aligned and look @ the evolution of the system over time*

XI. Other items?

- *N/A*
7.1.6 SYSTEMS ENGINEERING REQUIREMENTS LEAD
(Systems Engineering Requirements Lead, 2009)

I. How were areas of obsolescence identified?

- Evaluate documentation obsolescence:
  - Find a list of all standards, design handbooks, procedures and internal methods referred to in the specifications
  - Identify if they have changed or if they could even apply today
    - For build-to-print items, how out of date was the standard and what changes have occurred
      - Must change → if the government has passed laws that prohibit the use of certain materials or methods (e.g. lead paint)
      - Can’t change → Items that are cost prohibitive or design intensive
      - Like to change → Improve drawings (old drawings may not include the rev of the MIL-STD) Current vendors may be working at newer levels
    - New designs must meet new standards
  - Evaluate the specification suite
    - Some areas may be updated where others were not maintained

II. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?

- Once the deltas in the documentation were known, the suggested revisions were sent to the design teams which indicated more scope than originally planned in order to comply with the new standards → Not enough to just rebuild the old system

III. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?

- The latest MIL-STD in safety actually had a less stringent requirement, requested the customer to agree to hold the system to an older requirement that was more stringent
- Certain handbooks actually have a clause that forbids their use as a specification; Old specifications just referred to the handbook, which means new requirement generation required or the requirements need to be lightened to be “wills” not “shall”s
- Human Factors example: at MIL-STD used long ago, women weren’t in the Army and the systems were not designed to be used by them
IV. Was there any engineering change in an item required because of obsolescence in another item?

- Since lead paint can no longer be used, a different paint with tin in it was substituted. This alternative product could lead to “tin whiskers” which can cause adverse effects. New requirements needed to be imposed for cleaning, coating and maintenance in order to meet the systems needs.
- When there are a lot of changes in a unit, like consolidation of components into one computer, the heating and cooling constraints on the ambient air change and need to be re-evaluated.

V. What approaches can be used to help deal with obsolescence?

- Emulating SW with the same functionality on new HW
  - Timing and Performance needs need to be maintained
  - May need to throttle some capability to maintain overall system performance
- “form, fit, function” → for our purposes do not want to change as much as possible because less integration issues and less verification required

VI. What were the decision criteria used in the trades to determine which approach would be used on the project?

- Can we maintain “form, fit, and function”

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?

- HW → thousands of obsolete parts in one sub-system alone

VIII. What type of complications does obsolescence bring to the project/product lifecycle?

- To maintain reasonable costs, sometimes need to get waivers to the standards from the customer → however the customer may ultimately be responsible to other agencies who may have to grant them a waiver
- Can’t buy elements and therefore need to replace with something similar that will have limited impacts on other elements
- Standards are easier to reference in whole than in piece part, but need SME’s in place who understand the impact of changes in the standards to the product and are also cognizant of the multiple standards that are applied throughout the multiple configurations of the system.
IX. **What engineering tasks were developed in the project that helped address obsolescence?**

- *Update the requirements to today’s systems engineering standards* (Used NASA requirements quality assessment tools)
  - Of ~28,000 requirements about 20% or more required updates in quality
- *Document obsolescence*
  - Retrieval, to word, then to DOORS
  - Version control to ensure that each configuration ties out to appropriate versions of the specifications
  - Discover the impact of new standards and references → what is the appropriate replacement if the standard is out of date or not maintained
  - What are the other updates required
    - This is nuanced and often comes down to the “best engineering decisions”
    - “write up to modern systems engineering standards”

X. **What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?**

- *Long term obsolescence strategies need to be evaluated throughout the lifecycle and need to be either documented or passed on through institutional memory*
- *Improved documentation of design decisions with rationale would have been helpful*
- *Improved traceability will increase ability to foresee changes required*
- *Document Rationale for design decisions*
- *COTS whenever possible with support from the supplier*
  - Effective COTS management
- *Align product improvement plans with vendor product release*

XI. **Other items?**

- *N/A*
7.1.7 **AUTHOR**

I. How were areas of obsolescence identified?

- N/A

II. Was there a discrepancy in the amount of obsolescence known at the beginning of the process and the amount eventually identified?

- N/A

III. If so, were there any characteristics about the obsolescence identified later that made them less likely to be identified in the beginning?

- N/A

IV. Was there any engineering change in an item required because of obsolescence in another item?

- N/A

V. What approaches can be used to help deal with obsolescence?

- Determine if gap can be satisfies with existing spares (delay the obsolescence issue)
- Try to find a manufacturer willing to build to print (recreate existing design)
- Redesign functionality onto new HW trying to minimize impact to SW design
- Redesign functionality onto new HW while improving the SW design
- Migrate functionality from HW to SW

VI. What were the decision criteria used in the trades to determine which approach would be used on the project?

- Feasibility
- Lifecycle cost
- Design Cost
- Risk
- Future Growth/Evolution

VII. Where did the primary obsolescence manifest itself (HW, SW, Interfaces)?

- N/A

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VIII. What type of complications does obsolescence bring to the project/product lifecycle?

- Multi-Configurations
  - Design
  - Logistics
  - Training Materials
  - Training Programs
  - Documentation
  - Manufacturing: Technical Data Packages
  - Testing: More paths to test

IX. What engineering tasks were developed in the project that helped address obsolescence?

- Identification of obsolescence
- Determine approach for obsolescence – trade studies and risk mitigation activities
- Model/Prototype changes and assess performance against critical parameters
- Assess possible impact to existing requirements and design
- Update Requirements where necessary
- Update Design Documents where necessary
- Development/Validation of the ECP

X. What are current plans or ideas for future plans to deal with obsolescence mitigation in the future?

- N/A

XI. Other items?

- N/A