OBSOLESCENCE DRIVEN DESIGN REFRESH PLANNING FOR SUSTAINMENT-DOMINATED SYSTEMS

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Many technologies have lifecycles that are shorter than the lifecycle of the product they are in. Lifecycle mismatches caused by the obsolescence of technology (and particularly the obsolescence of electronic parts) results in high sustainment costs for long field life systems, e.g., avionics and military systems. This paper presents a methodology for performing optimum design refresh planning for sustainment-dominated electronic systems based on forecasted technology obsolescence and a mix of obsolescence mitigation approaches ranging from lifetime buys to part substitution. The methodology minimizes the lifecycle cost by determining the optimum combination of design refresh schedule for the system (i.e., when to design refresh) and the design refresh content for each of the scheduled design refreshes. The analysis methodology can be used to generate application-specific economic justifications for design refresh approaches to obsolescence management.

In the normal course of product development, it often becomes necessary to change the design of products and systems consistent with shifts in demand and with changes in the availability of the materials and components from which they are manufactured. When the content of the system is technological in nature, the short product lifecycle associated with fast moving technology changes becomes both a problem and an opportunity for manufacturers and systems integrators.

For most high-volume, consumer oriented products and systems, the rapid rate of technology change translates into a critical need to stay on the leading edge of technology. These product sectors must adapt the newest materials, components, and processes in order to prevent loss of their market share to competitors. For leading-edge products, updating the design of a product or system is a question of balancing the risks of investing resources in new, potentially immature technologies against potential functional or performance gains that could differentiate them from their competitors in the market. Examples of leading-edge products that race to adapt to the newest technology are high-volume consumer oriented electronics, e.g., mobile phones and PDAs.

There are however, significant product sectors that find it difficult to adopt leading edge technology. Examples include: airplanes, ships, traffic lights, computer networks for air traffic control and power grid management, industrial equipment, and medical equipment. These product sectors often “lag” the technology wave because of the high costs and/or long times associated with technology insertion and design refresh. Many of these product sectors involve “safety critical” systems where lengthy and expensive qualification/certification cycles may be required even for minor design changes and where systems are fielded (and must be maintained) for long periods of time (often 20 years or more). Many of these product sectors also share the common attribute of being “sustainment-dominated”, i.e., their long-term sustainment (lifecycle) costs exceed the original procurement costs for the system. In this paper, sustainment refers to all activities necessary to:[1]

- Keep an existing system operational (able to successfully complete its intended purpose),
- Continue to manufacture and field versions of the system that satisfy the original requirements
- Manufacture and field revised versions of the system that satisfy evolving requirements.

A significant problem facing many “high-tech” sustainment-dominated systems is technology obsolescence, and no technology typifies the problem more than electronic part obsolescence,[2] where electronic parts refers to integrated circuits and discrete passive components. In the past several decades, electronic technology has advanced rapidly causing electronic components to have a shortened procurement life span. Industry experts estimated that over 200,000 electronic components from over 100 manufacturers had become obsolete by the end 2003 (Texas Instruments 2003). Driven by the consumer electronics product sector, newer and better electronic components are being introduced frequently, rendering older components obsolete. Yet, sustainment-dominated systems such as aircraft avionics are often produced for many years and sustained for decades. Sustainment-dominated products particularly suffer the consequences of electronic part obsolescence because they have no control over their electronic part supply chain due to their low production volumes. This problem is especially prevalent in avionics and military systems, where systems often encounter obsolescence problems before they are fielded and always

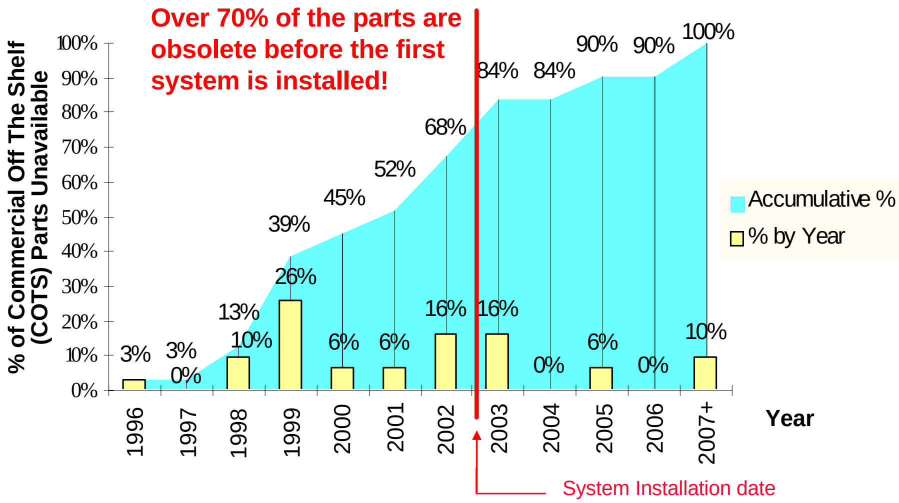

FIGURE 1. Percent of Commercial Off The Shelf (COTS) parts that are out of production (un-procurable) versus the first 10 years of a surface ship sonar system's lifecycle. (Courtesy of NAVSURFWARCENDIV Crane)

during their support life, e.g., FIGURE 1. As an indication of the magnitude of this problem, the projected electronic part obsolescence budget for the F-22 fighter aircraft is in excess of one billion dollars (Tepp 1999).

ELECTRONIC PART OBSOLESCENCE

Electronic part obsolescence began to emerge as a problem in the 1980s when the end of the Cold War accelerated pressure to reduce military outlays and lead to an effort in the United States military called *Acquisition Reform*. Acquisition reform included a reversal of the traditional reliance on military specifications ("Mil-Specs") in favor of commercial standards and performance specifications (Perry 1994). One of the consequences of the shift away from Mil-Specs was that Mil-Spec parts that were qualified to more stringent environmental specifications than commercial parts and manufactured over longer-periods of time were no longer available, creating the necessity to use Commercial Off The Shelf (COTS) parts that are manufactured for non-military applications and, by virtue of their supply chains being controlled by commercial and consumer products, are usually procurable for much shorter periods of time. Although this history is associated with the military, the problem it has created reaches much further, since many non-military applications depended on Mil-Spec parts, e.g., avionics, oil well drilling, and to some extent automotive.

The key input that enables refresh planning for sustainment-dominated systems (the topic of this paper) is obsolescence forecasting. Most of the emphasis associated with methodology, tool and database development targeted at the management of electronic part obsolescence has been focused on tracking and managing the availability of parts, forecasting the risk of parts becoming obsolete, and enabling the application of mitigation approaches when parts do become obsolete. Most electronic part obsolescence forecasting is based on the development of models for the part's lifecycle. Traditional methods of lifecycle forecasting utilized in commercially available tools and services are ordinal scale based approaches, in which the lifecycle stage of the part is determined from an array of technological attributes, e.g., Henke and Lai (1997), Josias, Terrpenny and McLean (2004) and available in commercial tools such as TACTRAC™, Total Parts Plus, and Q-Star™. More general models based on technology trends have also appeared including a methodology based on forecasting part sales curves (Solomon, Sandborn and Pecht 2000), leading-indicator approaches (Meixell and Wu 2001), and data mining based solutions (Sandborn, Mauro and Knox 2005).[3] A few efforts have also begun to appear that address non-electronic part obsolescence forecasting including Howard (2002) and ARINC (2006).

Many part obsolescence mitigation strategies exist for managing obsolescence once it occurs, including (Stogdill 1999): lifetime buy (also referred to as final order), last-time buy, part replacement, aftermarket sources, emulation, re-engineering, salvage, and design refresh/redesign of the system. Design refresh (or redesign) ultimately occurs as other mitigation options are exhausted and functionality upgrades (technology insertion) becomes necessary.[4] There are also efforts targeting enterprise wide solutions by tracking obsolete parts and "equivalent" substitutes thereby enabling the determination of the lowest cost option for mitigating obsolescence (Tilton 2006).

PRO-ACTIVE OBSOLESCENCE MANAGEMENT

The obsolescence mitigation approaches discussed in the preceding paragraph are *reactive* in nature, focused on minimizing the costs of obsolescence mitigation, i.e., minimizing the cost of resolving the problem after it has occurred. While reactive solutions will always play a major role in obsolescence management, ultimately, higher payoff (larger sustainment cost avoidance) will be possible through *pro-active* oriented methodology/tool development efforts (Sandborn 2004).

If information regarding the expected production lifetimes of parts (with appropriate uncertainties considered) is available during a system's design phase, then more strategic approaches that enable the estimation of lifetime sustainment costs should be possible, and even with data that is incomplete and/or uncertain, the opportunity for sustainment cost savings is still potentially significant with the application of the appropriate decision making methods.

Two types of strategic planning approaches exist: material risk indices and design refresh planning. A Material Risk Index (MRI) approach analyzes a product's bill of materials and scores a supplier-specific part within the context of the enterprise using the part, e.g., Robbins (2003). MRIs are used to combine the risk prediction from obsolescence forecasting with organization-specific usage and supply chain knowledge in order to estimate the magnitude of sustainment dollars put at risk within a customer's organization by the part's obsolescence. The other type of strategic planning approach is design refresh planning discussed in the remainder of this paper.

DESIGN REFRESH PLANNING

Because of the long manufacturing and field lives associated with sustainment-dominated systems, they are usually refreshed or redesigned one or more times during their lives to update functionality and manage obsolescence. Unlike high-volume commercial products in which redesign is driven by improvements in manufacturing, equipment or technology; for sustainment-dominated systems, design refresh is often driven by technology obsolescence that would otherwise render the product un-producible and/or un-sustainable.

Ideally, a methodology that determines the best dates for design refreshes, and the optimum mixture of actions to take at those design refreshes is needed. The goal of refresh planning is to determine:

- When to design refresh
- What obsolete system components should be replaced at a specific design refresh (versus continuing with some other obsolescence mitigation strategy)
- What non-obsolete system components should be replaced at a specific design refresh.

This paper discusses a methodology focused on the question: if a forecast of parts obsolescence can be obtained, can optimum design refresh strategies be developed for the product over the product's overall lifecycle?

Numerous research efforts have worked on the generation of suggestions for redesign in order to improve manufacturability, e.g., Irani, Kim and Dixon (1989) and Das, Gupta and Nau (1996). Redesign planning has also been addressed outside the manufacturing area, e.g., general strategic replacement modeling (Meyer 1993), re-engineering of software (Lin 1993), capacity expansion (Rajagopalan, Singh and Morton 1998), and equipment replacement strategies (Pierskalla and Voelker 1976, and Nair and Hopp 1992). All of this work represents redesign driven by improvements in manufacturing, equipment or technology (i.e., strategies followed by leading-edge products), not design refresh driven by technology obsolescence that would otherwise render the product un-producible and/or un-sustainable. It should also be noted that manufacturers and customers of sustainment-dominated systems are often more interested in "design refresh" than "redesign" (see endnote 4 for the distinction).

Only one known effort has treated lifecycle planning associated with technology obsolescence (explicitly electronic part obsolescence). Porter's approach (Porter 1998), focuses on calculating the Net Present Value (NPV) of last time buys[5] and design refreshes as a function of future date. As a design refresh is delayed, its NPV decreases and the quantity (and thereby cost) of last time buys required to sustain the system until the design refresh takes place increases. Alternatively, if design refresh is scheduled relatively early, then last time buy cost is low, but the NPV of the design refresh is high. The Porter model performs the trade-off analysis discussed above on a part-by-part basis and considers only a single design refresh at a time. A version of Porter's model was used to plan refreshes in conjunction with lifetime buy quantity optimization by Cattani and Souza (2003). In order to treat multiple refreshes in a product's lifetime, Porter's analysis can be reapplied after a design refresh to predict the next design refresh. The Porter model effectively optimizes each individual design refresh, but the coupled effects of multiple design refreshes (coupling of decisions about multiple parts <u>and</u> coupling of multiple refreshes) in the lifetime of a product are not accounted for. This is a significant limitation of the Porter model approach, which is directly addressed by the MOCA methodology discussed in this paper.

THE MITIGATION OF OBSOLESCENCE COST ANALYSIS (MOCA) METHODOLOGY

A methodology and its implementation have been developed for determining the electronic part obsolescence impact on lifecycle sustainment costs for the long field life electronic systems based on future production projections, maintenance

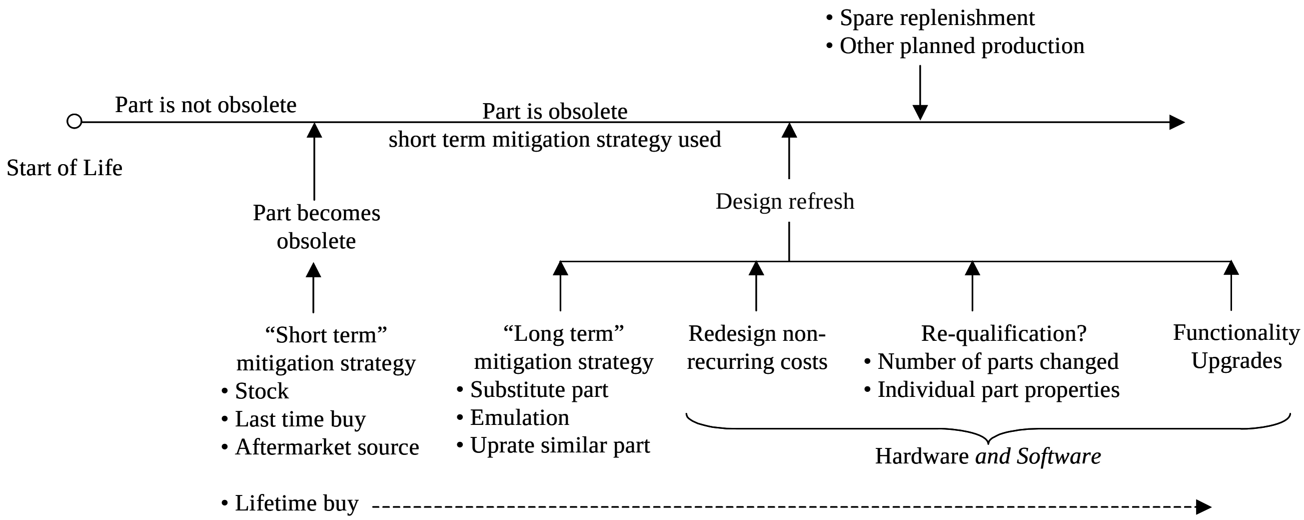

FIGURE 2. Design refresh planning analysis timeline (presented for one part only, for simplicity, however in reality, there are coupled parallel timelines for many parts, and design refreshes and production events can occur multiple times and in any order).

requirements and part obsolescence forecasts. Using a detailed cost analysis model, the methodology determines the optimum design refresh plan during the field-support-life of the product. The design refresh plan consists of the number of design refresh activities, their content and respective calendar dates that minimize the lifecycle sustainment cost of the product.

FIGURE 2 shows the design refresh planning timeline. Fundamentally, the methodology must support a design through periods of time when no parts are obsolete, followed by multiple part-specific obsolescence events. When a part becomes obsolete, some type of mitigation approach must take effect immediately: either sufficient inventory exists, a lifetime buy of the part is made or some other short-term mitigation strategy that only applies until the next design refresh. Next there are periods of time when one or more parts are obsolete, and short-term mitigation approaches are in place on a part-specific basis. When design refreshes are encountered (their date is defined either by the user or by the methodology during its optimization process) the change in the design at the refresh must be determined and the costs associated with performing the design refresh are computed. At a design refresh, a long-term obsolescence mitigation solution is applied (until the end of the product life or possibly until some future design refresh), and non-recurring, recurring, and re-qualification costs computed. Re-qualification may be required depending on the impact of the design change on the application – the necessity for re-qualification depends the role that the particular part(s) play and/or the quantity of non-critical changes made. In many cases, if the expense of a design refresh is to be undertaken, then functional upgrades may also be considered. The system functional upgrades must be forecasted (including forecasting the obsolescence of future parts). All the design refresh activities have to accommodate both hardware and software redesign and re-qualification. The last activity appearing on the timeline is production. Product often has to be produced after parts begin to go obsolete due to the length of the initial design/manufacturing process, additional orders for the product, and replenishment of spares.

FIGURE 3 summarizes the MOCA methodology for making decisions about how to refresh a sustainment-dominated system's design. The methodology is used during either: a) the original product design process, or b) to make decisions during system sustainment, i.e., when a design refresh is underway, determine what the best set of changes to make given an existing history of the product and forecasted future obsolescence and future design refreshes. MOCA only treats the hardware portion of the design refresh problem.[6] The obsolescence dates for the chosen technologies (electronic parts in our case), are forecasted. The forecasts are generally in the form of a probability distribution whose shape depends on the forecasting method used. The other type of the information necessary to make decisions about how to modify a design at design refreshes comes from production information. From the design process, an anticipated production plan (quantity that need to be manufactured as a function of time) is used along with a forecast of the number of spare products that will need to be produced to replace product that fails in the field during the product's usage life. Remember we are dealing with sustainment-dominated products that will fail in the field due to wearout and overstress, and will require replacement. The production plan associated with "spare replenishment" will be determined from the forecasted reliability of the product's components and the forecasted usage profile for the system. Using a production plan, viable locations for design refreshes can be determined (see the Uncertainty Analysis subsection for how this is done). With the viable design refresh dates chosen; a candidate refresh plan can be formed. A refresh plan is a group of one or more design refreshes that will be performed on a product during its lifetime.

Given the obsolescence forecasts, the production plan and a candidate design refresh plan, we now determine the lifecycle cost of the product subject to the candidate refresh plan by traversing the timeline and costing the events as they occur (each traversal of the timeline is basically a discrete event simulation). The production event cost is adjusted for the obsolete part acquisition cost which is usually many times greater than its original cost. The overall lifecycle cost in MOCA is summarized in

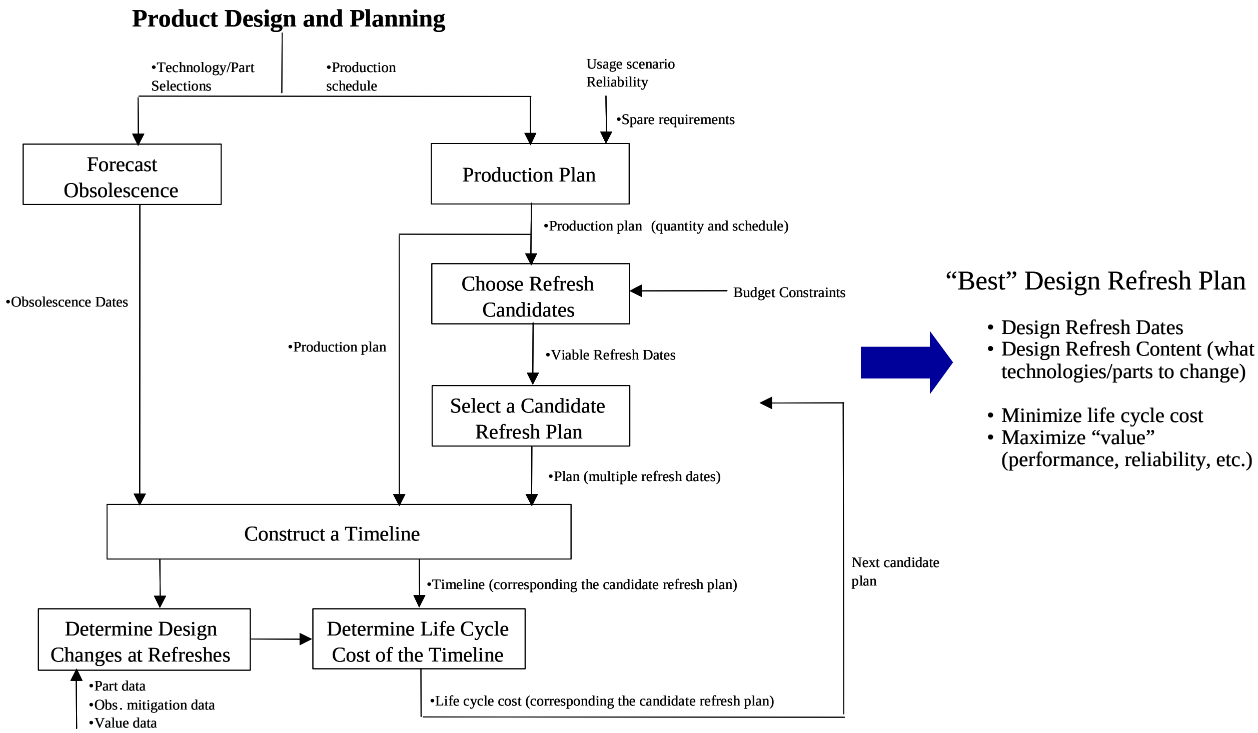

FIGURE 3. Methodology for making decisions about how to refresh a sustainment-dominated system's design.

(1)-(3),

$$\text{Lifecycle Cost} = \sum_{i=1}^{n} \frac{Q_i\ C_i}{(1+R/100)^{d_i}} + \sum_{j=1}^{r} \frac{NC_j}{(1+R/100)^{d_j}} \tag{1}$$

where,

Q_i = Quantity of systems to be manufactured at the ith manufacturing event
C_i = Recurring cost of manufacturing a system instance at the ith manufacturing event
NC_j = Non-recurring cost of the jth design refresh
n = Number of manufacturing events
r = Number of design refreshes
R = Interest rate including percentage discount
$d_{i/j}$ = Difference in years between i/jth manufacturing/design refresh event date and the net present value calculation date.

The recurring cost of manufacturing a system instance depends on the state of availability of the parts in the system and is given by,

$$C_i = C_{np} + \sum_{k=1}^{s} m_{i(k)} c_{o(k)} \tag{2}$$

where,

$m_{i(k)}$ = Modifier on the effective procurement cost of part k at the ith manufacturing event
$c_{o(k)}$ = Original procurement cost of all instances of part k adjusted for inflation
C_{np} = Non-part procurement associated recurring costs, e.g., testing, assembly, etc.
s = Number of parts in the system.

The part price modifier, $m_{i(k)}$, is 1 if the currently used part is not obsolete (note, the currently used part changes as the timeline is incremented due to design refreshes). If the part is obsolete, but exactly the same part is still used (obtained from existing inventory, aftermarket sources, lifetime buy, etc.) then $m_{i(k)}$ is either provided by the user or defaulted using recurring cost multiplier data associated with various obsolescence resolution approaches from (McDermott, Shearer and Tomczykowski 1999).

Design refreshes are defined (from a model perspective) as any action that results in the replacement of a part with a non-identical alternative. Refreshes can range from trivial, replacement of a part with a form, fit and function identical alternative part to complex redesign activities. Each refresh event adds non-recurring costs associated with re-engineering and re-qualification, and changes the effective recurring cost of the system components. In its simplest form, the non-recurring cost at the jth design refresh is given by,

$$NC_j = \left[C_f + C_b \sum_{u=0}^{N_{b(j)}} M_{b(u)} + C_p \sum_{k=0}^{N_{p(j)}} M_{p(k)} \right] + C_{Q(j)} \tag{3}$$

where,

C_f = Average cost of design refresh incurred due to assembly, documentation, etc., system-level changes
C_b = Average cost of design refresh for each board addressed at the design refresh
C_p = Average cost of design refresh incurred for each unique part addressed at the design refresh
$N_{b(j)}$ = Total number of boards with changed parts at the jth design refresh
$N_{p(j)}$ = Total number of part changes at the jth design refresh
$M_{b(u)}$ = Modifier on the design refresh cost of board u
$M_{p(k)}$ = Modifier on the design refresh cost of part k
$C_{Q(j)}$ = Re-qualification cost at the jth design refresh.

The design refresh cost model utilizes the two "M" modifiers in (3) in the following way: the cost of design refreshing the board "u" is $C_bM_{b(u)}$ where C_b represents the base cost of design refreshing a board. This procedure is utilized in order to specify different design refresh costs for different boards. Similarly, the cost modifier on the part design refresh cost ($M_{p(k)}$) signifies the relative cost incurred to design refresh the part "k" on the board compared to the base cost of design refreshing a part on the board (C_p).

The bracketed portion of (3) is a simple default model for the design refresh non-recurring re-engineering cost. The MOCA model is generally used in conjunction with detailed cost models such as Price Systems H and HL parametric commercial cost modeling tools (Price Systems 2006) or the Horizon Tool Suite from the Naval Surface Warfare Center (Crane) (Chestnutwood and Levin 1998). If an external cost analysis tool is used, MOCA exports the design refresh dates and content to the external tool, which computes and returns the bracketed portion of (3) and may provide an updated version of C_{np}. The two cost analysis tools mentioned both provide detailed modeling that can include design, prototyping, testing, documentation, training, etc.

The re-qualification cost appearing in (3) is often a significant part of the overall cost of performing a design refresh for sustainment-dominated systems. In MOCA, re-qualification cost is treated independently of the design refresh cost, in order to gain flexibility. MOCA treats re-qualification at two levels: board level (i.e., re-qualification can be performed separately for each unique board in the system) or system level (i.e., re-qualification is only performed for the system as a whole). A qualification cost is specified (for a system or for each board), which is allocated to various levels of qualification, e.g., full qualification, vibration, thermal, etc. There are two types of triggers for re-qualification, an individual part re-qualification trigger and the total number of components changed trigger. Where as, the individual part re-qualification trigger is based on the individual re-qualification requirements associated with particular parts when they are design refreshed, the number of components re-qualification trigger accounts for the small, but cumulative, changes in the system due to design refresh of non-critical components. To determine the "best" design refresh plan, multiple candidate refresh plans are assessed.

Synthesis of Replacement Parts

When an obsolete part is replaced at a design refresh, the characteristics of the replacement part must be synthesized. The synthesized replacement part's cost, procurement life, and reliability must be estimated. The replacement part cost is calculated using a trend equation (discrete or continuous), which is one of the user inputs. The lifecycle stage of the replacement part in conjunction with the part type, i.e., Microcircuit, Diode, etc. (used to define the total part procurement lifetime), is used to calculate the procurement life of the replacement part, (4),

$$D_o = D_r + \left[\frac{I_O - I_R}{I_O - I_I} \right] L \tag{4}$$

where,

D_o = Date of obsolescence for the synthesized replacement part
D_r = Date of the design refresh
L = Procurement lifetime of the part (time from introduction to discontinuance) in years

I_O = Lifecode indicating part is obsolete
I_I = Lifecode indicating part is in the emerging lifecycle phase
I_R = Lifecode of replacement synthesized replacement part.

Lifecodes (which are the a metric predicted by commercial obsolescence forecasting tools) represent the lifecycle stage of a part, e.g., 1 = emerging, 2 = growth, 3 = maturity, 4 = decline, 5 = phase out, 6 = obsolete. For example, if the replacement part desired by the system sustainers is one that has entered its growth stage (I_R = 2) just before the refresh, then the expression within the brackets in (4) becomes 0.8.

The reliability of the replacement part is set based on trend equations (discrete or continuous). Since MOCA deals with only system level or board level cost and reliability changes, these parameters are rolled up from the part level to the system level to reflect the changes throughout the system hierarchy.

DESIGN REFRESH DATE SELECTION AND UNCERTAINTY ANALYSIS ON DATES

Design refreshes can take place at any point on the timeline, however, we make the assumption that a design refresh that completes at a point in time that is significantly earlier than the start of the next production event (whether planned production or spare replenishment) will never be as economically advantageous as one that is completed “just in time” for the next production event. This assumption is always true if the rate of interest is non-negative, because the net present cost of a delayed refresh will always be lower than the net present cost of a refresh at an earlier date. In addition, since parts can become obsolete between the end of a design refresh activity and the next production event, a just-in-time refresh strategy ensures that all the obsolete parts have had a chance to be addressed at the refresh. Note, we assume that there is no significant procurement associated with a design refresh; parts are procured on a different schedule associated only with production events. In reality the “just in time” applies to the procurement of “materials” for the production event. This strategy for placing design refreshes has two significant advantages: obviously the number of possible locations on the timeline for design refreshes becomes finite (limited to the number of production events, which is a relatively small number especially for avionics and military systems – only 10 to 15 events is not unusual), and this allows each design refresh candidate to be associated a specific instance of some type of a production event, which enables a probabilistic treatment of the production event dates.

One of the key attributes of the methodology is its treatment of uncertainties. Obviously, much of the data that the method depends on to make design refresh decisions is highly uncertain. In order to solve the problem, two types of data uncertainties must be managed, 1) uncertainties in the inputs to the cost analysis, for example, the re-qualification cost associated with a particular type of qualification test; and 2) uncertainties in dates. The cost analysis input uncertainty is handled through straightforward Monte Carlo modeling. The second type of uncertainty (dates) is more complex to accommodate. At the highest level in the solution, an algorithm that selects candidate refresh plans is used. A candidate refresh plan consists of the quantity of design refreshes in the lifetime of the product and the dates of completion of those refreshes relative to production events, FIGURE 4. A production event is any event that results in the need to produce additional instances of the product, i.e., additional orders or spare replenishment necessary for sustainment. Once a candidate refresh plan is chosen (relative to production events), then a sampling of dates for those production events is chosen (the date for each production event is inputted as a probability distribution). After the probability distributions for the dates are sampled, a sample refresh plan candidate (with real dates) is available. The methodology then computes the lifecycle cost of the candidate refresh plan for the sample. Using a basic Monte Carlo approach, the methodology repeats the process of sampling production dates and computing lifecycle costs a statistically relevant number of times producing a histogram of the lifecycle costs for the candidate refresh plan. For each unique combination of refreshes (relative to production dates), a distribution of lifecycle cost is calculated. In order to be consistent, the same set of appropriately distributed cost input samples is used to evaluate every combination of refreshes. The output design refresh dates (for a particular refresh plan) are the corresponding most likely production event dates to which the design refreshes were associated (relatively positioned).

TIME STEP FIDELITY

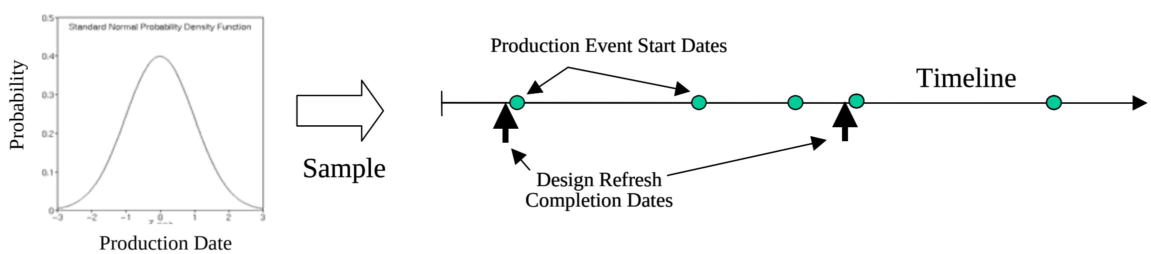

FIGURE 4. A candidate refresh plan is defined as one or more design refreshes and their dates relative to production events.

Another important aspect of the MOCA methodology is the identification and use of a time step for the discrete event simulation. In physical simulations of systems, e.g., thermal, mechanical, electrical, or chemical, choosing a smaller time step always produces a more accurate solution since physical systems are continuous and practically accepted models for physical systems are valid as the time step approaches zero. In the design refresh problem, smaller time steps do not necessarily produce more accurate answers; it is critical to choose the right time step. Too small a time step can result in just as inaccurate an answer as too large a time step. As an example, it is impractical for most companies to procure parts on a per minute basis 24 hours a day 7 days a week, rather, procurement happens on a coarser time scale, e.g., once a month or once a quarter. The one year time step assumed by common lifecycle cost analysis tools is a reasonably accurate representation of the time scale on which manufacturers of long field life systems plan and operate.

Two different approaches were taken to coarsen the data in MOCA. They are: 1) combining production events before design refresh optimization, and 2) rounding off dated events and associating the events with the nearest budget period. Combining production events in MOCA means that starting from a particular date, add up all the production events for a time span specified by the user. The production events in that time span are then treated as a single production event at the start date. In this way the support life of the product is fragmented into various sections and active simulation steps taken only on these fragments. Budgeting in MOCA means that each date input is rounded and included within the nearest budget period. Therefore, all the date inputs reflect budget period based inputs. For example, if the budget period is a year, the production date of 2005.6 would be considered to be 2005. In effect all the budget of procurements during the year 2005 are allocated at the beginning of the year.

DESIGN REFRESH PLANNING EXAMPLE ANALYSIS

A case study was performed for an avionics radar unit from Northrop Grumman. The portion of the radar unit considered in this study consisted of 2 boxes that contained a total of 20 boards (12 of the boards are unique and one specific board is common to both boxes). A total of 831 parts (116 unique parts) were included on the boards. The system is designed for a 20 year sustainment life with scheduled manufacturing taking place during the first 12 years. FIGURE 5 shows the hierarchy of the design; a total of 4 levels of hierarchy are used to model the unit (chip, board, box, system). The original design for the radar unit was performed in 1998 and manufacturing of the first production lot began in 1998 (first lot production was completed in 2001).

In order to demonstrate the MOCA analysis, the system was modeled as though the analysis was being performed in 1998 using TACTech[7] part lifecode forecasts performed when the original unit design was performed. Our objective was to compare MOCA design refresh forecasts with the actual design refresh decisions made by Northrop Grumman for the radar unit. FIGURE 6 shows an example analysis result from MOCA for the radar unit. MOCA generates results for all possible combinations of design refresh locations (dates) up to a user specified maximum number of design refreshes during the life of the product (4

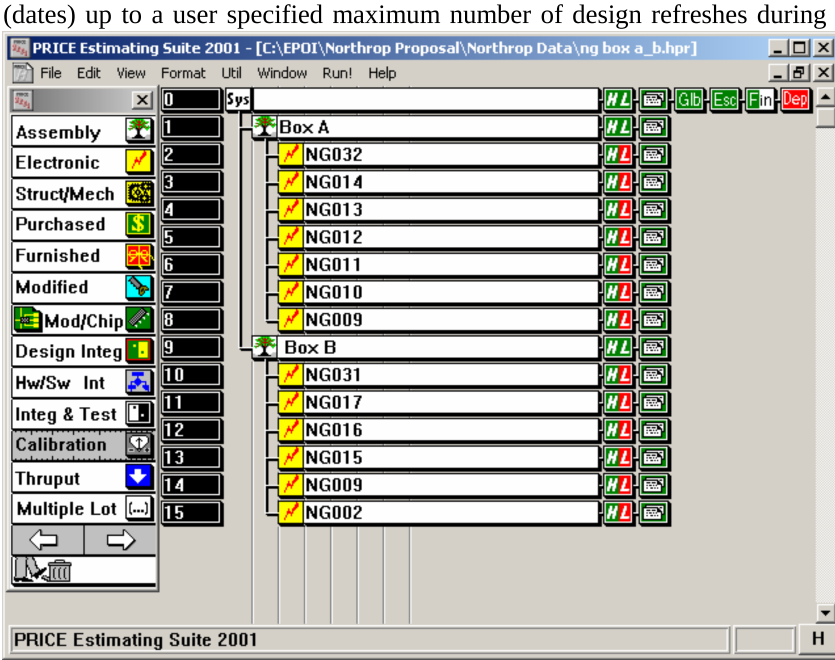

FIGURE 5. Radar unit design hierarchy shown in the Price HL parametric cost modeling tool. The Price model was used in this example case, in conjunction with MOCA to compute non-recurring costs at design refreshes.

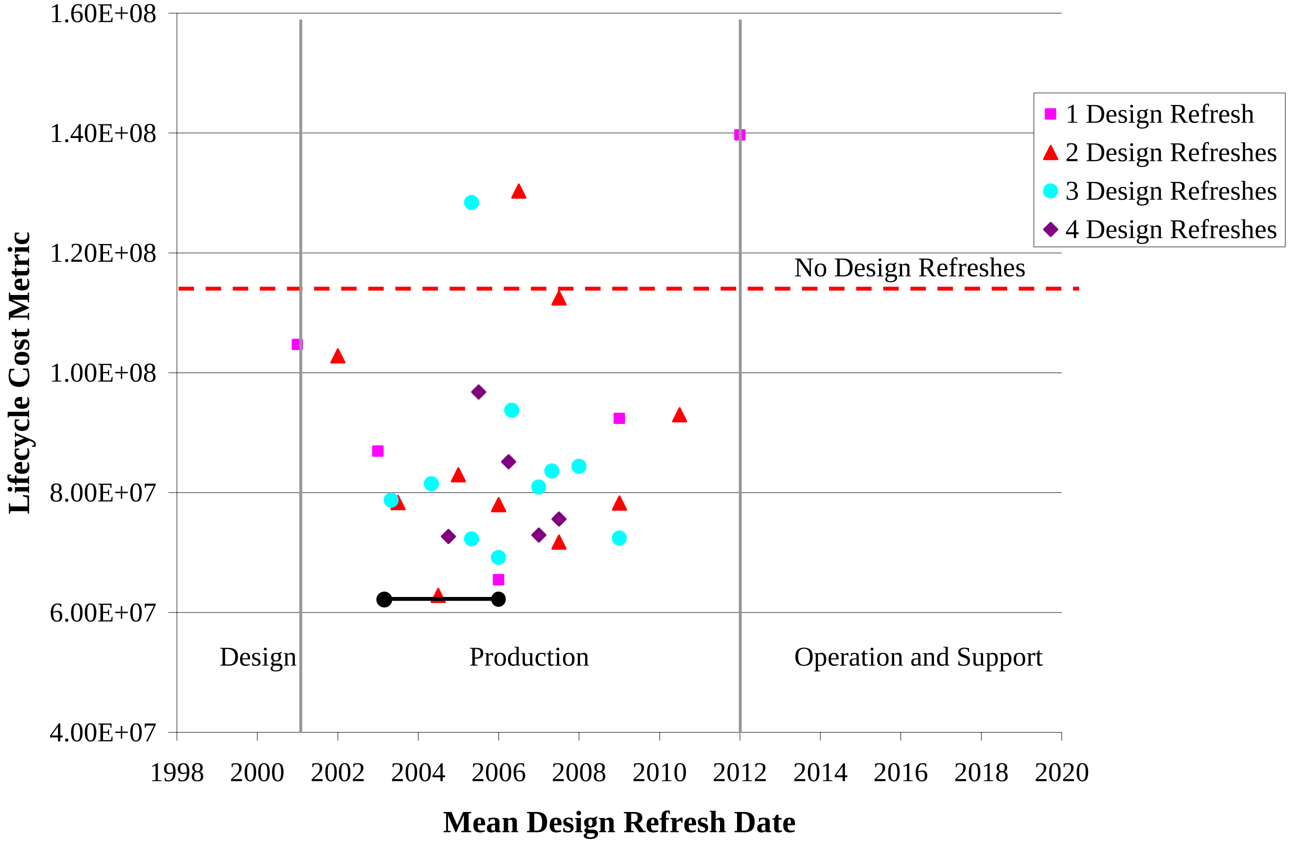

FIGURE 6. MOCA generated refresh plans. Only plans consisting of exactly 0, 1, 2, 3, or 4 refreshes during the lifetime of the system are shown. The candidate refresh plan with the lowest cost is expanded to show and the actual refresh dates associated with it.

refreshes, 20 year life in FIGURE 6 for example). The data points on the plot in FIGURE 6 each represent a different refresh plan (a refresh plan is a group of one or more design refreshed on specific dates during the lifetime of the unit). The "Mean Design Refresh Date" is the average date of the refresh in the plan (it is not important to the solution, i.e., it is just a way of spreading the results out along the horizontal axis for viewing). If the refresh plan only contains a single refresh, then the mean design refresh date is the actual date that the refresh takes place. The cost axis is a cost metric that is proportional to the lifecycle cost of manufacturing and sustainment of all the units (design refresh and any associated re-qualification are included, but initial design and the original qualification cost is not included). This cost does not necessarily correspond to total lifecycle costs for the system, but a smaller value of the metric does indicate lower lifecycle cost. Note; 2001 was the date that the first production lot completed. However, this does not preclude in any way, parts used in the radar unit becoming obsolete prior to 2001; in fact, some parts were forecasted to be obsolete prior to the completion of the first lot. It also does not preclude MOCA from considering design refreshes prior to 2001. A refresh plan is also generated by MOCA that summarizes the actual refresh dates and content of each refresh.

Up to this point we have only discussed the general interpretation of MOCA results. The radar unit specific questions to be answered by the MOCA analysis are:

- How many refreshes to plan on?
- When those refreshes should be performed?
- What actions to take at the refreshes?

For the radar module considered here, the relative lifecycle costs associated with a refresh plan were found to be most sensitive to the production plan (quantity manufactured and how that manufacturing is distributed in time), and what actions are taken at the design refreshes (to what extent future obsolescence events are mitigated at each design refresh).

The results in FIGURE 6 are for a one year look-ahead time – this means that at a design refresh, parts that are forecasted to become obsolete within one year after the conclusion of the design refresh activity are designed out, in addition to those that have already become obsolete. If we vary the look-ahead time and determine the minimum lifecycle cost refresh plan solution (i.e., find the lowest data point on graphs like the one shown in FIGURE 6) for each look-ahead time, we obtain the result shown in FIGURE 7. The data points in FIGURE 7 represent the lifecycle cost associated with the "best" plan (it is minimum when the look-ahead time is 1 year), and the dashed line shows that number of refreshes in the minimum lifecycle cost solution.

FIGURE 7 indicates several intuitive results: 1) no look-ahead time leads to larger lifecycle costs because of inefficiency at design refreshes, and 2) long look-ahead times eventually lead to larger lifecycle costs because you are basically replacing everything at every refresh. In fact, the result shown in FIGURE 7 immediately raises a flag in the case of the radar unit where the contractual obligation of the manufacturer to manufacture and sustain the unit may not accommodate the replacement of non-obsolete parts at design refreshes.

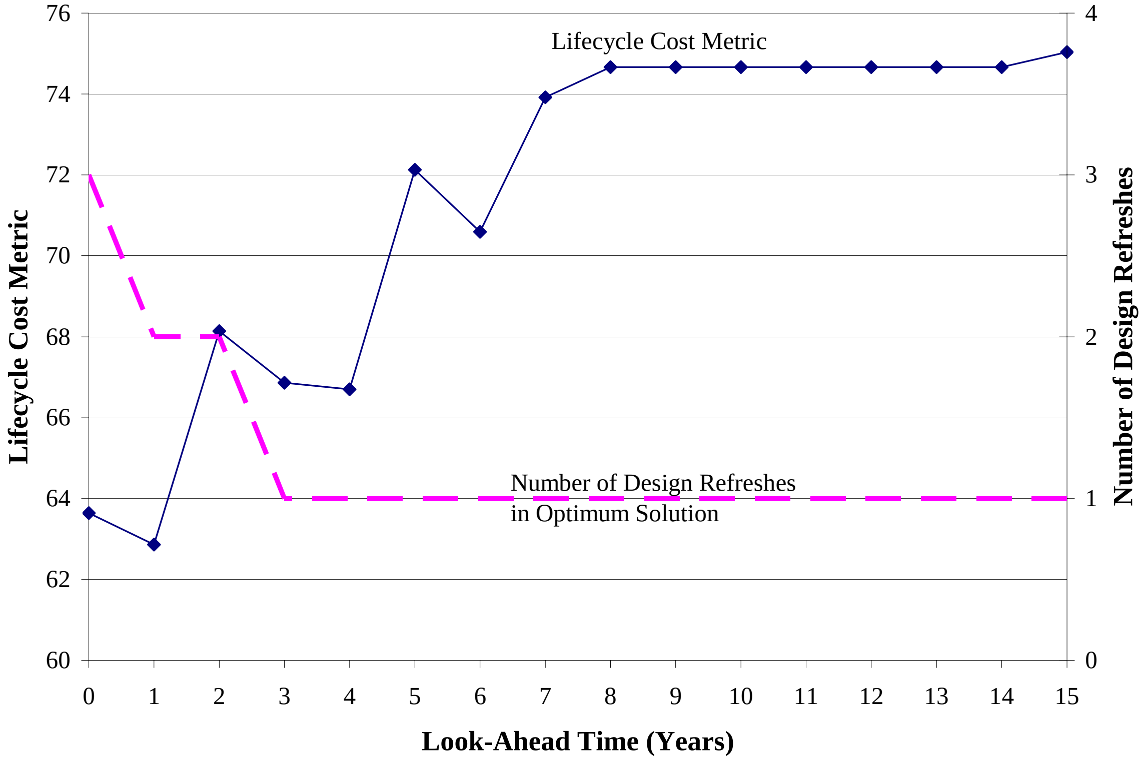

FIGURE 7. Sensitivity of MOCA radar unit solution to "look-ahead time". Look-ahead time is how far into the future forecasted obsolescence events are addressed at a design refresh.

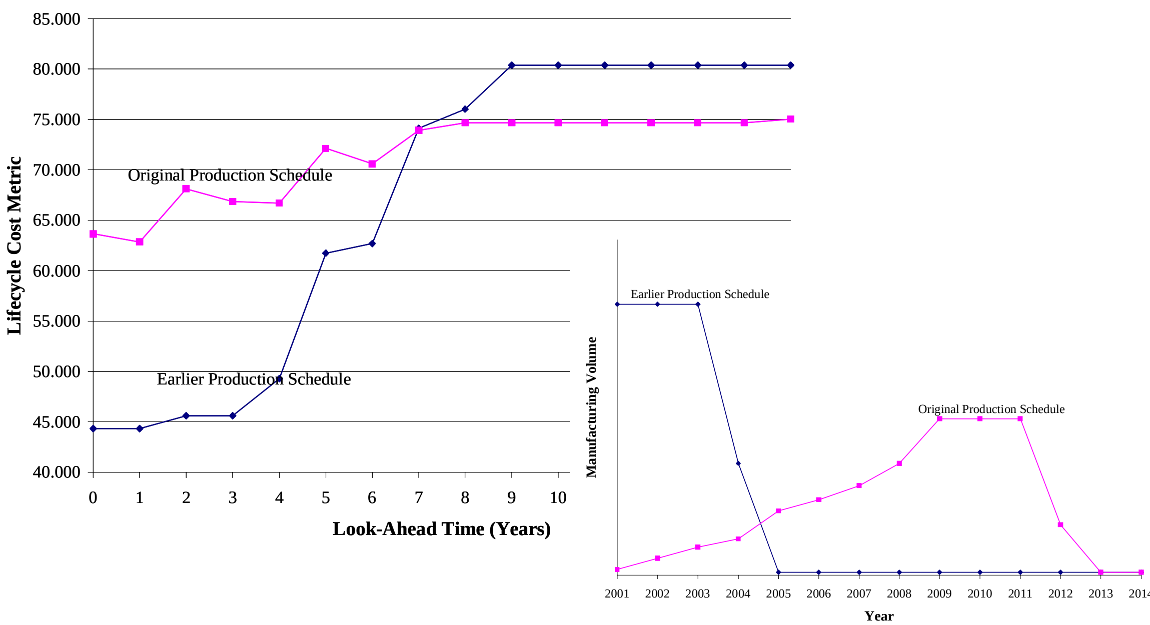

FIGURE 8. Effect of production schedule on the optimum refresh plan

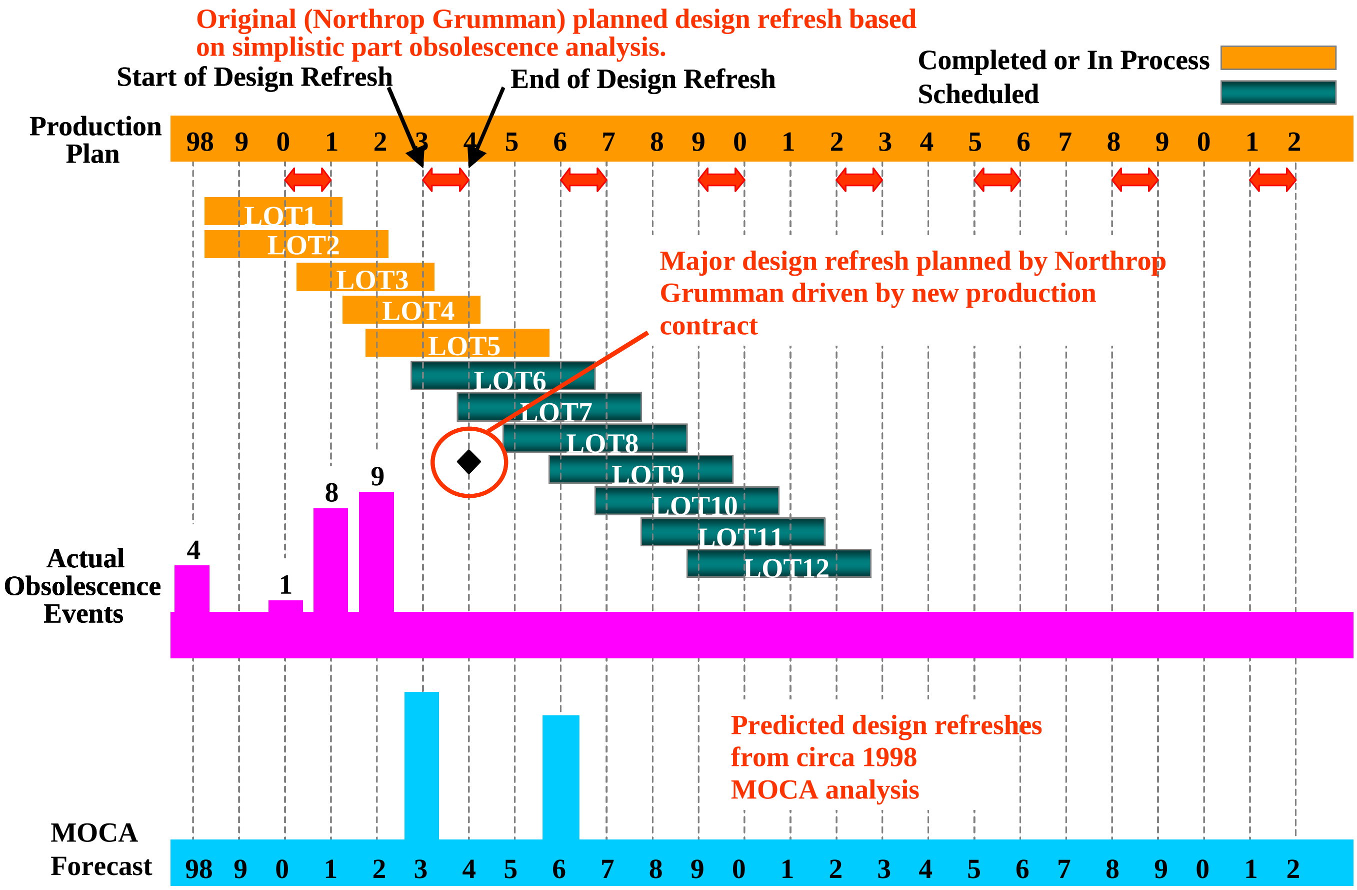

FIGURE 9. Comparison of MOCA forecasted optimum design refresh dates (forecasted from only the 1998 design data), a simplistic original redesign plan, and the first major redesign date determined by Northrop Grumman.

As stated above, the other primary sensitivity in the radar unit model is the production plan. FIGURE 8 shows the characteristics of the look-ahead time analysis for two different production plans. The results for the actual or original production plan (the same as that shown in FIGURE 7) are plotted – in this case the production peaks in years 10 and 11. If the same total number of units are manufactured, but the manufacturing is front-end loaded, the total lifecycle cost decreases, and the optimum look-ahead time decreases to zero. This makes intuitive sense; if you are going to build all the units in the first 3-4 years, why bother to spend money refreshing the design for parts forecasted to become obsolete 5 or more years in the future? In fact, if you are going to force a long look-ahead time on the earlier production plan, eventually you give up all the advantage gained by building the units at the beginning of the lifecycle. Finally, the optimum refresh plan forecasts from MOCA were compared to the actual refresh plans determined from the state of the actual obsolescence events and production. FIGURE 9 shows the original production plan, the number of actual part obsolescence events that occurred, the originally planned redesigns based on a simplistic part obsolescence analysis, and the first major design refresh. This design refresh date was set based on a combination of observing the actual part obsolescence events, the state of the production process, and budgetary realities. Also shown on FIGURE 9 are the MOCA forecasted refresh dates (forecasted only from the information available during the design for the unit in 1998). As can be seen, the first MOCA forecasted refresh falls one year earlier than the manufacturer determined design refresh. The fact that the MOCA forecasted refresh occurs slightly earlier than the actual can be attributed to the fact that the TACTech lifecodes used from the 1998 data are generally conservative resulting in earlier forecasted obsolescence dates than actually occur for many parts. Conservative obsolescence forecast inputs to MOCA result in MOCA seeing more obsolescence events early in the product lifetime than are actually present, thereby tending to shift the first refresh date prediction earlier than actual.

DISCUSSION

The challenge addressed in this paper is the determination of the optimum refresh date(s) and content for sustainment-dominated systems subject to electronic part obsolescence pressures. For these types of systems, the problem is not necessarily that people cannot figure out when to refresh a design and what the content of the refresh ought to be, it's that they cannot figure these things out soon enough to put the necessary resources in place (e.g., budget) at the optimum point(s) in time. Using a design refresh methodology like MOCA enables early enough forecasting of refresh dates and content to allow the optimum refreshes to actually be performed. This is demonstrated in the case study, where MOCA was able to predict approximately the same optimum refresh date as the system manufacturer/sustainer's analysis, but used data that was four years older.

There are several situations in which the present MOCA solution is incomplete. The biggest hole in the current MOCA solution is the treatment of software. In its present form, MOCA only treats hardware, or at best, hardware and software decoupled. In reality, hardware changes will cause software to be changed and potentially re-hosted and/or re-qualified too. MOCA has no mechanism to understand the connection between the hardware and the software. A second issue with MOCA is that it does not have a view into the parts inventory, i.e., MOCA assumes that the obsolescence date provided as an input is in fact the effective obsolecence date for the part in the application. Depending on the inventory you are drawing your parts from, the effective obsolescence date of a part may be significantly different than the original manufacturers last order date. An additional problem is that while existing commercial forecasting tools are good at articulating the current state of a part's availability and identifying alternatives, their capability to forecast future obsolescence dates is limited. More accurate forecasts or at least forecasts with a quantifiable accuracy must be developed in order to enable the use of planning tools like MOCA (Sandborn, Mauro and Knox 2005).

This paper treats design refresh that targets maintaining a system's capability over its life, as opposed to redesign that targets maintaining and improving the design. For many sustainment-dominated products, refresh is as important (and often more important) than redesign. However, if a roadmap of *value* attributes for the product over time is available, it may be possible to extend methodologies like MOCA to consider design refresh coupled with optimum technology insertion redesign strategies. Possible methods for extending the refresh planning methodologies to address the technology insertion problem for sustainment-dominated systems have been proposed including the introduction values metrics that include sustainability (Ardis 2001) and the use of Bayesian networks to capture and implement the extended value metrics (Sandborn et al. 2003).

There are several real payoffs from strategic lifecycle planning that reactive optimization cannot provide. Pro-active treatment of electronic part obsolescence has the potential to provide the program manager with the ability to predict as early as possible (while the input data is uncertain) how to best design and plan for system sustainment:

- more accurate allocation of budget earlier in program development phases
- more accurate guidelines for how systems are modified at design refreshes
- improved operational availability
- enables broader impacts to be considered when mitigation approach decisions are made
- enables the opportunity for shared solutions across multiple systems and applications.

Realizing these payoffs however requires the incorporation of decision process approaches (decision making under uncertainty), design optimization, product planning, and data fusion capabilities to bear on this problem.

Sustainment problems are going to get worse, not better in the future and are going to become significant lifecycle cost drivers in numerous product sectors. The key is learning to design for the inevitability of obsolescence – we are focused on product sectors that, by definition, do not control critical portions of their technology supply chain and never will control them. The broader impacts of research in obsolescence go well beyond electronic parts. Solutions could contribute to fundamental technology insertion decision making for long-life sustainment-dominated systems in general as well as shorter-life high technology products such as computer hardware and software.

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NOTES

1. This usage of the term "sustainment" in this paper is consistent with the Brundtland Report definition (Brundtland Commision 1987): "Development that meets the needs of present generations without compromising the ability of future generations to meet their own needs". In the context considered in this paper, "present and future generations" refers to the users and maintainers of a system.

2. The military refers to electronic part obsolescence (and more generally technology obsolescence) as DMSMS – Diminishing Manufacturing Sources and Materials Shortages.
3. Note, obsolescence forecasting is an "outside looking in" form of product deletion modeling, e.g., Avlonitis, Hart and Tzokas (2000), performed without access to internal business knowledge of the manufacturer of the part.
4. Technology refresh is used as a reference to system changes that "Have To Be Done" in order for the system functionality to remain useable. Technology insertion is a term used to identity the "Want To Be Done" system changes, which include both the new technologies to accommodate system functional growth and new technologies to replace and improve the existing functionality of the system, see Sandborn et al. (2003).
5. A last time buy means procuring and storing enough parts to sustain manufacturing and fielded units until the next redesign.
6. Software becomes obsolete because either the system that must execute it changes (possibly due to hardware changes caused by hardware obsolescence), or the software vendor terminates its support.
7. TACTech was acquired by i2 and is the basis for the TACTRAC obsolescence forecasting tools.

REFERENCES

Ardis, B. (2001), Viable/affordable combat avionics (VCA) implementation update. Dayton Aerospace, Inc.

ARINC, Inc. (2006), ARINC Logistics Assessment and Risk Management (ALARM) Tool. Retrieved February 21, 2006, from http://www.arinc.com/news/2005/06-28-05.html

Avlonitis, G.J., Hart, S.J. and Tzokas, N.X. (2000), An analysis of product deletion scenarios. *Journal of Product Innovation Management*, 17, pp. 41-56.

Brundtland Commission (1987), *Our common future*. World Commission on Environment and Development.

Cattani, K.D. and Souza, G.C. (2003), Good buy? Delaying end-of-life purchases. *European J. of Operational Research*, 146, pp. 216-228.

Chestnutwood, M. and Levin, R. (1998), Technology assessment and management methodology – An approach to legacy system sustainment dynamics. *Proceedings Navy Logistics Conference*.

Das, D., Gupta, S.K. and Nau, D. (1996), Generating redesign suggestions to reduce setup cost: A step towards automated redesign. *Computer Aided Design*, 28, pp. 763-782.

Henke, A.L. and Lai, S. (1997), Automated parts obsolescence prediction. in *Proceedings of the DMSMS Conference*.

Howard, M.A. (2002), Component obsolescence – It's not just for electronics anymore. in *Proc. FAA/DoD/NASA Aging Aircraft Conference*.

Irani, R.K., Kim, B.H. and Dixon, J.R. (1989), Integrating CAE, features, and iterative redesign to automate the design of injection molds in *Proc. of the ASME International Computers in Engineering Conference*.

Josias, C., Terpenny, J.P. and McLean K.J. (2004), Component obsolescence risk assessment. in *Proceedings of the 2004 Industrial Engineering Research Conference (IERC).*

Lin, F. (1993), Re-engineering option analysis for managing software rejuvenation. *Information and Software Technology*, 35, pp. 462-467.

McDermott, J., Shearer, J. and Tomczykowski, W. (1999), Resolution cost factors for diminishing manufacturing sources and material shortages. ARINC. Retrieved February 21, 2006, http://smaplab.ri.uah.edu/dmsms98/papers/trunnell.pdf. Supplemental Report, Resolution cost factors for diminishing manufacturing sources and material shortages. ARINC, 2001.

Meixell, M. and Wu, S.D. (2001), Scenario analysis of demand in a technology market using leading indicators. *IEEE Transactions on Semiconductor Manufacturing*, 14, pp 65-78.

Meyer, B.C. (1993), Market obsolescence and strategic replacement models. *The Engineering Economist*, 38 pp. 209-221.

Nair, S. K. and Hopp, W. J. (1992), A model for equipment replacement due to technology obsolescence. *European Journal of Operations Research*, 63, pp. 207-221.

Perry, W. (1994), U.S. Secretary of Defense.

Pierskalla, W. and Voelker, J. (1976), A survey of maintenance models: The control and surveillance of deteriorating systems. *Naval Research Logistics*, 23, pp. 353-388.

Porter, G.Z. (1998), An economic method for evaluating electronic component obsolescence solutions. Boeing Company White Paper.

Price Systems (2006), LLC, Retrieved February 21, 2006, www.pricesystems.com.

Rajagopalan, S., Singh, M.R. and Morton, T.E. (1998), Capacity expansion and replacement in growing markets with uncertain technology breakthroughs. *Management Science*, 44, pp. 12-30.

Robbins, R.M. (2003), Proactive component obsolescence management. *A-B Journal*, 10, pp. 49-54.

Sandborn, P. (2004), Beyond reactive thinking – We should be developing pro-active approaches to obsolescence management too! *DMSMS Center of Excellence Newsletter*, 2, Issue 3, pp. 4 and 9.

Sandborn, P., Herald, T., Houston, J. and Singh, P. (2003), Optimum technology insertion into systems based on the assessment of viability. *IEEE Trans. on Components and Packaging Technologies*, 26, pp. 734-738.

Sandborn, P., Mauro, F. and Knox, R. (2005), A data mining based approach to electronic part obsolescence forecasting. in *Proceedings of the DMSMS Conference*.

Solomon, R., Sandborn, P. and Pecht, M. (2000), Electronic part life cycle concepts and obsolescence forecasting. *IEEE Trans. on Components and Packaging Technologies*, 23, pp. 707-713.

Stogdill, C.R. (1999), Dealing with obsolete parts. *IEEE Design & Test of Computers*, 16, pp. 17-25.

Tepp, B. (1999), Managing the risk of parts obsolescence. *COTS Journal*, September/October, p. 69.

Texas Instruments (2003), Obsolescence policy gains period of grace. *ElectronicsTalk*, 19 August. Retrieved February 21, 2006, from http://www.electronicstalk.com/news/tex/tex489.html.

Tilton, J.R. (2006), Obsolescence management information system (OMIS). Retrieved February 21, 2006, http://www.jdmag.wpafb.af.mil/elect%20obsol%20mgt.pdf, NSWC Keyport.

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