ABSTRACT

Title of Document: **INTEGRATION OF TECHNOLOGY ROADMAPPING INFORMATION INTO DMSMS-DRIVEN DESIGN REFRESH PLANNING OF THE V-22 ADVANCED MISSION COMPUTER**

Jessica L. Myers, Master of Science in Mechanical Engineering, 2007

Directed By: Associate Professor, Peter Sandborn, Mechanical Engineering

As the pace of technological progress increases, technology obsolescence problems will have a greater effect on traditionally sustainment-dominated industries. Many organizations rely solely on reactive approaches to manage obsolescence events as they occur, often employing lifetime buys, aftermarket sources and other mitigation approaches to ensure that they have enough parts to last through the system's lifecycle. Strategically planned design refreshes coupled with various mitigation approaches can, in many cases, lead to greater cost avoidance than reactive mitigation alone.

Design refresh planning is performed by organizations that wish to avoid the high costs of purely reactive obsolescence solutions. Planning to phase-out specific parts at certain times lessens the reliance on reactive solutions (and the resulting quest

for obsolete parts) and, in turn, lessens the total cost of sustaining a system. However, design refreshing solely to manage obsolescence is not practical for many systems, and therefore, obsolescence management refresh activities need to be coordinated with the technology insertion roadmap. Technology insertion roadmaps are developed to dictate how the system's functionality and performance must be changed over time. Technology roadmaps reflect an organization's internal technology goals and budget cycles, and give insight into the organization's inherent modus operandi.

The MOCA (Mitigation of Obsolescence Cost Analysis) software tool has been designed to generate and select an optimum design refresh plan for a system. This thesis describes an extension to MOCA that allows information from technology roadmaps to be used as constraints in MOCA. The integration of technology roadmap information into MOCA's decision analysis ensures that selected refresh plans meet roadmap imposed timing constraints, and that the costs of roadmap specified actions are included within relevant refreshes.

These new developments in MOCA are discussed in the context of the V-22 Advanced Mission Computer (AMC) system. The mechanics of the MOCA tool's optimization analysis with roadmapping considerations are described and the cost avoidance resulting from the optimum refresh plan is articulated in business case terms.

INTEGRATION OF TECHNOLOGY ROADMAPPING INFORMATION INTO DMSMS-DRIVEN DESIGN REFRESH PLANNING OF THE V-22 ADVANCED MISSION COMPUTER

By

Jessica Lynn Myers

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Advisory Committee:
Associate Professor Peter Sandborn, Chair
Professor Donald Barker
Associate Professor Linda Schmidt

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1.1 Electronic Part Obsolescence

1.1.1 The Electronic Part Obsolescence Problem

Electronic part obsolescence is driven primarily by fast paced, consumer based markets that crave new technology and products at shorter and shorter intervals. Consumers often want a faster computer or better graphics for their video game console before the useful life of their existing system is over. This need for newer and better technology drives electronics companies to constantly upgrade their product lines and introduce new technology into the market. The quick turnover from one product to another and the subsequent discontinuing of older products results in many older parts becoming obsolete rather quickly. Manufacturing resources are dedicated to the new products, and the demand for the old product quickly disappears in consumer markets. This quick turnover is becoming an increasingly large problem for sustainment-dominated industries, whose products are built to last much longer than the average two to three years products in the consumer industry are built for. These sustainment-dominated products include airplanes, ships, communication networks, and other big-ticket, long term (20-30 year) investments. The sustainment-dominated product industry has no control over the procurement lifecycle of the electronic parts they buy, since the procurement lifecycle of the parts is driven by the much more lucrative consumer market. Thus when the electronic parts go obsolete, the sustainment-dominated product company is faced with the problem of how to support their product without the original parts. While the obsolescence problem has traditionally been associated with long term products, it has recently begun to affect shorter term industries too, since new technology is being introduced at a faster and faster pace.

<u>*Traditional Obsolescence Management Approaches*</u>

Traditionally, sustainment driven organizations have dealt with the obsolescence problem one part at a time; That is, when a part becomes obsolete, there is a sudden scramble to determine how to deal with the obsolescence event. Organizations that do not plan for the future are forced to react to obsolescence events as they occur, and are left to solve each obsolescence case individually. In most cases, organizations will choose to stock up on parts that are about to become obsolete by buying enough parts to last until the end of the product's lifecycle. This option is referred to as a lifetime buy, and it carries with it the associated cost of money and the cost of storing and handling the parts until they are used either in new products, or as spares [6]. Another cost associated with lifetime buying the parts necessary to continue a product line for years into the future is the cost associated with incorrect estimates of the number of parts that will be needed. If too many parts are ordered in a lifetime buy, the excess parts, even if they can be sold off at the end of the product's lifecycle, represent money that could have been used for something else in the meantime. Similarly, if too few parts are bought, additional parts, if they can be found at all, will need to be procured at some point in time at a higher price. Additionally, there is always a chance that stored parts may be pilfered for use on other products, or that parts may deteriorate while they sit on the shelf. In a large system with many obsolete parts, the cost of buying, storing, and protecting these parts can compound over time, leaving many organizations looking for other solutions to the obsolescence problem.

Another solution organizations implement to reduce the impact of obsolete parts is a combination of design refreshes and bridge buys. Design refreshes are undertaken to remove obsolete or about-to-be obsolete parts from a design. These parts are designed out of a product at a specific point in time (the design refresh point), when it makes economic and technological sense to redesign the product. That is, the new technology must be ready for integration, and the price must be right to replace older parts with newer ones. These new parts are often better than their obsolete counterparts, in that they are often faster, smaller, and/or more durable. Costs associated with design refreshes include the cost to re-qualify the new design and the costs of performing the redesign itself, along with the costs coupled with the associated bridge buys. Because design refreshes involve redesigning multiple obsolete or about-to-be obsolete parts, they are usually scheduled after some of the parts have become obsolete. The organization then needs to buy enough of these obsolete parts to last until the product can be redesigned. Thus bridge buys are stores of parts bought to ‘bridge’ the time between part obsolescence and design refresh. These bridge buys also have an associated cost of money, storage and handling cost for the duration of the bridge buy.

Finally, organizations also have the option of a performing a complete product redesign. In this case the company would start from square one to redesign the product, as if for the first time. This is usually not an inexpensive or time effective approach to obsolescence, and organizations will avoid total redesign in favor of any other viable option.

Just as completely redesigning a product is extravagantly expensive, choosing to make too many lifetime buys or choosing to refresh a product's design too many times can also become a monetary burden. The costs associated with design refresh can stack up quickly if every part that goes obsolete is refreshed and causes the product to need to be re-qualified. The same can be true for lifetime buying parts. If every part that becomes obsolete is bought and stored, much of the company's money will be tied to parts that are sitting in warehouses, where it does little good. The bottom line is that until the problem of part obsolescence can be solved at a higher level, companies must strike a balance between design refresh and lifetime buying parts. This balance is a way of managing sustainment costs before they grow out of control, and developing a plan for dealing with part obsolescence before it occurs is the best way to manage these costs.

Stogdill has identified a fourth obsolescence mitigation option: part substitution. In this case organizations look for parts that are similar in terms of function, but may vary in their shape and performance. Organizations are often forced to replace obsolete parts with modern components that have been redesigned to fit into the same package as the old component. The newer components often carry with them a greater functionality and a greater cost because of this [28]. Other ways of finding substitute parts include aftermarket sources, organizations that stock obsolete parts and sell them at marked up prices, emulated parts, where new technologies are used to mimic obsolete ones, and using reclaimed parts. All of these options carry hefty penalty costs with them, and organizations often only rely on them when they are forced to.

Many of the above obsolescence solution options are only considered after a part or component has become obsolete. In this way the usual solutions to obsolescence problems are purely reactive, since organizations respond to obsolescence events only after they have taken place. However, many organizations have begun to strategically plan for obsolescence events through the creation of technology roadmaps, which delineate a plan for the development of new technology and its insertion into older products. Managing obsolescence in such a manner allows an organization to avoid the high costs associated with a more reactive obsolescence strategy, and developing a plan to manage the trade offs between design refresh and lifetime buy strategies can alleviate the increasingly high costs associated with part obsolescence.

1.1.2 The MOCA Methodology [27]

A tool has been previously developed to aid organizations in creating a plan for managing part obsolescence before it occurs. The Mitigation of Obsolescence Cost Analysis (MOCA) tool has been designed to output a plan consisting of design refreshes, lifetime buys, and bridge buys where the total sustainment cost of the plan has been minimized. MOCA takes as its input the bill of materials (BOM) for a given product, along with the procurement cost and projected obsolescence date of the individual parts. MOCA can model multiple levels of hierarchy for the bill of materials, so that an entire system made up of different circuit boards with different parts may be loaded into the tool.

MOCA also requires a production schedule as an input, and this production plan along with a forecast of required spares is used to locate all possible refresh dates for the system. MOCA creates a timeline of all possible design refresh dates and couples it with a timeline of all of the projected obsolescence dates for the parts contained in the bill of materials. It is assumed that if a part is obsolete at the time of a refresh that it will be refreshed, and a 'look-ahead-time' can be applied at refresh dates so that parts that are about to go obsolete can also be refreshed. MOCA generates candidate refresh plans consisting of zero refresh dates (an all reactive mitigation strategy), exactly one refresh date in the lifetime of the product, exactly two refresh dates, etc.

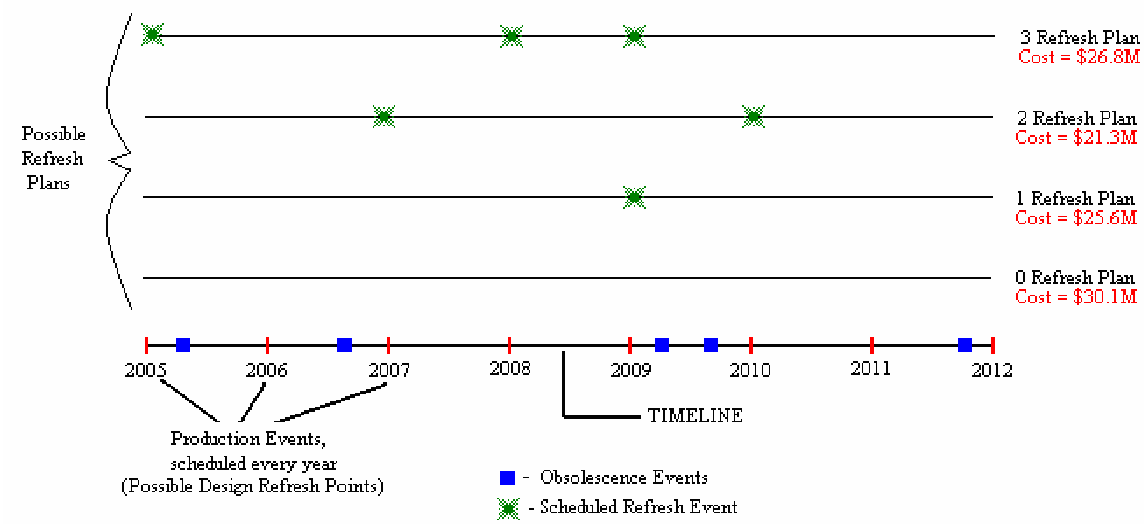


Figure 1 – A Simplified Timeline Used by MOCA to Generate Possible Refresh Events

Every possible candidate plan is generated and ranked according to the total cost of the plan. By selecting the lowest lifecycle cost plan (i.e., greatest sustainment cost avoidance), MOCA is able to optimize a system's design refresh plan with respect to cost. Figure 1 presents a basic timeline complete with scheduled production events (red marks shown at every year) and obsolescence events (intermittent blue squares). These timeline events are used to generate the possible refresh plans (design refresh events are marked by green stars) that can contain anywhere from zero design refreshes to six or more refreshes.

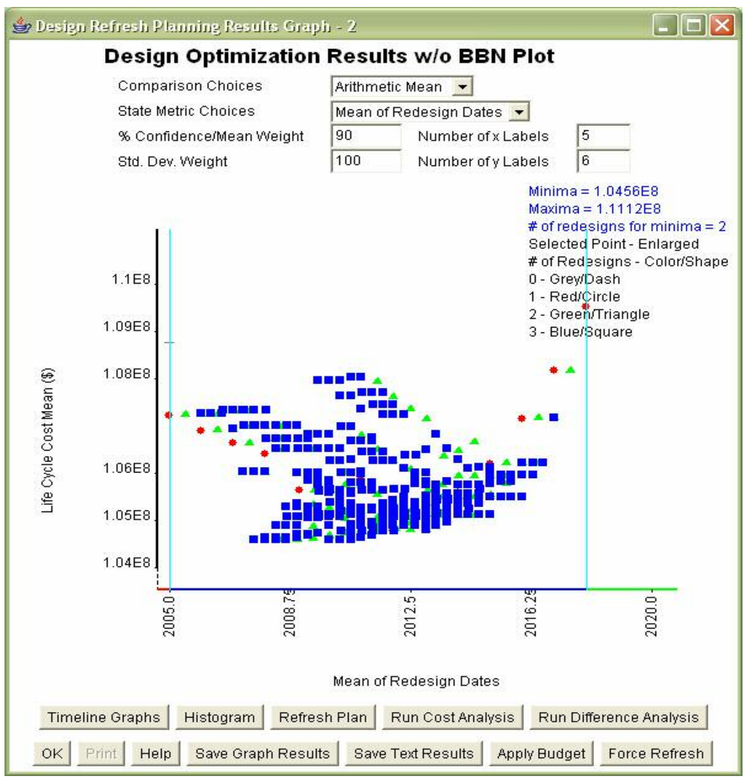


Figure 2 – An Actual MOCA Output

Figure 2 shows a sample MOCA output, where each point on the graph represents a unique refresh plan. Refresh plans can contain anywhere from zero to six actual refresh dates (the result in Figure 2 contains plans with exactly one, two, or three refreshes in them). At these refresh dates MOCA generates a list of parts that are obsolete or about to go obsolete so that they can be refreshed. Parts that become obsolete before the designated refresh date are managed using a user defined "short term" mitigation scenario (e.g., a bridge buy) until they can be replaced. The cost of the bridge buy, along with the storage and handling costs and the costs of the design refresh itself are all included in MOCA's total lifecycle cost calculation for each refresh plan. Once the plans have been generated and their costs estimated they are represented on plots like the one shown in Figure 2. The vertical axis on the graph is lifecycle cost and the horizontal axis is time. The data points corresponding to plans with multiple refreshes are plotted at the mean of the refresh dates they represent. In Figure 2, the optimum plan would be the lowest data point in the vertical direction. This data point has the lowest total lifecycle cost and represents the greatest cost avoidance combination of design refreshes and bridge buys.

MOCA's view of the obsolescence problem focuses primarily on the obsolescence dates associated with the parts contained in the product's bill of material. The projected obsolescence dates are determined by prediction algorithms associated with impending technology that is independent of the organization or product. Because this view focuses on trends and forecasts associated only with the technology, it generally ignores the internal technological goals and milestones of the specific organization. Organizations almost always have an internal set of plans for themselves and their products, and this set of plans is not currently reflected in MOCA's refresh planning solution.

1.2 Technology Roadmaps

One recent development in industry is the advent of technology roadmapping. Many organizations have been forced to focus more on technology as the driver behind their product lines and business goals. This is different from the focus on customer wants and needs and the competitive demands that have previously determined the path of an industry. Technology roadmaps are seen as a way to combine customer needs, future technologies, and market demands in a way that is specific to the organization, and they map out a specific plan for technologies and the products and product lines they will affect.

1.2.1 Definition of a Technology Roadmap

Technology roadmapping is a step in the strategic planning process that allows organizations to systematically compare the many paths toward a given goal or result while aiding in selecting the best path to that goal. Roadmapping itself is an actual process that results in a final, multi-layered, graphical document (a roadmap) [19], which must include an axis for the time dimension [13] or otherwise show how time affects the nodes and links that make up the milestones and paths found on the roadmap.

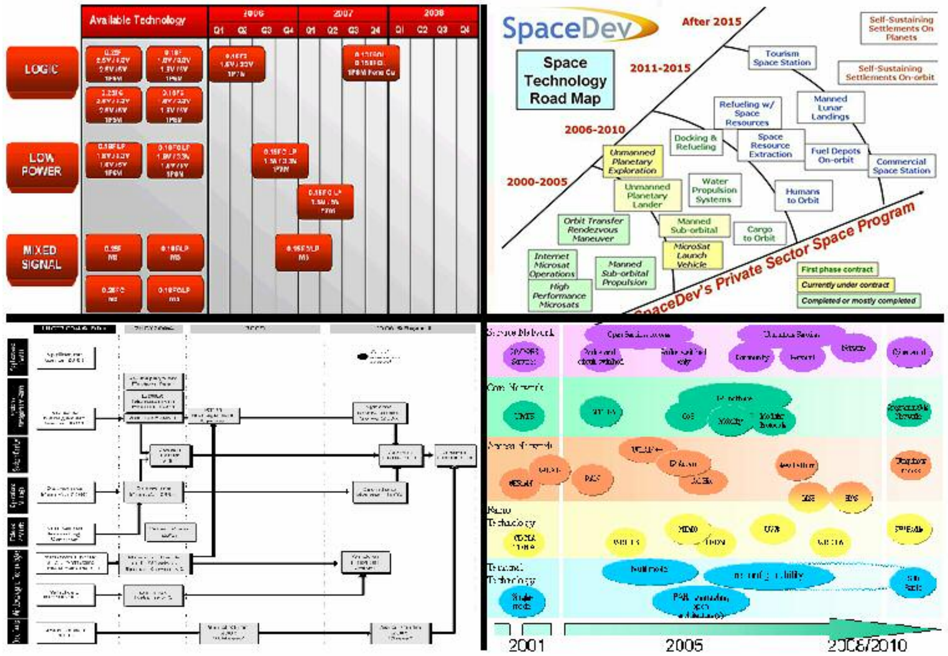


Figure 3 – A Variety of Different Roadmaps
[www.directionsonmicrosoft.com]
[http://msnbcmedia.msn.com]
[www.1si.com]
[www.eurescom.de]

Although there are many types of technology and product roadmaps, as shown in Figure 3, most roadmaps seek to show how science, technology, and business markets interact with each other [15], and how they affect the development of a product, product line, product component, or some other given product or process aspect over time. The nodes and links depicted in the roadmap contain quantitative and qualitative information [15] regarding how science, technology, and business will come together to solve problems and reach the organization's end goal, whatever that may be. The goal of a roadmap is often updating a product or product line, or creating a new product entirely. The time domain factors into the roadmap because it takes time for new technologies to be discovered and incorporated into a product, for markets shares to grow to encompass new products, or for new possibilities to arise. In essence, technology roadmaps are simple graphical representations of the complex process of "identifying, selecting, and developing technology alternatives to satisfy a set of product needs" [30]. Thus organizations often place more emphasis on the process of roadmapping than on the document itself, since it is during the formation of the roadmap that all subjective decisions are made and all consensuses are reached. It is important to note that, like their real world counterparts, technology roadmaps are not just needs driven documents (as in, "I need to get somewhere, what direction do I go?") but can also be based on current position (as in, "Where could we go from here?"). It should also be stressed that roadmapping is an iterative process and that roadmaps must be continually maintained and kept up to date [24]. This is because the information contained in the roadmaps will change as time passes and new paths emerge or old paths disappear, but also because an iterative roadmapping process will lead to a mature roadmap with clear requirements and fewer unknowns [21]. An iterative roadmapping process also leads to better understanding and standardization of the process, allowing roadmaps to be created more quickly, and the information in them to be more valuable. The reasons and affects of updating and iterating a technology roadmap are summarized below in Figure 4.

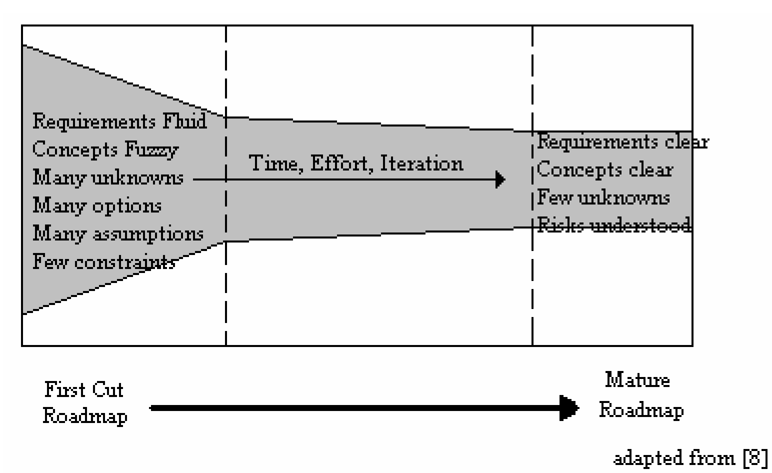


Figure 4 – The Results of an Iterative Roadmapping Process

Regardless of the type of roadmap and the information it contains, all roadmaps seek to answer three basic questions: 1) Where are we going, 2) Where are we now? and 3) How can we get there [21]? The process of creating a roadmap should answer these questions by listing and evaluating the possible paths to an end goal, and result in the selection of a single path to focus funding and resources on. Despite selecting a 'final path', organizations should remain open minded and keep alternative paths open in case a poor decision has been made. This is yet another reason to continually update the roadmap, since it serves as a mechanism to correct previous bad decisions.

1.2.2 Scope and Reasons for Roadmapping

There are many different types of roadmaps that focus on the many ways to reach different goals. This is due in part to the fact that many different types of organizations have attempted the roadmapping process. In fact, it has been suggested that approximately 10% of large companies have used technology roadmapping at least once [20]. Roadmaps describe many different types of systems, but the most common type of roadmap shows a simple product line. Product Line technology roadmaps deal with the innovations and changes needed to sustain a product line and keep it fresh for customers (e.g., a line of cell phones). Alternatively, roadmaps can be created at the company or organizational level (where they describe a product, or a part of a product), sector level, or they can even be industry wide (as in the Semiconductor Industry of America, which has created a roadmap for the entire semiconductor industry [12]), or they can be 'issue-oriented' (where the roadmaps identify budgeting and planning issues and their consequences). Some more experimental roadmaps involve mapping emerging technology, disruptive technology, etc. An emerging technology roadmap follows a single new technology and compares it to a single existing technology [30], while a disruptive technology roadmap follows many new technologies and compares them to many currently implemented technologies, since any number of these many technologies may be combined to disrupt the market. Roadmapping has become so popular recently, that the term has even been used to describe processes unrelated to technology or business, such as President Bush's roadmap for peace in the Middle East [21]. Because so many different types of organizations create so many different types of roadmaps, no set, standardized form of roadmap exists, making it difficult for an organization to implement a roadmap for the first time.

Some organizations have attempted to create a general structure for their roadmaps, especially when several different internal divisions of the same organization are each implementing roadmaps in their own way. A standardized roadmap form in this case will make it easier for the different divisions to read and interpret each other's roadmaps, and it will allow the roadmaps to be linked together without being modified or changed. Linking roadmaps together is an important way of transmitting information throughout an organization, and it allows everyone to see the 'big picture'. Linking roadmaps is especially important in the avionics industry, where a change on one platform's roadmap could affect other roadmaps, or they could all be experiencing the same change without even knowing it. Sometimes linking roadmaps together will not make common changes easier to stomach, since money for parts and changes is coming from different places [12]. Motorola, one of the first companies to implement technology roadmaps into their strategic planning, has standardized their roadmaps to contain eight sections. The first section is a general description of business, which includes Motorola's business mission, strategies, market share, sales history and forecast, and applicable product lifecycle curves. The sections that follow consist of a Product Plan (with milestones), a Technology Forecast, the Technology Roadmap Matrix (which is a graphical summary of the Product Plans and Technology Forecast), a list of Quality Goals, the Allocation of Resources, a Patent Portfolio (which contains a list of internal patent committee disclosures as well as a list of competitors' disclosures), the Product Descriptions, Status Reports, and Summary Charts, and finally, a Minority Report, which prevents important information from slipping away [31]. While this is a list specific to Motorola, it covers almost all of the information one is likely to find in a Product Technology Roadmap. Other information that can be contained in a roadmap includes theories and trends, models, and the identification of knowledge voids, areas of 'white space' that have yet to be developed [7].

1.2.3 The Timeframe of Roadmaps

Roadmaps also differ in the timeframe that they cover. Obviously the number of years shown in a roadmap depends on what the subject of the roadmap is. Products with relatively short lifecycles, like cell phones and desktop computers, should have roadmaps that go no more than three or four years into the future. Not only is there no need for the roadmaps to show any more of the future, but much of the information available on the technologies existing more than three years into the future is too nebulous to be useful. Products with longer lifecycles or roadmaps involving products lines often contain a longer timeframe than those with short lifecycles. These roadmaps could stretch as far as ten years into the future [10]. As a general rule, roadmaps should go far enough into the future so that the end results of any actions taken can be seen [13]. For example, if a new type of cell phone is being developed, the roadmap should include enough of the future to see the revenue realized from the sale of the cell phone. Additionally, the frequency with which roadmaps are updated also varies with the type of roadmap. Some roadmaps must be updated as frequently as every six months, while others, like the Semiconductor Industry of America Roadmap are only updated every two years [8]. The frequency of roadmap updates should depend both on the speed of the given industry's growth and on the cost of updating the roadmap. A balance should be struck between having an up-to-date roadmap and the amount of money spent on keeping it current. Technology roadmaps are meant to make money, save money, or result in cost avoidance for the organization, not to become a sinkhole for funds.

1.2.4 Motivation for Roadmapping

There are as many different reasons for an organization to create a technology roadmap as there are different types of roadmaps. The process of roadmapping has recently become popular because it results in a simple, easy to understand, graphical depiction of complex ideas and trends. Additionally, the realization that technology is a major driver in both economic growth and strategic planning may be the reason behind the greater organizational focus on technology and technology roadmapping [30]. These drivers may have made technology roadmapping into a bit of fad, leading some managers to roadmap simply because everyone else is doing it. Roadmaps undertaken for these reasons are usually not effective, since there is no real 'buy-in' from the roadmappers, and since it may be difficult for roadmappers to ascertain the reason for the roadmapping exercise [13].

Many reasons exist for instituting technology roadmapping in an organization other than a mandate from the boss alone. Most roadmaps are used to help align technology and research and development goals with the business goals and market priorities of an organization. Because roadmaps can be expanded to include both technology milestones and business goals, it is not hard to imagine a roadmap where a technological development maps directly to a gain in market share. In this way, organizations can ensure that their research and development funding will result in a tangible business related gain. Organizations may also use roadmaps to coordinate their many departments and ensure that the departments' objectives are aligned with the objectives of the organization [24]. This can help prevent research and development overlap, by preventing two different departments from researching the same thing and wasting company money. Roadmapping can also be seen as simply an organizational tool, since the process of creating a roadmap forces organizations to consider their basic structure, how research is funded, and how that research drives profits. Another reason that roadmapping has caught on in the business world is that it forces a consensus view on the companies who use it. Technology roadmaps show a very clear goal that the entire company is trying to attain.

1.2.5 Who Contributes to Roadmaps

Organizations often have all or most of their employees contribute to the technology roadmaps, including both technical and non-technical employees, so that all aspects of the business can be included, and so that all employees can buy into the roadmap plan. Often times, engineering, technical experts, management, marketing, and business consultants are all included in the roadmapping process. Having a diverse roadmapping team allows different perspectives on the industry to have their say and gives a well rounded snapshot of the state of business at the given moment in time. This ensures that consensuses are reached and decisions are made [15] in a well informed state and in a way that pleases the majority of people. Roadmapping can also be undertaken as a way to clarify the costs, benefits, and risks associated with a specific product, product line, or technology [15], since having many different types of employees present will allow these things to be evaluated at all stages of their development, from the birth of the technology to the end of its market run. Sometimes roadmaps are undertaken simply because of some external stimulus, i.e., the competition uses roadmaps [13]. This may be a poor reason to begin the roadmapping process in and of itself, but it would be worthwhile to consider why the competition uses roadmaps and what could be obtained by implementing them.

The technology roadmapping process may be undertaken for many reasons, but it is usually done as a way to organize a 'plan of attack' to get the company to a certain goal or state in the industry. Roadmaps "encourage business managers to give proper attention to their technological future, as well as provide them a vehicle with which to organize their forecasting process [31].” Similarly to most fads, interest in roadmapping and technology is cyclical [16]. Even though it is the ‘hot’ thing to do in the corporate world right now, it is still a valuable practice. Assuming that a roadmap has been started at the appropriate time, and that roadmapping is a valued and important activity for those working on it, the roadmap will help align strategic goals and set a path toward product enhancement and development. Regardless of the reason why the roadmap was undertaken, it will be successful as long as roadmapping was appropriate for the situation and as long as the roadmapping team and upper level management are devoted to developing the best roadmap they are capable of creating.

1.2.6 Roadmaps Summarized

Since there is no standard format for roadmaps, they come in many shapes, styles, and sizes. Besides having an axis devoted to time, there are not many other aspects that roadmaps have in common physically. Most roadmaps will have a graphical element that shows multiple layers of bars, tables, graphs, pictures, flow charts, or text [19]. Roadmaps are multi-layered so that each layer can show a different aspect of development. The top layer usually shows the business and marketing goals of the organization, while the middle layer shows the products, services and operations that drive the business and market goals. The bottom-most layer shows the resources, including technology, that make new products possible [21]. In this way all aspects of product and technology development are shown. The simple graphical document allows compression of extensive and complex info, makes it easy to understand, and allows users to check that the data is consistent.

1.3 Thesis Plan

The graphical document that results from the roadmapping process can be seen as a summary of how an organization expects technology to influence and help it achieve its goals. Obviously this plan for technological development should be reflected in (or at least consistent with) the plan that the MOCA methodology generates for technology refreshes for a specific product. It makes no sense to generate a plan with MOCA that is at odds with the organization's goals or does not fit with an organization's budgeting cycles. For these reasons, a link needs to be created between the roadmap process and MOCA that will allow details of the roadmap to influence the solution that MOCA generates.

In order to design and implement a link to MOCA, the types and uses of technology roadmaps must first be determined. Further clarification of the uses of roadmaps will determine the information contained in roadmaps that is of value to MOCA. This will result in the definition of a 'good' roadmap, and will allow the many types of roadmaps to be classified into groups. In addition to classifying roadmaps into types, it will also be necessary to ascertain the types of information found in a roadmap that need to be inputted into MOCA, and the level of detail this type of information exists at. This information could include budget constraints, pre-defined design refresh periods, specific technology goals, design refresh black-out periods, etc…

A mechanism needs to be provided in MOCA to allow roadmap-derived information to be inputted and to affect the generated solution. A model is created that describes the types of information found in technology roadmaps that may be valuable to the MOCA analysis. This model must accomodate a broad variety of information, since roadmaps exist in many different forms and contain different types of information. The model must then be incorporated into MOCA's decision analysis process, with the end effect being that MOCA will only consider possible refresh plans that fit with the constraints defined by the roadmaps as described by the model.

Once this new architecture for MOCA has been designed and developed, it needs to be tested and refined. A test case (the V-22 Advanced Mission Computer) that includes a bill of materials as well as a roadmap for the product is used. The end goal of this work is to incorporate the specific time and cost information found in a roadmap into the MOCA tool. This will allow MOCA to generate a design refresh plan that is optimized while also being relevant to the organization's goals.

The primary goal of technology roadmapping is to create a plan for the future of an organization that is acceptable to everyone in that organization. This consensus view ensures that everyone is working towards the same things, and is a way to reduce budgets by preventing overlap amongst departments. Linking roadmap information into MOCA ensures that the final obsolescence solution that MOCA proposes is consistent with the plans delineated in an organizations technology roadmap. This allows for the selection and adoption of the most cost effective and most feasible obsolescence management strategy.

Chapter 2: Technology Roadmaps

In order to incorporate information from technology roadmaps into the MOCA analysis, the many types of technology roadmaps must be classified. Roadmaps exist at a variety of levels and can cover both short term and long term lifecycles. Because of this, not all roadmaps are suitable for inclusion in an obsolescence mitigation analysis. Additionally, the types of information found in roadmaps must be translated into constraints that can be fed into the MOCA tool. This chapter discusses technology monitoring and forecasting methods and then classifies the documents that are considered to be technology roadmaps.

2.1 Technology Prediction Strategies

Technology roadmapping is a process that results in a strategic plan to remove obsolete electronic parts from a given product and to allow for the inclusion of new technologies in that product. However, the term 'technology roadmapping' refers more generally to the creation of the roadmap document, and not to the surveillance, monitoring, and development of technology, which are also steps in the planning process. Although these processes are separate from roadmapping, the development of the roadmap, and the direction the organization will take, are highly dependent on them. The information found through technology surveillance and monitoring greatly influences the final content and format of the roadmap.

2.1.1 Technology Monitoring and Forecasting

The attempt to predict the future of technology and to characterize its affects has been undertaken by many different organizations, which use many different terms to describe their forward looking actions. These terms can include 'technological intelligence', 'technology foresight', 'technology opportunities analysis (TOA)' [23], 'competitive technological intelligence', and 'technology assessment' [4]. These terms fall under two, more general umbrella terms: 'technology monitoring' and 'technology forecasting'. To 'monitor' is 'to watch, observe, check and keep up with developments, usually in a well-defined area of interest for a very specific purpose [22].' Technology monitoring is the process of observing new technology developments and following up on the developments that are relevant to an organization's goals and objectives. Technology forecasting, like technology monitoring, takes stock of current technological developments, but takes the observation of technology a step further by projecting the future of these technologies and by developing plans for utilizing and accommodating them.

For high-volume consumer oriented products, there are many reasons for organizations to monitor and forecast technological advances. First, when the organization's products are technologically-based, a good understanding of a nascent technology is needed as early as possible in order to take advantage of it. Additionally, monitoring and forecasting technology allows organizations to find applications for new technology [4], manage the technologies that are seen as threats, "prioritize research and development, plan new product development, and make strategic decisions [33]. For manufacturers of sustainment-dominated products, monitoring and forecasting technology advances is of interest for the same reasons stated in the previous paragraph and also to enable prediction of obsolescence of the currently used technologies.

The primary method for locating and evaluating materials relevant to technology monitoring is a combination of text mining and bibliometric analysis. These methods monitor the amount of activity in databases on certain specified topics and categorize the information found into useful, graphical groupings. Because of the amount of literature available on a given technology, much of the text mining process has been automated and computerized. Software is used to monitor databases full of projects, research opportunities, publications, abstracts, citations, patents, and patent disclosures [33]. The general methodology for the automated text mining process is summarized in Figure 5.

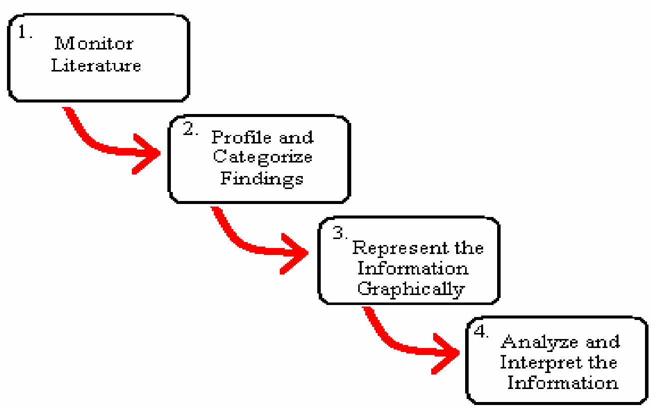


Figure 5 – Steps in the Data Mining Process

The monitoring process involves identifying relevant literature by searching text that has been converted into numerical data [29]. Often there are previously defined search criteria and search bins where results can be placed. After legitimate literature has been found it must be clustered [32] with similar findings and categorized into trends. The data is categorized by decision trees, decision rules, k-nearest neighbors, Bayesian approaches, neural networks, and regression and vector-based models [29]. This categorization allows hidden relationships and links between data sets to be determined, and locates gaps in the data [32]. Once the data has been grouped, it is organized graphically in a scatter-plot like form. Each point on the scatter plot can represent either a publication or an author. These points can be linked or grouped together to show the relationships and similarities between points. An example graphical map is shown in Figure 6.

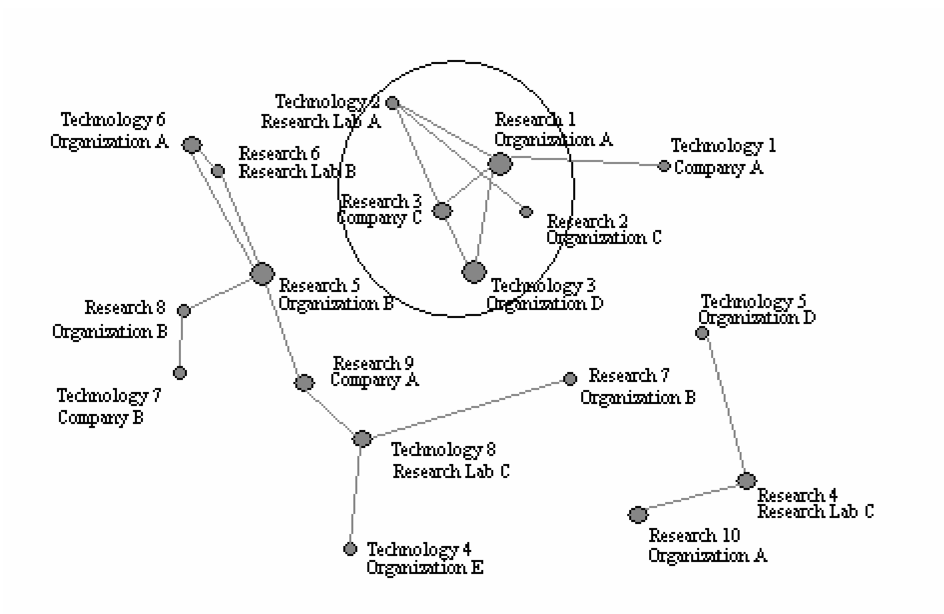


Figure 6 – Sample Technology Monitoring Output

In Figure 6, the separate research areas (i.e., Research 9 and Research 8) can overlap or represent the same basic technology concept as created by different organizations or research labs. Additionally, a single organization or company can be developing many different technologies at once. This is reflected in Figure 2, since several organizations and research labs are associated with more than one technology.

Monitoring data must then be interpreted and analyzed to determine which new technologies are viable and relevant. To do this, many organizations network with experts in related fields, and they often employ surveys and other review techniques similar to the Delphi method to force consensus among the experts. The opinion of the experts allows organizations to assess the implications of new technology, and it is the first step in planning and taking action cope with the benefits and risks associated with new technology [23].

Many technology monitoring and forecasting methods are still relatively new and untested, especially for larger databases of documents. Automated methods of forecasting and monitoring will need to be refined and improved upon before they truly perform as they are intended to. Additionally, these tools will need to operate on a larger scale and in a more diverse environment. Eventually, there may be a need for forecasts on a national, government sponsored level, where predictions could exist for entire industries [4]. Also, many organizations may also begin to seek customer and client input when monitoring and forecasting. Finally, forecasts will eventually be 'evaluated against global, political, environmental, social trends [4],' placing them in a broader context, and expanding their uses beyond singular organizations.

2.1.2 Tools for Technology Monitoring and Forecasting

Organizations often look for outside help in the form of software tools and databases when it comes to monitoring the obsolescence of current technology and the development of new technology. These tools range from technology roadmapping aides to electronic part databases with shared obsolescence information. These tools, while helpful in the roadmapping process and valuable for their obsolescence information, generally are not capable of creating proactive obsolescence management plans or otherwise aide in the minimization of obsolescence costs.

One company, Alignent, has created a computer software that allows the roadmapping process to be automated [1]. Alignent's Vision Strategist is a centralized database that supports real-time information changes in a multi-dimensional view. This software lets organizations create standardized roadmaps that can be seen and edited by everyone in the organization. Alignent strives to help their customers align resources, improve technology reuse, and see what opportunities they are missing. Alignent's automated roadmapping process may 'force' roadmaps onto sectors of the organization that are not ready for it, and their one size fits all approach may not work for all organizations. However, their attempt to standardize the roadmapping process may make roadmapping easier for organizations that have never attempted it before.

While Alignent's software tool aides in the creation of a technology roadmap, other tools and databases have been developed to help supply the information that roadmaps are based on. These types of tools are most often large databases of component level parts that list the predicted obsolescence date for a given part, and can identify alternative parts. Commercial parts databases include: Qinetiq's Q-Star, i2 Technologies' TacTrac, and MTI's AVCOM, which is used by NAVAIR [11].

While these software tools are commercially available, many times organizations simply create their own databases for part obsolescence information and track part changes on their own. This is inefficient in cases where several different organizations or programs are using the same part, since when that part becomes obsolete each organization must solve the obsolescence problem on its own. Hence the appeal of a centralized part database is that it allows organizations to share obsolescence information and solutions. While these tools are helpful to those in sustainment dominated industries, they do not provide any decision making support or cost analysis.

One example of in-house developed software is the OMIS (Obsolescence Management Information System) created by NAVSEA. This tool takes obsolescence information as well as stocking and reliability information and determines when a given product or circuit card assembly is no longer sustainable. From this, the user can run 'what if' scenarios to find resolution possibilities and their associated cost [5]. The output of the OMIS tool is a pictoral representation of the assembly or circuit card in question where problematic parts are highlighted so that the user can see their impact on the entire system. OMIS also provides a health analysis of the assembly as a whole, allowing the user to see what percentage of parts on the assembly are no longer sustainable [11]. While this tool is a convenient repository for obsolescence information, its decision process depends heavily on the user, who is given the task of creating and comparing the possible obsolescence scenarios. Similarly, Lockheed Martin and the Stevens Institute of Technology have jointly developed the Rapid Response Technology Trade Study, R2T2 tool. This tool takes various inputs, including a bill of material, sparing requirements, and maintenance and repair schedules, and determines a technology refresh frequency. That is, R2T2 determines how long an organization will wait between design refreshes and provides a plan of action at each refresh date [11]. Because R2T2 is only capable of finding a refresh frequency, instead of an optimum refresh plan, it does not truly optimize the design refresh process. Refresh strategies developed by R2T2 may either over refresh or under refresh a given system and the tool may also miss critical refresh periods, since it is only capable of deriving a refresh frequency, instead of an optimized refresh plan.

These software tools aid in the management of avionics obsolescence, but, with the exception of the R2T2 tool, they are unable to generate any type of plan for the sustainment of obsolete systems. These tools are especially inadequate when it comes to predicting the cost of a given obsolescence strategy. This makes it difficult for the organizations that use them to make a supporting business plan argument that is necessary to gain the necessary management buy-in in order to take strategic sustainment management actions. The MOCA tool is different in that it both generates all possible design refresh plans and predicts their total lifecycle cost. In this way MOCA can recommend a design refresh strategy along with its expected cost avoidance, a result that no other tool can reproduce. The inclusion of technology roadmap information into the MOCA analysis will ensure that MOCA's recommended design refresh strategy will fit with an organization's technology and budget goals, assuming that the technology roadmap accurately represents this information.

2.2 Roadmaps in More Detail

2.2.1 Issues with Technology Roadmapping

Perhaps the most salient problem with roadmaps is the fact that they do not present a methodology for sensing and utilizing disruptive technology. Roadmaps work much better for products and product lines that are sustained by steady and incremental progress [30]. Disruptive technologies are by nature difficult to roadmap, since they often need to find suitable applications once they have been discovered. In the case of disruptive technology the innovation has been created, but it has yet to find a market [30]. Historically it has been very difficult for marketshare leaders to catch disruptive technologies. For example, compare advances for portable CD players (like longer anti-skip protection periods, bass boost, and longer battery life) to the advent of digital MP3 players. Companies should have learned from history that a disruptive technology can destroy them, but they often choose to ignore unproven technologies, since their customers express little interest in them; “it is nearly impossible to build a cogent case for diverting resources from known customer needs in established markets to markets and customers that seem insignificant or do not yet exist” [3].

There are, however, ways of dealing with disruptive technology so that it does not come as a total surprise. Sometimes keeping an up-to-date, comprehensive roadmap is all that is needed to catch disruptive technologies before they become big problems. Other times, businesses create a separate functional group for creativity and forward thinking research [13]. By separating out the creative thinkers, businesses can ensure that they are not affected by the more conventional roadmaps. Some (Kostoff, Boylan, Simons), have attempted to roadmap disruptive technologies themselves. This is done through a combination of text mining, which is used to identify experts in related (although disjointed) technological areas, and then by convening these experts in a workshop to find which advances in which fields are needed for a breakthrough. This information is then roadmapped [14]. These steps may not be enough to keep disruptive technology from ruining a current product line, thereby sinking a company. Because disruptive technologies are so unpredictable, the best way of dealing with them may be by having smart managers who recognize what benefits these types of technologies can bring to the company.

Other pitfalls of the roadmapping process include using incorrect assumptions, such as using assumptions that work today and extrapolating them into the future where they may not hold true [16]. Also, because there is no standard form for technology and product roadmaps, organizations must often reinvent the process when they first start roadmapping [20]. This slows the process down and may end up costing the organization money. Finally, when roadmapping in an industry setting, organizations should be cautious of opportunistic behavior on the part of their roadmapping partners. Information can easily be mishandled in these situations, and when a competitor notices a ‘knowledge gap’ that ‘knowledge gap’ may soon disappear [18]. Knowledge ‘leakage’ may also occur in these situations, so it is best to stay on top of the information being shared [18].

Some additional challenges in the roadmapping process have been identified by Phaal, Farrukh, and Probert [19]. These challenges include getting the roadmapping process started, keeping the process alive once it has been started, and developing a robust process. All of these occur during the actual roadmapping process, and each could derail a roadmapping project before it even has a chance to get moving. Additionally, organizations should beware of distractions from other short term projects that will keep them from their roadmapping task. One final challenge is what to do when required information for completing a roadmap is not available. This information gap will make it difficult to fill in a roadmap completely.

Additionally, there are several other pitfalls associated with the process of roadmapping that could have detrimental affects on the company. First of all, roadmaps can stifle creativity [13], since they purport to include all possible paths to a solution. Research and development may be forced to stay on the roadmap, which may in turn keep them from making a crucial discovery. Roadmaps may be misleading for this same reason. Someone unfamiliar with the roadmap may assume that it holds all of the solutions [17], instead of being the guide to most solutions that it actually is. Similarly, companies will want to bank one roadmap path and stick with it, narrowing the strategies and scenarios [13] and increasing the chance of missing some crucial detail

2.2.2 Benefits of Roadmapping

The issues with technology roadmaps expressed in Section 2.2.1 should not outweigh the benefits they impart to the organizations who adopt them. Technology Roadmaps and especially the roadmapping process itself are beneficial because of the common view they impart on the organizations who utilize them. They increase communication among the many sectors of a business and create a common language across the boundaries of the engineering and marketing divisions [21] [17]. Because there is no standardized format for technology roadmaps they are a very customizable document that can be fitted to many different types of strategic planning needs. Roadmaps help combine short term goal-oriented viewpoints with long term 'visionary' views, creating a more cohesive timeline for product development, with a clear and specific end goal [13], [10]. Roadmaps also aid in finding patterns in the product lifecycle (such as generation skipping [24]), all while "improving time to market and time to money, creating a competitive edge" [10]. Roadmaps are also seen as a useful tool because they incorporate both analytical methods as well as some of the 'soft stuff' [13], which gives them a more realistic feel than models based solely on mathematics or pure intuition. Additionally, roadmaps represent the ideal mix of explorative and normative forecasting methods, since they allow their creators to express the possibilities of what could happen, while also allowing them to choose what will happen [13]. In this way roadmaps sometimes become self-fulfilling prophecies, so it is important that management set the bar high if this is the case. Roadmaps could be considered as smarter explorative forecasts, since they bring in more complex forecasting methods, or as more realistic normative methods, since they do not require as many estimated inputs as most normative estimations [25].

2.2.3 Measuring the Value of a Roadmap

Since there is no set format for roadmaps, and since roadmaps are undertaken for many different reasons, it is sometimes difficult to determine whether roadmapping is a worthwhile exercise, or whether anything was gained from the creation of the roadmap. While some roadmaps are considered 'self-fulfilling', in the sense that aggressive targets are set [8] and then chased until they are reached, other roadmaps seek only to be accurate representations of the future. These 'accurate' roadmaps do not try to change the future but merely seek to predict what the future of their industry will look like. These two types of roadmaps have two different metrics to describe their worth to their organizations: the prediction roadmaps should be valued by the accuracy their predictions, while 'self-fulfilling' roadmaps should be valued by the amount of influence they have over organizational policies. Setting an aggressive goal does no good if no one takes the goal seriously. Thus the amount of 'decision influence' determines the worth of a goal oriented roadmap [13]. These types of roadmaps should not just influence decisions, but they should also hold sway over assumptions and should hold this influence over a period of time [13].

Another important metric for determining the worth of a roadmap is the repeatability of the roadmap. Roadmaps are considered repeatable if they can be duplicated by a separate team of people at a separate time period. Achieving a repeatable roadmap is harder than it would seem, since many assumptions and decisions are made by the group during the roadmapping process. One main benefit of roadmapping is that it increases communication throughout an organization and affords teams of people who usually have no contact the chance to correspond on a regular basis. Communication increase can also be used to measure the success of a roadmap, along with the common outlook and consensus view they create. While it is hard to measure the creation of a common outlook or consensus view, roadmaps can still be considered unifiers, and the amount by which they unify a company is another way to measure their value.

It is important to remember that it is often difficult to measure the effectiveness of a roadmap. Roadmaps are meant to organize and unify organizations, and these benefits may not be reflected in the final paper document. The process of roadmapping is much more important than the roadmap itself, and as long as it results in a clear cut strategic plan it has probably been a successful venture.

Kostoff and Schaller [15] have identified some critical factors for roadmapping success. These factors include management commitment, a good roadmap manager, who makes good decisions regarding the formation of the roadmap, a competent (technically) roadmap team, and clear goals for the future. Additionally, it helps if there is a standardized roadmap form within the company, as well as standardized criteria for what can become a link or node within the roadmap document. Finally, roadmaps should be able to be duplicated reliably, should be cost affective, and all encompassing.

2.3 Classification of Roadmap Types

Several attempts have been made to try and classify the many different types and reasons for roadmapping into easier to digest categories. Most roadmaps can easily be classified as either prospective or retrospective roadmaps. Retrospective roadmaps look backward in time from the present, filling out the roadmap with successful products, and seeing where good things occurred [15]. Retrospective roadmaps allow organizations to find out how something was done correctly.

Generally, retrospective roadmaps do not look any further back in time than a decade or two [15] although, in theory, retrospective roadmaps could go as far back as the first human invention. Much more common are the prospective roadmaps, which are concerned with predicting and shaping the future. It is these types of roadmaps that will be integrated into MOCA, since MOCA is only concerned with predicted obsolescence events occurring in the present and future. Since most roadmaps are prospective in nature, retrospective roadmaps will be ignored from this point forward.

Kappel has proposed a simple, four sectioned classification system for the many types of roadmaps [13], shown in Figure 7. He suggests that there are only two real ways to classify roadmaps: the purpose of the roadmap, and the emphasis of the roadmap from a scientific point of view.

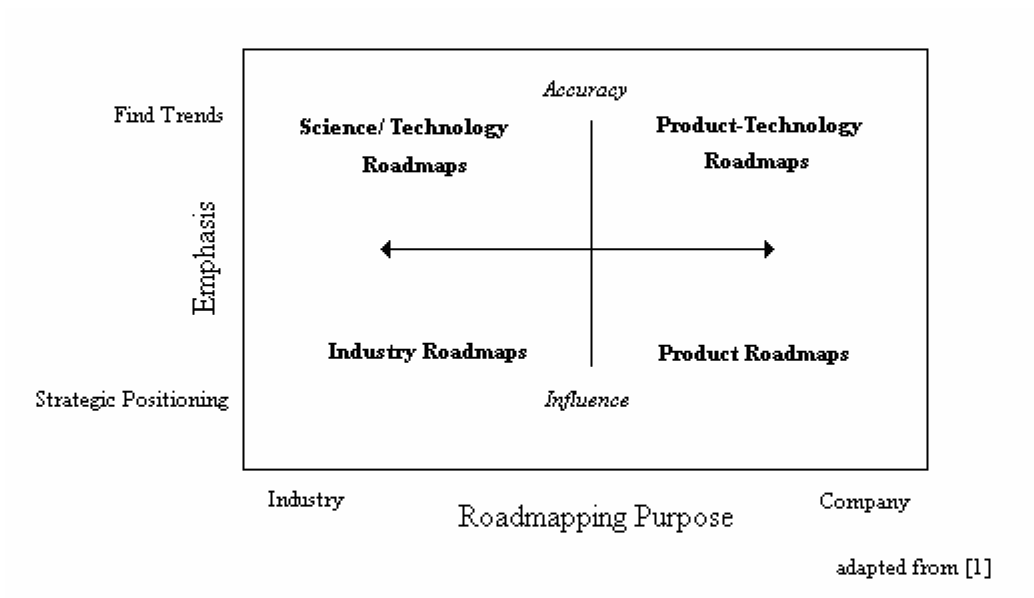


Figure 7 – Kappel's Taxonomy of Roadmaps

These two classification levels, purpose and emphasis, can be seen as axes used to classify the type of a roadmap. The purpose axis has two extremes: a roadmap can exist to describe as high a level as an entire industry, or for as low a level as a single part on a single product. The two extremes associated with the emphasis axis are prediction style roadmaps (which are concerned mainly with accuracy and finding trends) and self-fulfilling roadmaps (which seek to influence the way the future will unfold and to jockey for strategic position). These two axes can then be combined to develop a four sectioned taxonomy of roadmaps. The resulting four types of roadmaps are industry roadmaps, product roadmaps, science/technology roadmaps, and product-technology roadmaps.

Kostoff and Schaller have developed a similar two axis taxonomy for describing the many different types of roadmaps, which is shown in Figure 8 [15]. In order to create this taxonomy they collected over 150 roadmap and roadmap related documents. Like Kappel, Kostoff and Schaller have an axis dedicated to the scope of the roadmap, but they opted to show the roadmap's basic use on the other axis, instead of showing the roadmap's influence.

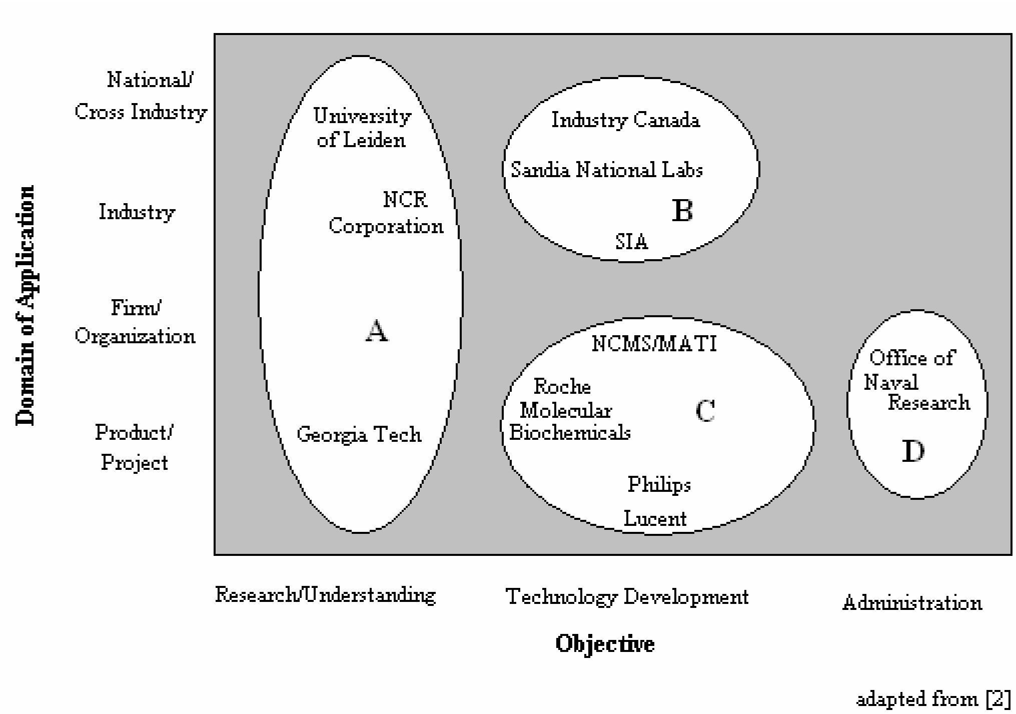


Figure 8 – Kostoff and Schaller's Classification of Roadmaps

In their review of roadmapping literature, Kostoff and Schaller identified many different types of roadmaps, including science/research roadmaps, cross industry roadmaps, industry roadmaps, technology roadmaps, product roadmaps, product-technology roadmaps, and project/issue roadmaps. Using their taxonomy, they narrowed these types of roadmaps into four main categories, which are shown in Figure 4. The four types of roadmaps are: a) S&T Roadmaps, b) Industry Technology Roadmaps, c) Corporate or Product Technology Roadmaps, and d) Product/Portfolio Management Roadmaps [15]. These categorizations match up well with the categories as defined by Kappel, and a combination of the two taxonomies can be found below.

A new taxonomy has been devised that has been derived from the previous two. It is similar to Kappel's taxonomy in layout, but has different axes, and is shown in Figure 9. The axes have been altered to show the scope and influence of the many different types of roadmaps. The horizontal axis shows the scope of the roadmap, whether it exists on the product or industry level, and the vertical axis shows whether the roadmap is more concerned with accuracy or influence. The section of the taxonomy that is circled with a dashed line includes the type of roadmaps that MOCA will be able to accept as inputs. Since MOCA deals only with specific product lines and platforms, only roadmaps that deal with advances that are relatively small in scope will be useful. While larger, industry wide changes may in fact be driving obsolescence; MOCA is only interested in how specific companies deal with these changes on specific products. MOCA is also only interested in prospective roadmaps, since information on the past is of no value to a tool that works with dates in the present and future.

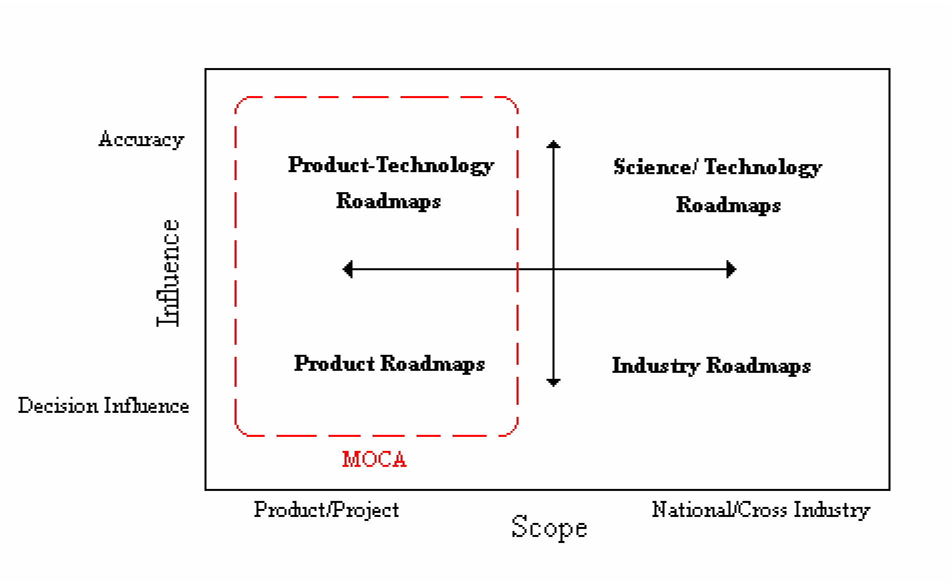


Figure 9 – A New Taxonomy of Roadmaps

Some newer, experimental roadmaps do not fit into any of the previously described roadmap taxonomies. Rinne suggests that the nodes and links included in technology roadmaps could and should be modeled as computer objects [24]. These computer models will be shared in such a way that many nodes and links can be added until all innovations, past and present would be included. Rinne sees this master roadmap as a way of developing new technologies, since new technologies could be developed by linking together other technology objects. He believes that this will lead to "innovation factories", an automated way of generating new technology virtually by forcing virtual roadmaps of objects to their logical conclusion [24].

Rinne also suggests that a third dimension could be added to technology roadmaps, making them technology landscapes. A z-axis would be added to conventional roadmaps, and the height of a node would be analogous to cost. Additionally, search areas around nodes could be modeled to show how far a company is capable of going and how much they are willing to spend [24].

2.4 Linking Roadmaps to the MOCA Methodology

Roadmaps show how technology will force a product or product line to evolve and develop over time, and it is this technology-product evolution relationship that will allow MOCA to generate a more accurate picture of the product lifecycle. The timeline aspect of a technology roadmap can be directly modeled in MOCA since MOCA is a discrete event simulator, although not all types of timeline events can be accepted. Petrick and Echols suggest that there are only three main types of innovation involving products and product lines [18]. The first type is to develop a new component for use in an existing system (minor development), the second type is to develop a new system with existing components (major development), and the third is to develop a new system with new components (radical development) [19]. MOCA is only really capable of dealing with the first type (minor developments) and the second type (major developments), but to a lesser extent. Product technology roadmaps show these types of innovation events on their timeline, along with information concerning the costs and resources required to implement the changes associated with the events. Thus the main outputs from technology roadmaps that will be used in MOCA are specific part for part replacements, when they occur, and how much they cost. Additionally, MOCA can accept information on when design refreshes may occur and how much they will cost. There are two main reasons for changing parts in a given design: changing a part because you want to change it to and changing a part because you are forced to change it (i.e., obsolescence) [12]. While roadmaps contain little information on what parts will become obsolete and when, they should contain information on when new technologies will be ready and what parts would be best to change for reasons other than obsolescence. Roadmaps should also have information on product lifecycle curves, and should suggest the best times for product redesign along with the information on individual parts and new technologies. This will be the most important piece of information for MOCA, since it will force a design refresh to take place in a certain time period, and will force certain non-obsolete parts to be changed during that period of time. It is very important to note that in most cases electronic part obsolescence is not well correlated to the appearance of a new replacement technology because there are many additional business and supply chain issues associated with a manufacturer's decision to discontinue a part.

Adding a roadmapping element to MOCA will improve its forecasting accuracy and make its models much more complete. Before roadmaps were included as inputs for MOCA there was no guarantee that the plan MOCA created would match up with the plans of a given organization. Design refreshes are major events from both commercial and technological corporate viewpoints, and they should be undertaken when it is best for the company as a whole, and not necessarily when it is best for a certain product or product line. Design refreshes are an expensive investment for a company to make, and they can only occur if funds are available and have been allocated correctly. MOCA can now take these concerns into consideration when creating a product plan, and can now begin to encompass parts that need to be changed for non-obsolescence related reasons. This allows MOCA to create more useful plans that are better linked to overall corporate goals, all while making MOCA's decision model more correct.

Chapter 3: Modeling Roadmap Information in MOCA

In order to add technology roadmapping information into the MOCA analysis, a model must first be developed to represent the data collected from the technology roadmaps. This model can then be used in the MOCA analysis to ensure that any suggested design refresh strategy conforms to the organization's long term goals and objectives as articulated in the technology roadmap for the product. The purpose of instituting the use of technology roadmaps is to create a pervasive and comprehensive plan of action that all stakeholders can buy into and follow. Allowing MOCA to generate a design refresh strategy without consulting an organization's technology roadmap could be a waste of time and resources. Therefore, the model should be created to act as an interface between the technology roadmap and the MOCA analysis.

The developed model should accept a wide range of data types since each roadmap is unique and stores a variety of information in a variety of ways. Allowing MOCA's decision making process to reflect the internal roadmap of an organization will result in the selection of the 'best' design refresh strategy: a strategy that fulfills organizational goals and constraints all while keeping obsolescence costs to a minimum.

3.1 MOCA's Current Refresh Planning Methodology

As previously mentioned in Chapter 1, the Mitigation of Obsolescence Cost Analysis (MOCA) methodology has been developed to aid organizations in determining the best dates for design refresh actions and the other steps needed to ensure that an electronic system remains sustainable. The methodology uses a product's bill of material, its production schedule, and obsolescence information to generate a set of possible design refresh plans. These plans can have zero, one, or more scheduled design refreshes. MOCA is designed to consider every scheduled production event as a possible end date for a design refresh event, and systematically generates design refresh plans by considering different combinations of these possible design refresh event end dates. The generated design refresh plans are then ranked graphically by the total lifecycle cost of the given plan, and each plan is represented by a single point on the MOCA plot (plotted at the mean of all the refresh dates in the plan), Figure 10. For plans with multiple refresh dates, the points can be expanded to show the actual refresh dates. In Figure 10 the optimum solution, a solution with two refresh dates, has been expanded to show the actual design refresh dates. The optimum design refresh plan can be found by locating the lowest point on the plot, since the y-axis shows the lifecycle cost of the plans. However, because MOCA systematically generates the refresh plans based on refresh possibilities generated by the production schedule, there is a chance that some of the generated plans may not be viable in the broader context of the organization's goals.

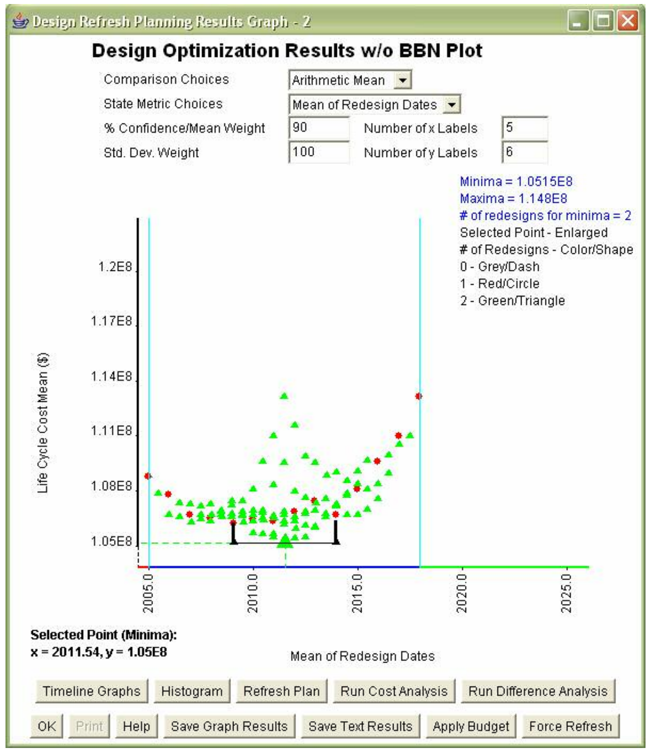


Figure 10 – Sample MOCA Output

3.2 Modeling Roadmap Information

Technology roadmaps usually contain information on big-picture budget cycles and technology goals, and these types of constraints need to be included within the MOCA refresh planning analysis. Without inclusion of the roadmapping information, MOCA's obsolescence strategies are developed from the bill of materials, production plans and part obsolescence dates alone, ignoring constraints placed on the management of the system by broader organizational requirements articulated in the product's technology roadmaps.

3.2.1 The Ideal Roadmap

As previously noted, technology roadmaps come in different forms and exist at different levels of completeness and accuracy. The information found in roadmaps is always subject to change and should be taken with a grain of salt. Roadmap 'facts' are often simply a graphical representation of their creators' opinions and ideas. While the ideal technology roadmap would consist of specific planned events and precise budgets, predicted from technology forecasts and historical data derived from more accurate technology monitoring and forecasting methods, this is almost never the case. Even if the information upon which the roadmap was based was perfect, the organization may not carry through and follow the roadmap as articulated. This makes creating an information model to hold the data gathered from roadmaps a difficult task. Any information model must be broad enough to incorporate a wide range of information, and yet must still be detailed enough to be useful in the decision making process. Because the information found in roadmaps is so variable and in some cases vague, it may be necessary to allow the user to interpret the data before it can be included in the information model. Additionally, the information model addressed in this thesis will only apply to roadmaps that are concerned with a specific project or product, not those roadmaps created for an entire industry or research area. However, it should not matter whether these product roadmaps are striving for accuracy or decision influence, since both accurate predictions and technology goals can and will affect when a design refresh can occur. These different styles of roadmap both describe a single platform or product, which gives them enough in common to share an information model. The information contained within larger scale roadmaps, those dealing with technologies on the national or industry level, would not be compatible with an information model developed for smaller scale roadmaps, although the information found in them assumably would eventually be included on the product- or platform- specific roadmaps.

3.2.2 Deriving the Information Model

Product or platform roadmaps differ in the types of information they can contain, but the information relevant to obsolescence and sustainment can be grouped into the following four categories:

- Timeline Events (Exclusive) – This category includes budget cycles and schedule constraint events. These events eliminate particular MOCA generated refresh plans from consideration if they contain refreshes during periods when no refreshes are allowed to take place.
- Timeline Events (Inclusive) – These events require a specific action during a specific time period, and force MOCA generated plans to contain one or more refresh events in specified time periods.
- Costs – Roadmaps often dictate the specific actions that must take place at a refresh, which will in turn increase or decrease the cost of events in MOCA's timeline.
- Individual Parts – Roadmaps may also reference specific parts that need to be phased out or introduced at specific times.

These types of events must be included within the MOCA analysis along with the bill of material, component costs, component obsolescence dates, production dates, etc., in order to attain more viable refresh solutions that better reflect an actual implementable design refresh strategy.

All roadmapping constraints can, at their very broadest, be considered as timeline events. In this sense, all constraints included in the information model should have a start date and an end date, since constraints will be applied over a period of time. These constraints can be interpreted as either exclusive events, where only plans that have no events in the time period are considered, or inclusive events, where only plans that have events that contain some action within the time period are considered. Note, inclusive events do not preclude plans that contain actions outside of the constrained period, they only required that the plan include some action within the inclusion period. Additionally, the information model must also accept a cost constraint along with the timeline start and stop dates. This cost constraint can be used to adjust the lifecycle costs of plans that are affected by the timeline constraints. That is, the cost constraint will either increase or decrease the total lifecycle cost of a given plan or set of plans. Finally, any information model with timeline and cost constraints should also include a list of affected parts (or groups of parts) that will be either redesigned out of the system or subjected to some other prescribed mitigation action (e.g., last time bought) because of a given timeline constraint.

3.3 Application of the Model

3.3.1 Collecting Constraints from a Roadmap

Thus the model has been designed to include timeline events (both inclusive and exclusive), cost constraints, and changes to individual parts. However, it is unlikely that this type of information will be readily discernable from an average technology roadmap; in all likelihood the user will need to evaluate the roadmap and derive constraints from it. Most roadmaps do not explicitly enumerate when a design refresh should occur and how much the refresh should cost, but they will show when a new technology becomes available and will present budget and resource allocation for a given time period. This information can be used to derive the data used to fill the model.

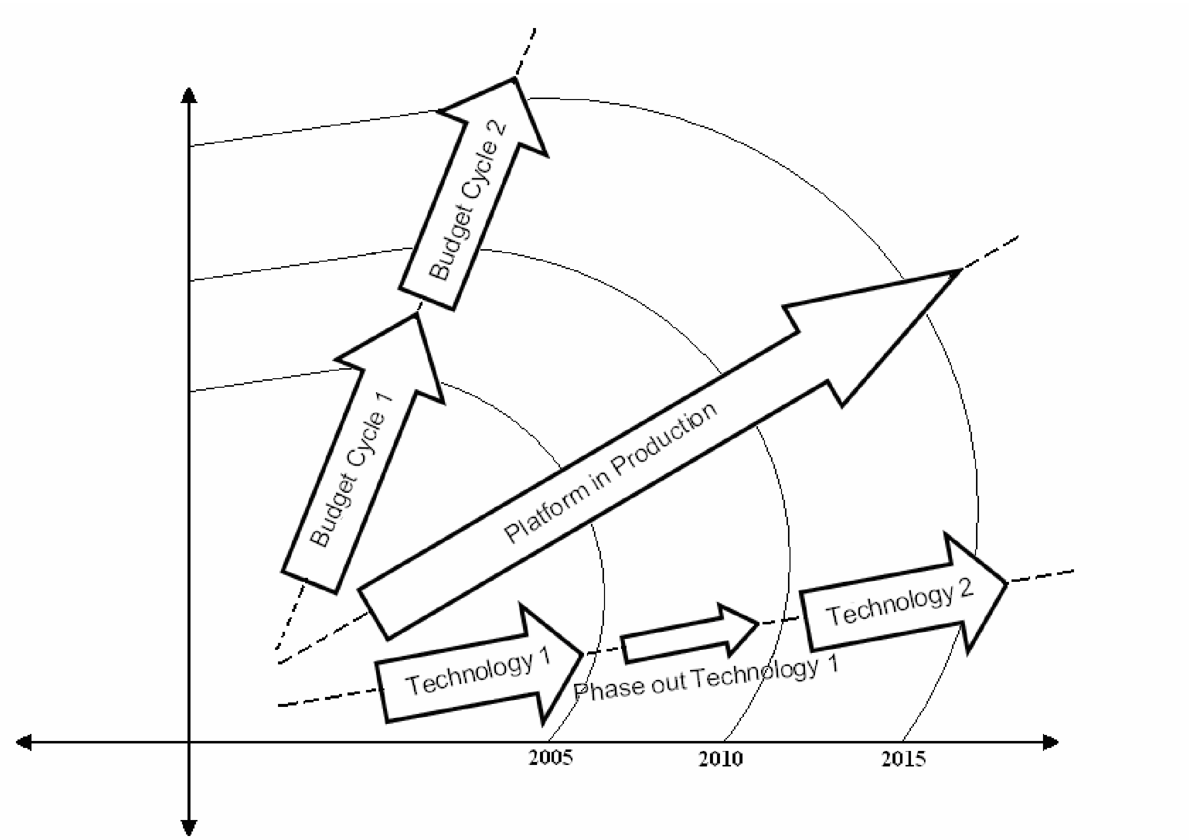
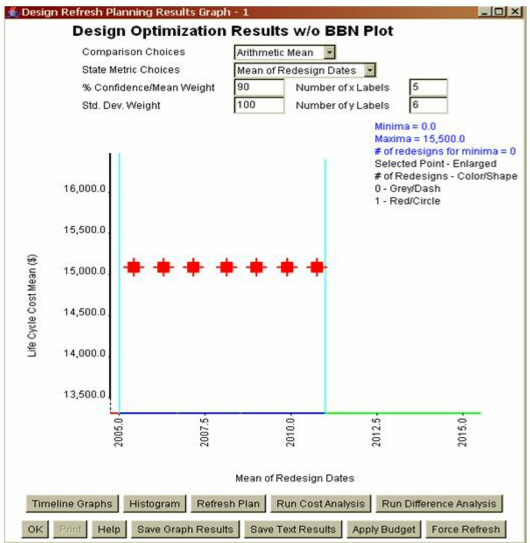


Figure 11 – Sample Technology Roadmap

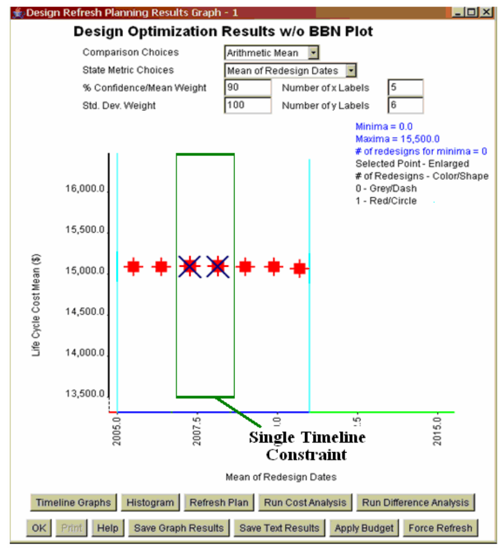
Figure 11 is a sample roadmap depicting the type of information that is usually available from a corporate technology roadmap. From the roadmap, if the current date is 2007, one can ascertain that the organization is currently dependent on Technology 1, but is expected to phase Technology 1 out in favor of Technology 2 over the next five years.   Additionally, the roadmap in Figure 11 shows the frequency of the organization's budget cycles. Since the platform depicted in the above roadmap will continue to be produced for some time, it is safe to assume that some sort of action should be taken to ensure that the platform is sustainable for the future. As previously noted, the most common options considered to ensure platform sustainability are lifetime buy of obsolete parts and design refresh. The current version of MOCA is capable of determining which of these options is the most cost effective, but will ignore the budget and technology constraints articulated in the roadmap without the technology roadmapping model. From the sample roadmap, it can be deduced that any possible design refresh should occur before Technology 2 becomes available, and during either Budget Cycle 1 or Budget Cycle 2. Because Budget Cycle 2 is in its initial stages when Technology 2 becomes available, it is probably necessary for the funding of any design refresh to come from funds allocated in Budget Cycle 1. These two data pieces from the technology roadmap, that a design refresh should occur after Technology 1 is obsolete and before the end of Budget Cycle 1, can be translated into a single roadmapping constraint: there must be at least one design refresh between 2005 and 2007 Additionally, the user may also be able to determine some sort of budget limit for the design refresh using in house information concerning how much of the budget from Budget Cycle 1 is available for refreshing the design. These data constraints derived from the above sample roadmap show the type of information that the new information model can accommodate.

3.3.2 Applying the Roadmapping Constraints

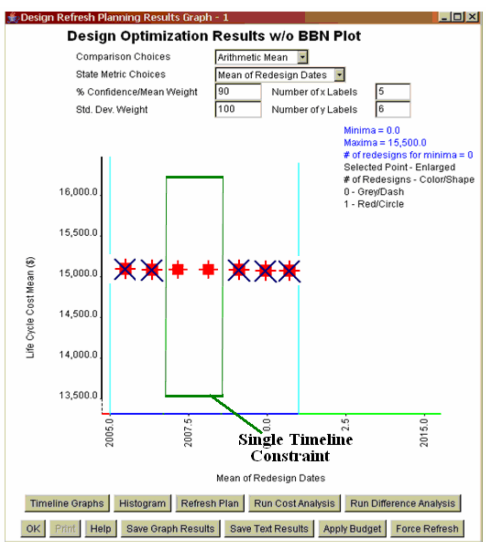
Figure 12 shows how roadmapping constraints are applied to candidate refresh plans. Graph A shows a set of candidate refresh plans before any roadmapping constraints have been applied, i.e., no plans have been eliminated ('x'-ed out) from consideration. This represents a very simple MOCA output graph. Each plotted point on the graph represents a single design refresh plan that dictates when lifetime/bridge buys and design refresh events should be performed. In this illustrative example, every refresh plan costs the same amount to implement; hence every point on the graph has the same y-axis value. The other three graphics in Figure 12: B, C, and D, show how the set of possible solutions is changed by the addition of technology roadmap constraints. In graph B a single exclusive timeline event has been applied, and any design refresh plans within the event's start date and end date have been eliminated from consideration and marked with an 'x'. This case models a blackout period, where no design refreshes can take place, possibly because of budget or personnel limitations. Similarly, if the timeline event was considered inclusive, as in graph C, only plans falling within the timeline constraint's start date and end date will be considered; all other plans are eliminated. This models a scenario where a design refresh must take place within a certain time period, similar to a planned design refresh where new technology is inserted or an operating system upgrade must be performed. Finally, graph D shows an inclusive timeline constraint with an additional cost constraint added to the viable plans. In this case, only plans included within the timeline event are considered and a cost has been added to each. Like the purely inclusive case shown in graph C, this models a planned design refresh scenario, and the added costs in graph D exemplifies a case where there are additional costs associated with this planned design refresh.



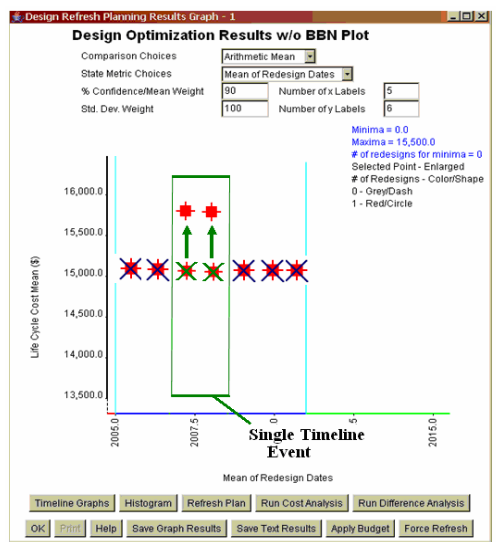
A. Unconstrained set of Plans



B. Exclusive Constraint (a MAY NOT refresh scenario)



C. Inclusive Constraint (a MUST refresh scenario)



D. Added Costs Associated with Events

Figure 12 – Sample of how Roadmapping Constraints Can Affect MOCA Generated Refresh Plans

Additionally, a method for applying multiple constraints must be devised, i.e., more than one constraint could be active in a given time period. This is not a problem for exclusive constraints, since any plan that violates the exclusive constraint is removed from consideration, regardless of whether multiple exclusive constraints exist or overlap.

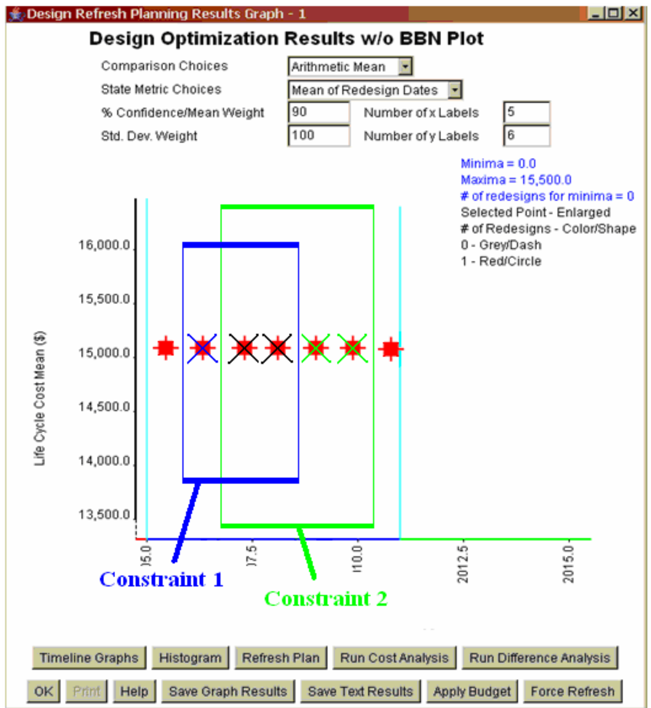
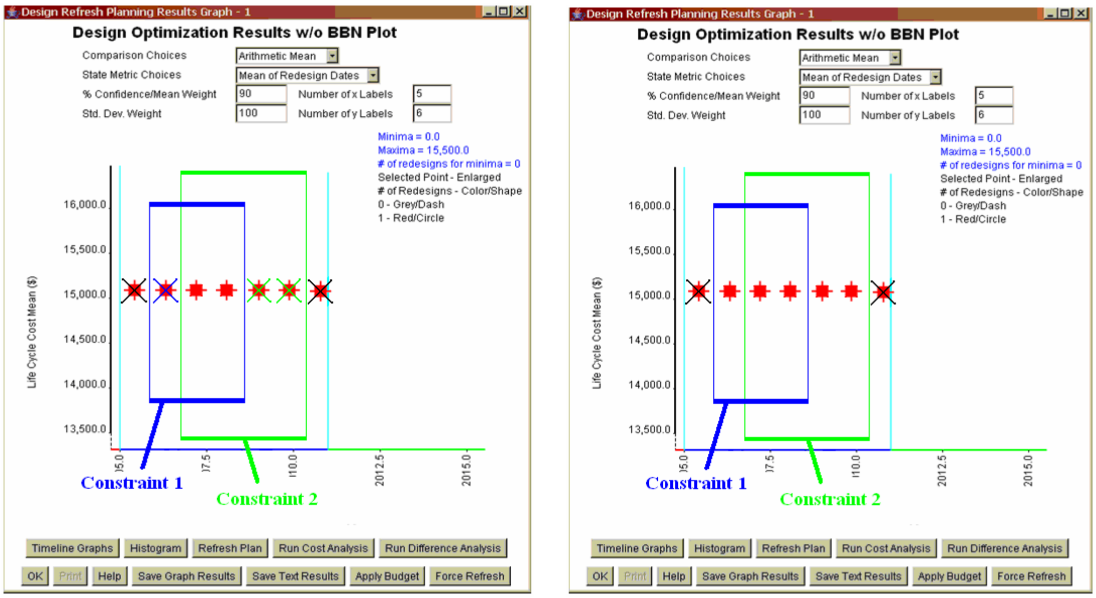


Figure 13 – Multiple Overlapping Exclusive Constraints

In Figure 13, the two exclusive constraints eliminate the possible refresh plans that fall within their given timeline constraints, and the possible refreshes that fall in the period of overlap that the two constraints share have also been eliminated. The case of multiple exclusive constraints is trivial, unlike the case of multiple inclusive constraints.

There are two ways that multiple inclusive constraints could affect possible solutions: 1) any viable plan must meet all of the provided constraints (constraint 1 AND constraint 2 AND …), and, 2) any viable plan must only meet at least one of the provided constraints (constraint 1 OR constraint 2 OR…). It should be noted that the

OR scenario is not an ‘exclusive or’ (XOR), but is a case where constraint 1 or constraint 2 or BOTH constraints could be fulfilled. The XOR case has not been implemented in the MOCA model because it is more theoretical than realistic. That is, it is difficult to imagine a real life scenario that would require a refresh to occur in one of two periods, but not in both. If an XOR scenario does present itself, it could modeled by comparing an OR scenario and an AND scenario, assuming the XOR scenario is simplistic enough. More complex XOR scenarios may require that the XOR constraint be modeled in the MOCA tool, but more actual roadmaps need to be studied and inputted into MOCA before this can happen. Any model describing technology roadmaps must be able to re-create either scenario. An example of how the results would differ because of the scenario chosen is shown in Figure 14. In Figure 14, two separate inclusive constraints have been applied to the sample output. Case 1 shows an example where only plans meeting both constraints are considered viable. This is similar to a situation where a single board or system is used on two different platforms, and each platform is scheduled to be design refreshed at a different time. In Case 1, the planned design refresh of each platform is modeled as a separate timeline event, and the place in time where these two plans overlap represents the only possible time when this system could be refreshed. Case 2 shows a case where plans are accepted if they meet at least one of the constraints. This approach to dealing with multiple constraints is useful if there are two periods of time that a design refresh could occur, as in two different budget cycle periods. Allowing users to model scenarios with multiple roadmapping constraints is a way to ensure that all types of roadmap information can be included into a design refresh analysis, and allowing either an ‘AND’ relationship or an ‘OR’ relationship between the constraints ensures that constraints are dealt with properly.



Case 1: AND Relationship Case 2: OR Relationship

Figure 14 – Applying Roadmap Constraints

3.3.3 Application of Constraints to Refresh Plans with Multiple Refreshes

The previous examples of roadmapping constraints applied to MOCA’s solution have demonstrated only the most trivial cases where only refresh plans with a single refresh date are considered. However, MOCA also generates solutions with two, three, four, or more design refreshes per plan. In these cases, it is not immediately obvious when analyzing possible refresh solutions which plans should be eliminated from consideration, since design refresh plans with multiple design refresh events are plotted as a single point at the average date of the refresh dates. That is, a design refresh plan with refreshes scheduled at 2008 and 2010 would be plotted at 2009. Figure 15 shows an example of how roadmapping constraints would affect design refresh plans with multiple refresh dates, which explainss why some plans that may seem to violate the constraints actually do not violate them. Because Inclusive Constraints only require that a plan have a single refresh date fall within the constraints, plans with multiple refreshes are not rejected as long as one of the refresh dates falls within the desired period. In Figure 15, refresh plans with two scheduled design refreshes are represented by green triangles, and the individual refreshes in the plan are shown as black squares connected to those triangles. Figure 15 shows how some plans that may appear to fulfill the inclusive constraint actually do not satisfy it, while others that appear outside of the constraint meet the requirements. A much more complex example is presented in the next chapter, where the NAVAIR case study is discussed in detail.

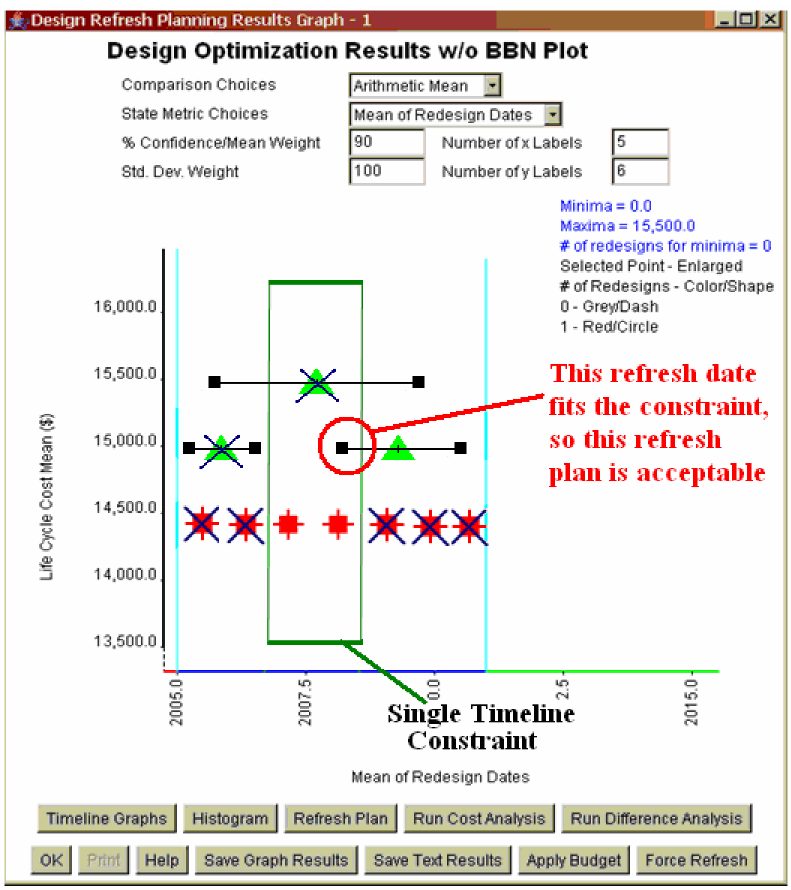


Figure 15 – Considering Plans with Multiple Refresh Dates

3.3.4 MOCA Implementation Details

The MOCA tool uses the model discussed in this chapter to weed out design refresh plans that do not fit with corporate and technology goals as defined in an organization's technology roadmap. To do this, two additional steps have been added to MOCA's decision analysis. First, MOCA adds costs to those plans that will be more expensive because of newly introduced technologies or other actions that are specified in the technology roadmap. The second added step in the MOCA tool's decision process is a post-processing step where individual refresh plans are determined to have either met or not met roadmap requirements. Both of these steps can be skipped if they are not desired, but the second step requires a specific user action to initiate it. The user must click on a 'Force Refresh' button to activate the design refresh plan weed out process. Once this is done, MOCA will eliminate those plans that do not fit the roadmapping requirements by placing an 'x' on the non-viable design refresh plans. Plans that do meet the roadmap requirements are left as is, allowing the user to sort through them to find the least expensive and most useful refresh plan. Appendix B summarizes supplemental MOCA user manual information for the technology roadmapping interface.

3.4 Summary

The addition of a technology roadmap information model to the MOCA tool ensures that only those design refresh plans that satisfy an organization's technological and fiscal goals will be considered for adoption. Because MOCA automatically generates every possible design refresh plan from a product or platform's production schedule, sometimes plans are created that are simply not viable from a technological or financial standpoint. The inclusion of the technology roadmapping model has the ability to change MOCA's optimum design refresh plan, since often times the optimum plan violates some constraint defined in the technology roadmap. This new addition to the MOCA methodology allows the user to find the best design refresh plan that fits within the context of the organization's specific aims and goals. Obviously, the final solution is dependent upon the information found in the technology roadmap, so the suggested refresh plan is only as good as the roadmap itself. It is also important to note that the MOCA suggested optimum refresh plan is only an optimum if an organization actually follows their roadmap. But, assuming that a sincere effort was made to ensure that the roadmap reflects technological and economic goals, and will be followed, the plan that MOCA generates will be an optimum solution. The next chapter presents a case study demonstrating how the inclusion of constraints from a technology roadmap can change MOCA's suggested solution, and how the new solution is more appropriate then those developed without the inclusion of technology roadmapping information.

Chapter 4: The NAVAIR V-22 Advanced Mission Computer Case Study

The technology roadmapping information model described in Chapter 3 was implemented in the MOCA tool to allow the information and opinions found in a technology roadmap to influence the MOCA design refresh analysis. Before the addition of the technology roadmapping model, the MOCA analysis considered all possible design refresh plans, and assumed that every plan was equally viable and suitable for adoption by the organization. This is not the case however, since organizations develop their own plans for products and platforms independently of the MOCA analysis, and these plans are reflected in technology roadmaps. The goal of the technology roadmapping addition to the MOCA tool is to reconcile the MOCA design refresh plan with the plan specified in the technology roadmap.[1]

This chapter details a case study performed for NAVAIR using the Advanced Mission Computer (AMC) on the V-22 Osprey. In addition to the bill of materials, production schedule, and other input data, a sample technology roadmap was obtained from NAVAIR in order to perform the case study. Results were first obtained for the AMC system without using the information found in the technology roadmap. This baseline solution was then compared to results generated with roadmap information included. Using technology roadmapping information in the MOCA analysis resulted in the selection of a different design refresh plan than the one selected without the inclusion of roadmapping information, and this new plan is more likely to be adopted because of its compatibility with NAVAIR's goals and

[1] This is not meant to imply that the MOCA plan and the technology roadmap are competing, rather that they are complementary pieces of information that need to be considered concurrently when performing design refresh planning.

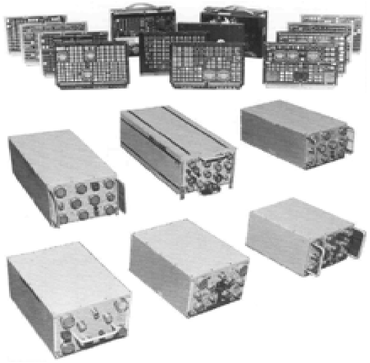
technology strategies. The results and insights gained from this case study are discussed in this chapter and an argument is made for the use of technology roadmapping information when performing MOCA analyses.

4.1 The Baseline Solution

4.1.1 The V-22 Osprey and the Advanced Mission Computer (AMC)

Figure 16 – The V-22 Osprey

The V-22 Osprey is a tilt-rotor helicopter with vertical take off and landing capabilities originally designed jointly by Bell Helicopter Textron and Boeing Helicopters (Figure 16). It has been in production since the late 1980’s, and it will continue to be produced for years into the future. Because of the V-22’s long term development and production schedule, the system as a whole has faced and will continue to face the problem of part obsolescence, since many of the electronic components in the system are no longer manufactured. Several of the V-22’s electronic systems have been analyzed using the MOCA tool at this time, but this paper will focus only on the Advance Mission Computer (AMC) system.



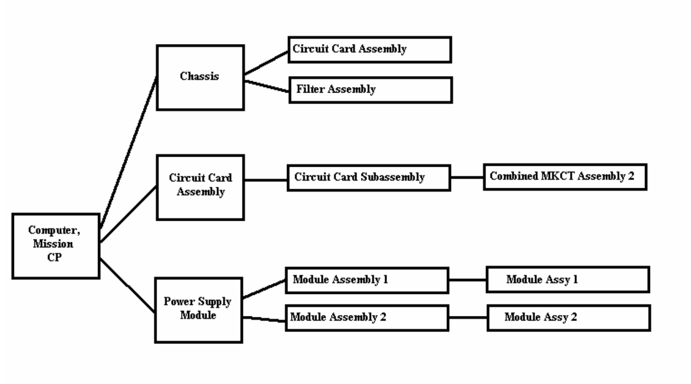


Figure 17 – The AYK – 14 [2]

Figure 18 – Hierarchy of the AMC System as Loaded into MOCA

An early predecessor of the AMC was the AN/AYK-14(V) shown in Figure 17, which was used for mission computing, navigation, targeting and onboard data processing. It consists of standard plug-compatible modules and multiple chassis types. It can be configured and designed to meet individual user requirements, and its off-the-shelf microelectronics technology building block approach allows for a variety of technology insertions and permits the system to keep pace with evolving processing [2]. The AMC was loaded into MOCA as a set of boards and parent boards with four levels of hierarchy. The loaded system consists of 303 total parts distributed on 12 boards. The hierarchy of the boards can be seen in Figure 18. In addition to the above hierarchy, 177 production events, 165 obsolescence dates, and the cost of the system were loaded as inputs into MOCA. From this data, a baseline solution was found using the MOCA tool alone, without consulting any technology roadmap.

4.1.2 Baseline AMC Results

The baseline solution was generated to determine what solution MOCA would suggest without consulting roadmap information, and was used to determine what the inputs the solution was most sensitive to. Figure 19 shows the initial MOCA analysis for the AMC system, where each point on the plot represents an individual design refresh plan. In Figure 19, red points represent plans with a single design refresh date, green points represent plans with two refresh dates, and blue points represent plans with three design refresh dates. MOCA is capable of generating plans with more refresh dates, but in the case of the AMC system, these plans were more expensive than plans with two or three refresh dates, so they were ignored.

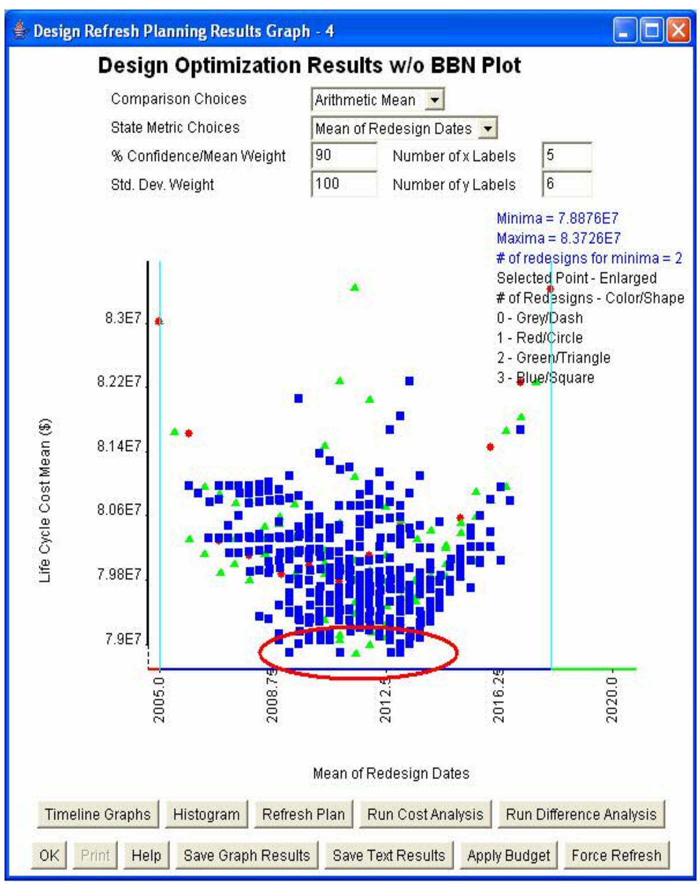


Figure 19 – Initial MOCA Output for the AMC System

The initial analysis of the AMC system suggests that the optimum refresh plan consists of two scheduled design refresh dates at 2009 and 2014, and that the cost avoidance, compared with a purely reactive obsolescence mitigation strategy, from adopting such a plan would be approximately $4.1 million. The actual derivation of this cost avoidance term is described later in this chapter. A sensitivity analysis was also conducted to determine how much the solution could vary when its inputs were varied.

There are several default input values used in the MOCA analysis. These values include look-ahead-time, economic inflation rate, storage and handling rate, re-qualification cost, and a mitigation factor. The look-ahead-time variable controls the number of parts that redesigned at a given design refresh date. While all parts that have already become obsolete at a design refresh event are obviously slated to be redesigned, the parts that are about to become obsolete shortly after the refresh event could also be considered for redesign. The look-ahead-time controls how far into the future the MOCA tool looks when determining which parts to design out of the system. That is, for a design refresh scheduled in 2007 with a look-ahead-time of two years, all parts that become obsolete before 2009 will be considered for redesign. The look-ahead-time for the AMC system was varied from zero years to ten years in order to find out which value for look-ahead time would minimize the cost of the solution. Figure 20 shows the cost of the least expensive plan associated with a given look-ahead-time. As the look-ahead-time grows larger, the minimum cost becomes smaller. However, because the actual difference in cost between a look-ahead-time of zero and a look-ahead-time of ten years is less than $100,000, the final value for look-ahead-time does not affect the solution as much as some of the other default input values.

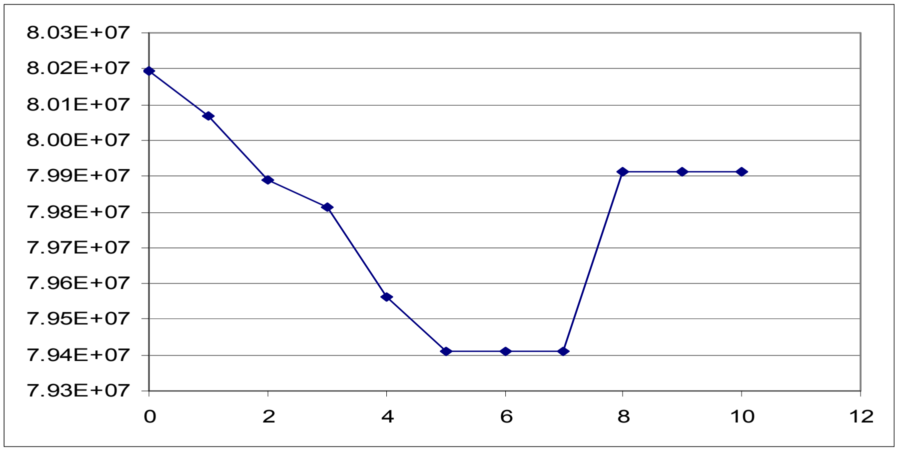


Figure 20 – Minimum Cost vs. Look-Ahead-Time

The storage and handling rate, economic inflation rate, re-qualification cost, and mitigation factor, were also varied to determine how much of an affect their values would have on the solution. The storage and handling rate is a factor used to describe the amount spent on storing and handling parts, while the mitigation factor describes the cost of buying parts for lifetime or last time buys. Finally, the re-qualification cost describes the cost of re-qualifying a redesigned system. NAVAIR has provided the information used to fill these data inputs with their default values, and these default values were then varied by plus and minus ten percent to determine which data values the solution was most sensitive too. A tornado chart of the results was generated and is shown in Figure 21.

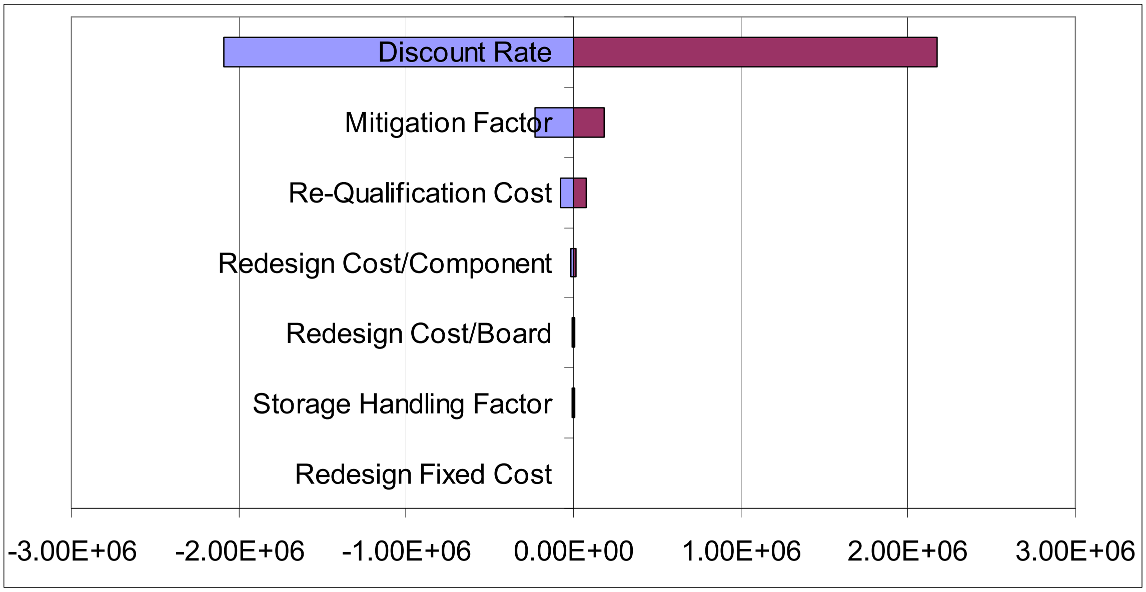


Figure 21 – Tornado Chart Depicting the AMC Sensitivity Analysis

The primary reason for the sensitivity analysis is to determine how volatile the solution MOCA generates is. In this case, the cost of the solution can change by up to plus or minus $200,000 and the actual refresh plan itself can be changed. Increasing the look-ahead time causes the optimum plan to change from one with two scheduled refreshes to a plan with only a single refresh, while increasing the mitigation factor adds an additional design refresh date to the plan. Varying these parameters can influence the solution MOCA generates, so it is important to ensure that the sensitive parameters are as accurate as possible. The acquisition of additional technical information or the opinion of an expert who can understand the big picture may be needed to help determine which MOCA scenario is best for the organization. Often times this type of information has already been collected and contained in the organization’s technology roadmap. Including this information in the MOCA analysis will allow the best, most cost effective obsolescence strategy to be selected.

The MOCA tool only ranks plans according to their cost and it does not account for plan viability or the non-tangible benefits of selecting one plan over another. Traditionally, the MOCA generated plans have been compared to a purely reactive solution, where all obsolescence events are solved through lifetime and last-time buys, never through redesign or design refresh. This reactive solution is also shown on the MOCA output graph, along with the strategic design refresh plans. The non-refresh solution appears as a gray dash along the y-axis, and can be seen circled on the left side of Figure 22. The graph on the right side of Figure 22 shows the cost of the no-refresh solution (red) and the optimum solution (blue) as a function of time. One can see that NAVAIR can save about $4.1 million by adopting the optimum solution. The term 'saved' refers here to money that NAVAIR avoided spending, and a more appropriate term for it is cost avoidance, since no one will get this money back, NAVAIR merely never had to budget for it.

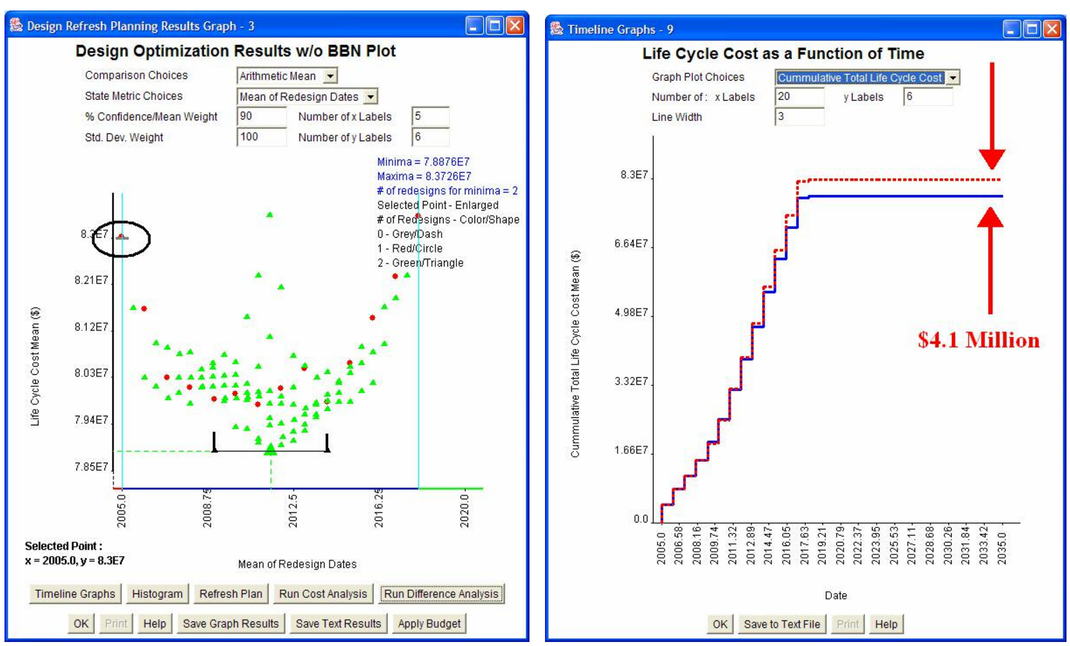


Figure 22 – Derivation of a Design Refresh Strategy's Cost Avoidance

While there is no mathematical way to measure how well a given design refresh plan or strategy fits with an organization's goals and aims, the addition of roadmapping information to the MOCA analysis will at least ensure that selected plans are viable and can be achieved within the constraints imposed by the roadmap. The roadmapping links allow possible refresh plans to be evaluated both in terms of cost, as shown above, and in terms of organizational fit. This allows for the selection and adoption of the most cost effective, viable design refresh strategy.

4.2 Introducing Roadmap Criteria

4.2.1 The NAVAIR V-22 Roadmap

Because of the scope and timeframe of the V-22 project, NAVAIR has developed a technology roadmap which depicts goals and targets for the Osprey's production and development. It is important to include this roadmap information into the MOCA analysis, which up until this point in time has developed its obsolescence strategies from the bill of material and part obsolescence dates alone, ignoring any strategies the company or organization has developed for itself. The November 2005 version of the roadmap for the entire V-22 was obtained in an electronic format. The roadmap exists both as a paper document and in electronic format, which can be expanded by clicking on individual portions of the roadmap so that more specific information can be collected.

Figure 23 shows a sample portion of an expanded roadmap section specific to the AMC system. This section of the V-22 roadmap will be used to demonstrate

MOCA's roadmap capabilities, and will show how roadmaps should be interpreted when being input into MOCA. This roadmap depicts four subsystems, three of which become obsolete at different times (the fourth is sustainable indefinitely). In Figure 9, the red bars represent obsolete and non-sustainable systems, the yellow bars represent obsolete but sustainable systems, and the green bars show non-obsolete systems. One can see that the below subsystems all become obsolete within the same 2 year period, assumed to be 2008 and 2010.

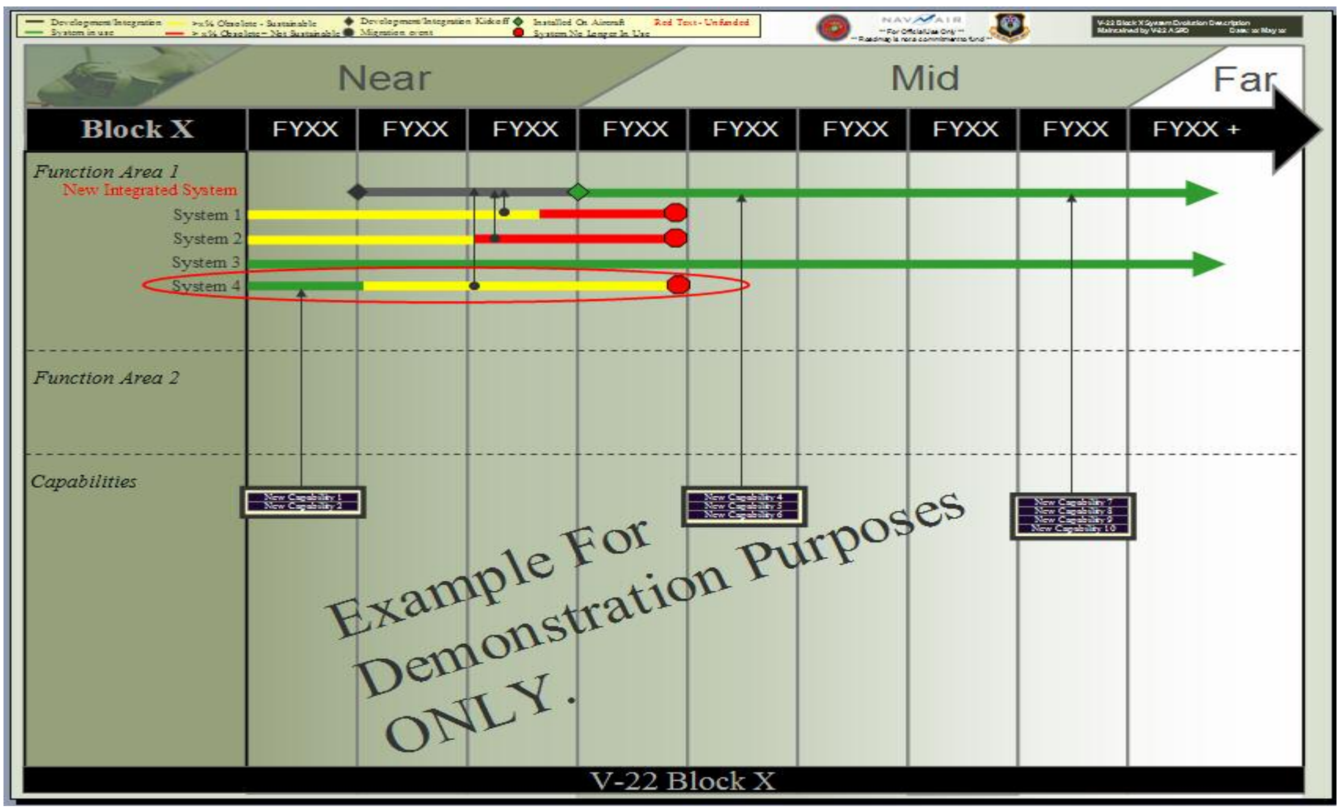


Figure 23 – V-22 Roadmap Fragment Corresponding to the AMC System

4.2.2 NAVAIR's Roadmap Limitations

The fragment of the NAVAIR roadmap shown in Figure 23 is in actuality only a sample of what NAVAIR hopes to eventually develop. The V-22 roadmap, as it exists now, is an immature document that merely indicates what information and technological predications will be needed for future reference. The current incarnation of the V-22 roadmap is simply a skeleton document with places reserved for information to be filled in as it is obtained. Developing the roadmap has shown NAVAIR what types of information they will need to efficiently manage the V-22, and as this information is discovered this roadmap will be completed and reach maturity. Until this point is reached it is difficult to determine how valuable the MOCA analysis will be for the management of the V-22's obsolescence. An evaluation of the V-22 roadmap was completed by Chris Wilkinson. This Evaluation can be found in Appendix A.

4.2.3 Interpreting the NAVAIR V-22 Roadmap

Although the V-22 roadmap is relatively immature and lacks much of the important information that is necessary for the development of an obsolescence management plan, there is still enough information to infer some constraints from the sample roadmap. As mentioned previously, the sample roadmap shows a "New Integrated System" that will eventually be made up of the four smaller subsystems, including the AMC. While one of the subsystems never becomes obsolete, the other three all become obsolete during the same four year period, and they are all sustainable for at least two years in that four year period. During the two year period when these systems are no longer sustainable it is NAVAIR's plan to design refresh these systems as a way to combat their obsolescence. It is safe to assume that there will be some sort of cost associated with this design refresh, and since these subsystems will be merged into the "New Integrated System," the associated cost will be rather large. For this reason the cost of the design refresh that must occur between 2008 and 2010 has been assumed to be $2.5 million, since it is a major redesign event that will probably require flight requalification and the design of a new housing and mounting system for the new unit. The roadmapping constraint derived from the above technology roadmap sample is summarized in Figure 24 below, which is presented in the same style as the technology roadmap interface in the MOCA tool.

Constraint Start Date	Constraint End Date	Constraint Cost	Consider Multiple Constraints Separately?
2008	2010	$2.5M	Yes

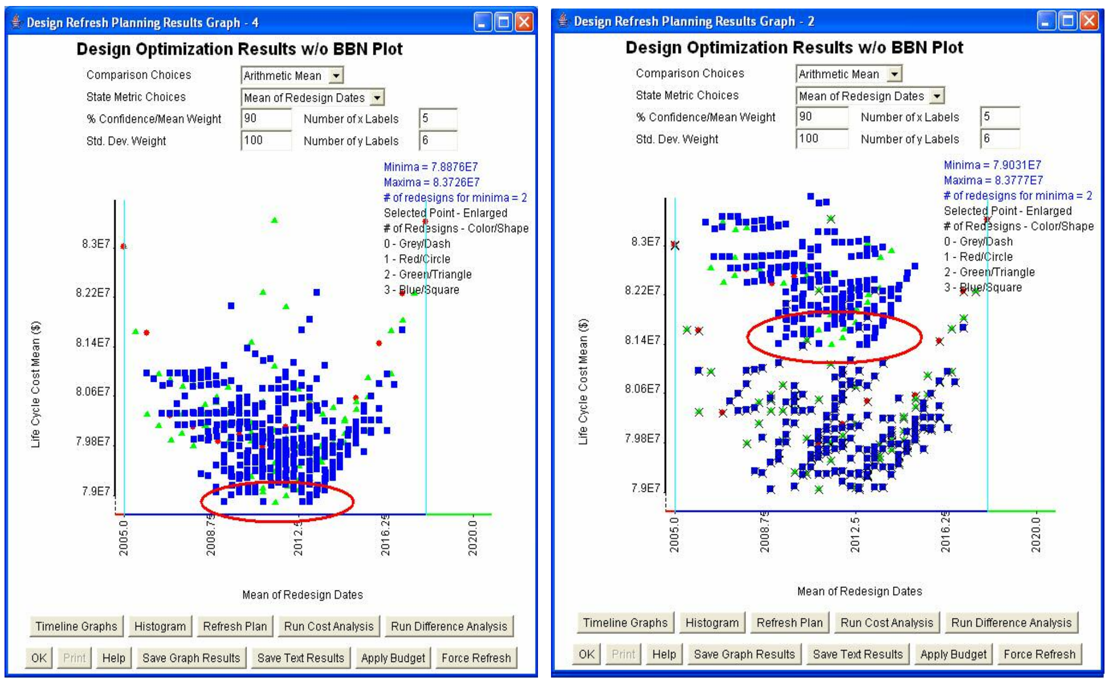
Figure 24 – Roadmap Constraint Summary

Thus the criterion used in the MOCA analysis was that a design refresh event must take place sometime between 2008 and 2010 at a cost of $2.5 million. This was modeled as an inclusive constraint in terms of the lexicon set forth in Chapter 3.

4.3 Results and Conclusions

4.3.1 Roadmapping Results

The criterion shown in Figure 24 was entered into the MOCA roadmap interface along with an accompanying cost constraint. Because of the roadmap criteria, MOCA only considered refresh plans with at least one design refresh between 2008 and 2010, since that is when all the subsystems become obsolete and non-sustainable. These design refresh plans could contain design refresh events outside of the constraint, but only if the constraint is fulfilled by having at least one design refresh date within the constraint. Additionally, the cost of this design refresh was assumed to be $2.5 million, so this cost was added to the first design refresh plan within the time period specified by the constraint.

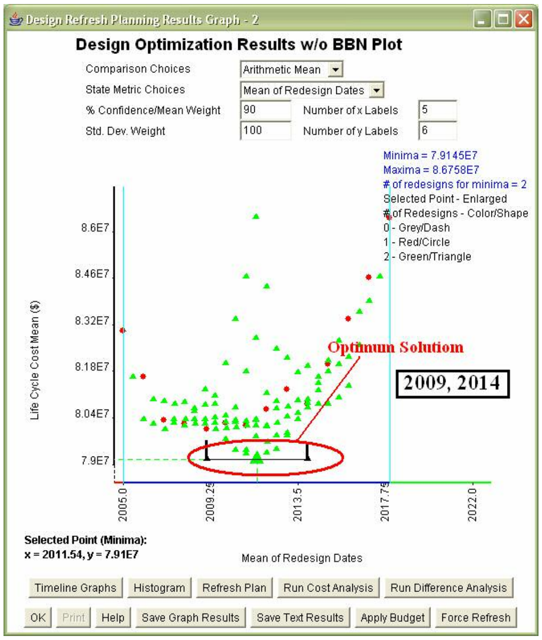


Initial Results without Roadmap Constraints

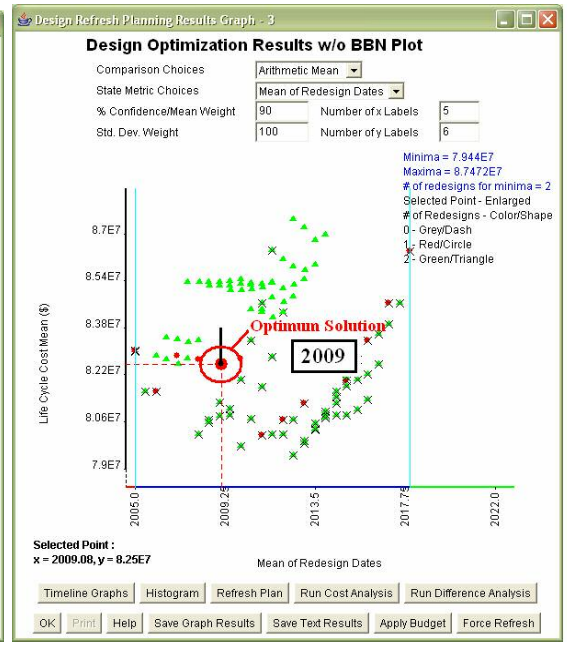
Results with RoadmapConstraints Applied

Figure 25 – MOCA Results With and Without Roadmap Constraints Applied

Figure 25 shows the MOCA solution before and after the roadmap constraints have been applied. The figure on the left shows a basic MOCA output without roadmap constraints, while the figure on the right shows the same results with the roadmap constraints. One can see that all the viable refresh plans have been shifted upwards along the y-axis in the right-hand diagram. This is because of the additional cost constraint that was applied to the first design refresh in the years between 2008 and 2010 in the acceptable plans meeting that constraint. The above graphics show that MOCA's final refresh plan, with design refreshes scheduled for 2009 and 2014, changes because of the roadmap constraints; it both costs more and the actual plan itself changes. After the roadmapping constraints are applied, the MOCA tool suggests only a single refresh date in 2009, instead of a plan with two refreshes in 2009 and 2014. This is not always the case, since changing the constraints associated with a data set sometimes will not change the solution of that set. On Figure 26, which has less points than Figure 25 so that it is easier to interpret, one can see many points in close proximity to the optimum solution that have been 'x'ed out because of the roadmap constraints. These are no longer considered viable solutions, and although the non-roadmapping optimum was not one of the eliminated points, its cost increased significantly enough to remove it from consideration. The results show that the MOCA tool has 'considered' NAVAIR's desire to perform one large design refresh on the system rather than several smaller scale design refreshes. The original sample technology roadmap showed three subsystems being redesigned into an integrated system sometime between the years 2008 and 2010 as a way of coping with the obsolescence issues on three of the four subsystems. Since the integration of the smaller subsystems into a larger unit is a major redesign event, it makes sense that this design refresh event should encompass all major changes, and that only small, minor changes should be needed to keep the system sustainable for the remainder of the AMC lifecycle.



Initial Results without Roadmap Constraints



Results with Roadmap Constraints Applied

Figure 26 – MOCA Results for 1 Refresh and 2 Refresh Plans

Although the application of the $2.5 million cost constraint has shifted all viable design refresh events up the y-axis, the recommended plan is still less expensive than the no refresh solution.

4.3.2 Conclusions

The MOCA tool has been extended to include technology roadmapping information in its design refresh analysis. The previous case study performed for NAVAIR depicts how this expansion can affect the solution MOCA suggests. In the case study, the addition of technology roadmapping information resulted in a solution that was different from the solution MOCA had selected without the roadmap data. The modified solution was more consistent with the information found in the technology roadmap, which fulfills the goal of the case study. NAVAIR now has an obsolescence solution for the Advanced Mission Computer that meets the requirements of their roadmap. While this case may seem trivial because of the rather simplistic constraint derived from the sample roadmap, the MOCA roadmap model is capable of handling more complicated roadmap constraints. The addition of the roadmapping information into the MOCA analysis ensures that the solution MOCA generates will be viable, and allows the opinions of the roadmap's creators to affect the final solution.

Chapter 5: Summary, Contributions, and Future Work

5.1 Summary

This thesis described the development of a model capable of capturing the types of organizational goals and milestones found in technology roadmaps. In order to develop this model, research was conducted to discover what types of information can be found in technology roadmaps and in what form roadmaps present this information. A taxonomy of roadmaps was adapted from two sources to show what types of roadmaps would provide information that was suitable for use in the management of product and platform obsolescence issues. The information found in these roadmaps was then grouped into two categories: timeline events and cost constraints. Although the types of information found in technology roadmaps is often broad and varies from roadmap to roadmap, almost all roadmap events occur in time and have an associated cost. From this fact, an information model was developed to include two types of timeline events, inclusive and exclusive, cost constraints, and information on individual parts that may have been earmarked for replacement. This model allows users to input roadmapping information into the MOCA design refresh planning tool, allowing the constraints derived from the technology roadmap to influence the decisions that the MOCA tool makes, and, ultimately, to ensure that the design refresh plan that MOCA suggests matches the goals and strategies enumerated by the roadmap. This results in the selection of the most cost effective design refresh strategy that is also viable and beneficial from the organization's standpoint.

Once the model was developed and implemented in the MOCA tool, a case study was performed for NAVAIR on the Advanced Mission Computer (AMC) for the V-22 Osprey tilt-rotor vehicle. A basic MOCA analysis was first run for the system, which determined that the optimum solution in terms of cost alone was to refresh the AMC system two times, once in 2009 and once in 2014. Doing so would cost approximately $4.1 million less than solving obsolescence issues reactively. In order to ensure that this plan was compatible with NAVAIR's independently generated plan for the AMC system, NAVAIR's technology roadmap for the V-22, and a smaller AMC specific sample roadmap were acquired and an inclusive timeline constraint as well as an associated cost constraint were applied to the MOCA simulation using the technology roadmapping model. The inclusion of the roadmapping information led to the selection of a different design refresh strategy. The MOCA analysis that included the roadmap information suggested a single design refresh event, with the design refresh scheduled for 2009 alone. This suggested strategy better reflects NAVAIR's technology roadmap, which suggests that the AMC system will be merged into a larger integrated system sometime between the years of 2008 and 2010, and that, once integrated, additional design refreshes of the system should be avoided. Thus the inclusion of the roadmap information allowed the MOCA tool to select the best design refresh strategy in terms of cost as well as viability.

5.2 Contributions

- The available literature describing technology roadmaps has been reviewed, and an alternative taxonomy of roadmaps has been developed that describes the types of roadmaps that are compatible with the MOCA analysis.
- A model has been developed that is capable of capturing the information found in technology roadmaps so that it can be included in obsolescence management and product sustainment analyses.
- This thesis represented the first known attempt to couple roadmapping information into strategic refresh planning and obsolescence management.

5.3 Future Work

Because technology roadmapping is a relatively new trend, many corporate technology roadmaps are not yet mature enough (or detailed enough) to be of value to obsolescence management. Like the NAVAIR roadmap, many roadmaps have reserved space for important information but have yet to fill that space in with the actual data. This data is necessary in order for any analysis of obsolescence strategy to be of value. However, the steps taken by large organizations towards roadmap development show that these organizations are aware of the gaps they need to fill before their planning processes can be truly streamlined and efficient. As better, more mature roadmaps become available the technology roadmapping information model may need to be expanded to include other types of information, or modified to include more specific types of information. An example of this is the ability to include changes to specific parts in the MOCA analysis or the inclusion of the XOR scenario discussed in Chapter 3. The technology roadmap information model, as it stands now, is prepared to accept this type of information, but since the NAVAIR technology roadmap was not detailed enough to provide it, nothing was implemented to allow this type of information to affect the MOCA analysis. If this type of information was available in future roadmaps the MOCA tool would have to be expanded to include it.

Appendix A - The V22 Avionics Roadmap (V1.1) and its Relation to MOCA

The following assessment of the gaps found in the V-22 technology roadmap was completed in June 2006 by Chris Wilkinson.

Introduction

The V22 roadmap sets out a technology insertion plan covering some 10 years+. This roadmap envisions the introduction of staged new functionality to the aircraft.

The roadmap identifies three stages of development for each functional change or addition. These are 1) trade studies, 2) tech. demos and 3) capability packages. These we interpret to mean 1) major sub-system functional requirements definition, 3) proof of concept technology development and 3) major sub-system development and first prototype build and test respectively.

In addition, the roadmap proposes a schedule for OT&E for MV (marine?) and CV (carrier?) V22 variants.

The roadmap identifies functions that are to be added or upgraded and a hierarchical tree leads down to a list of the hardware and software configurations items (HWCI/SWCI) affected by the change. In many cases these are TBD or vaguely stated in terms of major sub-systems (e.g. - 'radio').

Obsolescence is also listed in the roadmap, though this does not strictly constitute a functional upgrade. Consequently the HWCI's and SWCI's listed are simply 'all'.

Connecting the Roadmap to MOCA

MOCA needs data on 'parts', where parts are the lowest level of indenture at which maintenance is to be managed. This may be at the LRM or component[2] level. Since MOSA[3] is planned, COTS is most likely to be extensively used and the lowest indenture level will most likely be at LRM level. The other data required by MOCA consists of cost, quantity and schedule derived from a costed BOM, NREs, production schedule, and support life requirement.

The general process is illustrated in 27. An avionics functional upgrade is attended by the conventional development processes of requirements and design definition (see Figure 28). The inputs required by MOCA are derived from these processes along with cost, support and obsolescence data. There may be consequential changes at the airframe level such as wiring or even structural, but these are not considered by MOCA

There is an information gap between the functional requirements definition in the Roadmap and the MOCA tool. The gap consists essentially of the systems, hardware and software engineering processes that occur between a function requirement and an implementation package. This gap is the process shown in Figure 28.

Clearly these are early days for the IPTs and the functional requirements will become more refined over time into packages which can be fed into the systems engineering process to begin the development cycle. In the meantime, it is not clear how any generalized process for a meaningful sustainment plan can be generated.

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[2] Component here refers to electronic components

[3] Modular Open Systems Architecture

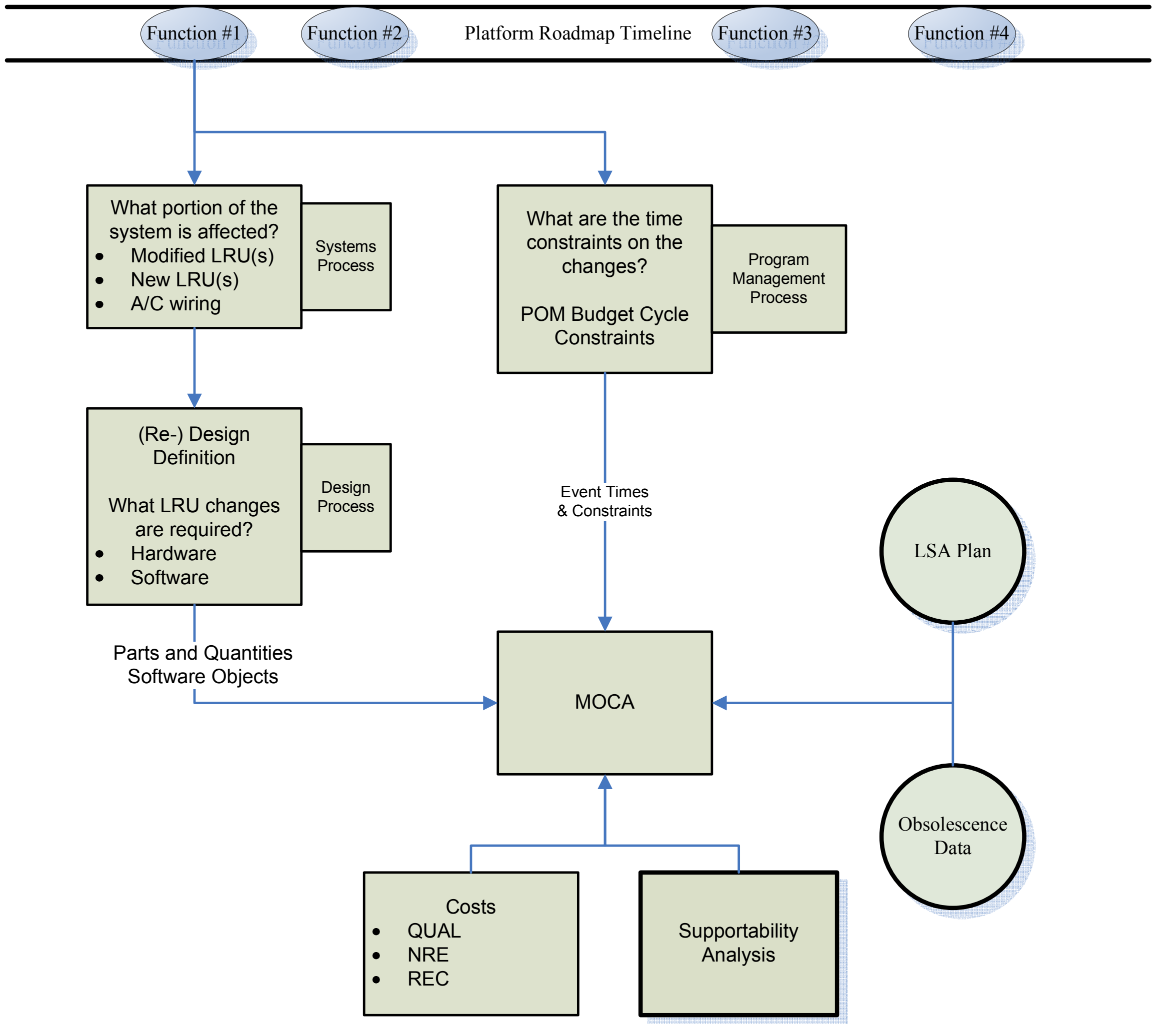

Figure 27 – MOCA Relationship to the Roadmap

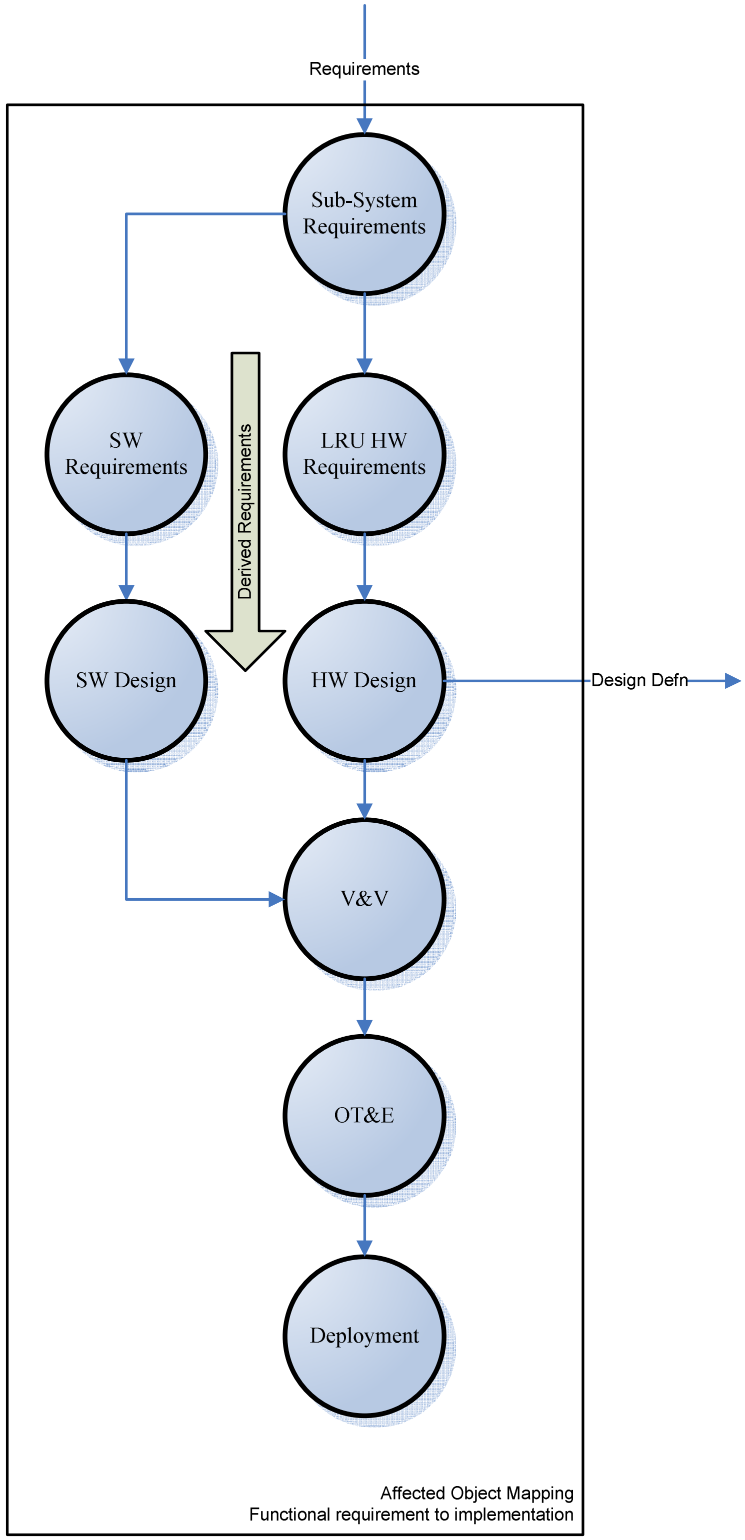

Figure 28 – Design Process

Appendix B - User's Manual for the Technology Roadmapping Interface in MOCA

This Appendix provides supplementary information for the MOCA User's Manual [26].

Roadmapping Constraint Instructions

To access the Redesign Constraint dialogue box go to 'Inputs' along the main toolbar and drop down to select the 'Redesign Roadmap Constraints' option. This will bring up the redesign roadmap constraint data field menu shown in Figure 29.

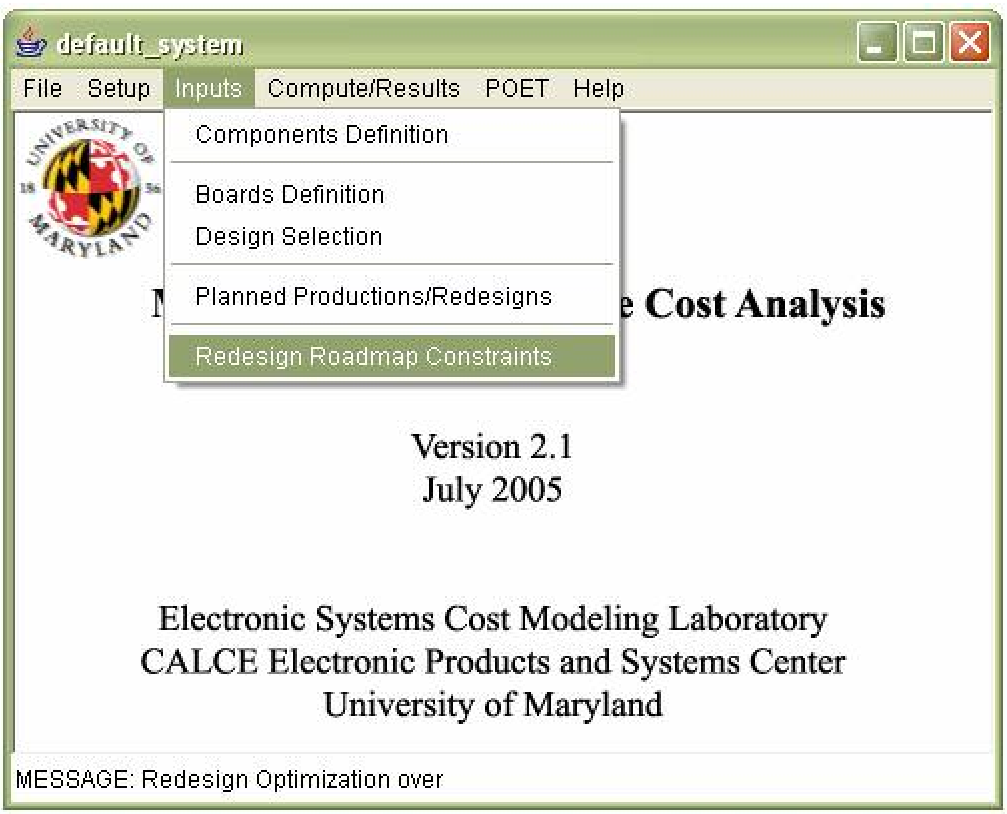

Figure 29 – MOCA Tool

The redesign roadmap constraint dialog box has several fields which must be filled in for each applicable constraint. Each row in the spreadsheet field represents a single constraint event to be taken from the roadmap. Constraints are representations of roadmap events that may effect the decisions the MOCA tool makes since they may either add additional costs to certain redesign plans or may make certain plans impossible to carry out. The columns of the row should be filled in as follows:

Constraint : The name of the event, or any other way of identifying the given roadmap constraint, provided that the identifier is a String.

Period Start : A double value representing the year the roadmap constraint will take effect. The value does not have to be an integer, as decimal places will represent partial years. (i.e., 2007.5 represents July of 2007)

Period End : A double value representing the year the roadmap constraint will end. The value does not have to be an integer, as decimal places represent partial years.

Associated Cost : This field represents any special costs associated with the constraint. If there are no additional costs associated with the constraint, the field can be set to zero, or the 'Apply Cost?' column can be set to false'.

Apply Cost? : This field accepts a Boolean operator ('true' or 'false' in lower case letters) which controls whether the associated cost in the previous column is added in or not. If the 'Apply Cost?' column is set to false, no associated cost will be added to any refresh plan. If the 'Apply Cost?' column is set to true, the associated cost will be added to refresh plans with refresh dates falling between the 'Period Start' and 'Period End'.

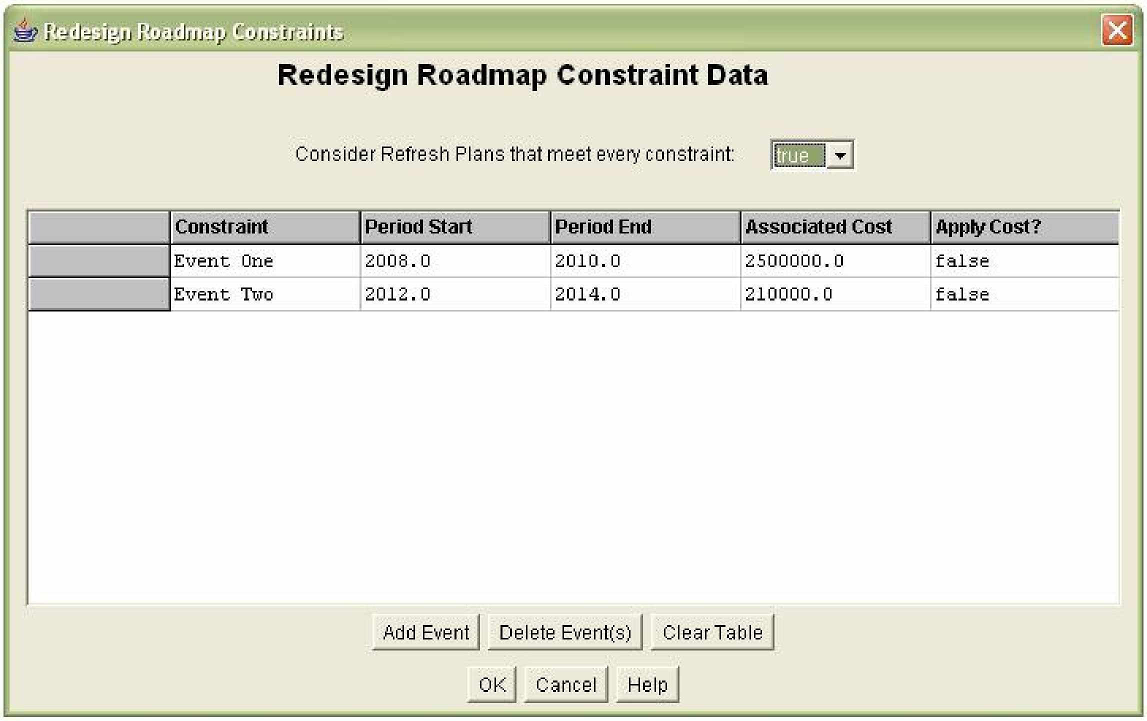

Figure 30 – Roadmap Constraint Dialog Box

In addition to the spreadsheet rows, there is a single Boolean drop down menu, with choices of 'true' and 'false', located above the spreadsheet fields next to the text 'Consider Refresh plans that meet every constraint'. This Boolean menu controls how the redesign constraints found in the spreadsheet are interpreted when the 'Force Refresh' button in the Design Refresh Planning Results Graph is pressed. The 'Force Refresh' button is located in the bottom right hand corner of the Design Optimization Results Graph. If the 'meet every constraint' Boolean is set to true, only refresh plans that contain design refresh events in both constraint periods will be considered. If the 'meet every constraint' Boolean is set to false, only one of the constraints must be met for a given refresh plan to be considered.

The 'Force Refresh' button will place an 'x' through all refresh plans on the Output Graph that do not meet the constraints specified in the Roadmap Constraint Dialogue. In the case of the example above, where there are two constraints, Event 1 from 2008 to 2010 and Event 2 from 2012 to 2014, changing the Boolean value associated with meeting every constraint will change the results of the MOCA analysis. If the Boolean is set to ‘true’, only plans with refreshes during both periods will be acceptable. In the case of the first figure below, all plans have been eliminated since all red dots represent refresh plans with only a single refresh date, and no single refresh can fulfill both constraints. If the Boolean is set to false, there are two sets of possible solutions, since fulfillment of either constraint is acceptable.

References

[1] Alignent Software. 'Alignent Vision Strategist'. 16 Feb. 2007. <http://www.alignent.com/products/visionstrategist/>

[2] "AN/AYK-14 (V)". General Dynamics Advanced Information Systems. <http://www.gd-ais.com/Capabilities/offerings/sr/Processors/ayk141.htm>

[3] Bower, J.L. and Christensen, C.M. 'Disruptive technologies: Catching the wave.' Harvard Business Review (January-February 1995), pp. 43-53, *Journal of Product Innovation Management*, Volume 13, Issue 1, January 1996, Pages 75-76.

[4] Coates, V., Faroque, M., Klavins, R., Lapid, K., Linstone, H.A., Pistorius, C., and Porter, A.L., "On the Future of Technological Forecasting," *Technology Forecasting and Social Change*, Volume 67, Issue 1, pp. 1–17, 2001.

[5] DeCamp, J., "Obsolescence Management Toolsets Survey," *Proceedings of the 2005 Aging Aircraft Conference,* 2005. <http://www.jcaa.us/AA_Conference2005/DMSMS/Ses35/35_0900_DeCamp.pdf>

[6] Feng, D. 'Optimizing Lifetime Buy Quantities to Minimize Lifecycle Cost'. Unpublished masters thesis, University of Maryland, College Park, Maryland, USA.

[7] Galvin, R. (1998) "Science Roadmaps" Science, Volume 280, Number 5365, p. 803

[8] Gargini, P., Glaze, J., and O. Williams, "The SIA's National Technology Roadmap for Semiconductors," *Solid State Technology*, Volume 41, Issue 1, pp. 73-84, Jan. 1998

[9] Gerdsri, N., "An analytical approach to building a technology development envelope (TDE) for roadmapping of emerging technologies," *Technology Management: A Unifying Discipline for Melting the Boundaries* , pp. 123- 135, 31 July-4 Aug., 2005

[10] Groenveld P., (1997) "Roadmapping Integrates Business and Technology", *Research-Technology Management*. Volume 40, Issue 5.

[11] Herald T., Genaw, D., "Technology and Obsolescence Sustainment for Integrated Systems," *Proceedings of the 16th Annual International Council of Systems Engineering (INCOSE)*, 2006.

[12] Hicks, B.; Riggs, L.H.; McDaniel, L.; Sanner, J., "Managing change through roadmapping," *Digital Avionics Systems Conference, 2003. DASC '03. The 22nd* , vol.2, no.pp. 11.D.4- 11.1-8 vol.2, 12-16 Oct. 2003

[13] Kappel, T.A. (2001), 'Perspectives on roadmaps: how organizations talk about the future', *Journal of Product Innovation Management*, pp. 39-50.

[14] Kostoff, R.N., Boylan, R., and Simons, G.R., Disruptive technology roadmaps, *Technological Forecasting and Social Change*, Volume 71, Issues 1-2, Roadmapping: From Sustainable to Disruptive Technologies, January-February 2004, Pages 141-159.

[15] Kostoff, R.N. and Schaller, R.R. Science and technology roadmaps. *IEEE Trans. Eng. Manage.* Volume 48, Issue 2, pp. 132–143, 2001.

[16] Linstone, H.A. TFSC: 1969-1999, *Technological Forecasting & Social Change* Volume 62, pp. 1-8, 1999.

[17] Nesdore, P., "Semiconductor Industry Association Roadmap: Blueprint for Tomorrow," *Solid State Technology*, Volume 40, Issue 12, p. 42, 45, Dec 1997.

[18] Petrick I.J., and Echols, A.E., Technology roadmapping in review: A tool for making sustainable new product development decisions, *Technological Forecasting and Social Change*, Volume 71, Issues 1-2, Roadmapping: From Sustainable to Disruptive Technologies, January-February 2004, Pages 81-100.

[19] Phaal, R., Farrukh, C.J.P. and Probert, D.R. (2001a), 'Characterisation of technology roadmaps: purpose and format', *Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET '01)*, Portland, 29^{th} July – 2^{nd} August, pp. 367-374.

[20] Phaal,R., Farrukh, C. and Probert, D. (2003)"Technology Roadmapping: linking technology resources to business objectives", Centre for Technology Management, University of Cambridge

[21] Phaal, R., Farrukh, C., and Probert, D. "Developing a Technology Roadmapping System," in *Technology Management: A Unifying Discipline for Malting the Boundaries*, T.R. Anderson, D.F. Kocaoglu, and T.U. Daim, Eds. Portland: PICMET, 2005.

[22] Porter, A.L., and Detampel, M.J., "Technology Opportunities Analysis," *Technological Forecasting and Social Change*, Volume 49, Issue 3, pp. 237-255, July 1995.

[23] Porter, A.L., Jin, X.Y., *et al.*, “Technology Opportunities Analysis: Integrating Technology Monitoring, Forecasting, and Assessment with Strategic Planning,” *SRA Journal,* Volume 26, Issue 2, pp. 21-31, October 1, 1994.

[24] Rinne, M. Technology roadmaps: infrastructure for innovation, *Technological Forecasting & Social Change.* Volume 71, Issues 1-2, pp. 67-80, 2004.

[25] Roberts, E. (1969), "Exploratory and normative technological forecasting: a critical appraisal", *Technological Forecasting and Social Change*, Volume 1. pp.113-27.

[26] Sandborn, P. ‘MOCA User’s Guide.’ CALCE Electronic Product and Systems Center. <http://www.calce.umd.edu/contracts/MOCA/restricted/Documentation/MOCA2-1/MOCA_manual_2.1.pdf>

[27] Singh, P. and Sandborn, P. "Obsolescence Driven Design Refresh Planning for Sustainment-Dominated Systems," *The Engineering Economist*, Volume 51, Issue 2, pp. 115-139, April-June 2006.

[28] Stogdill, ‘R.C. Dealing with obsolete parts’. IEEE Design & Test of Computers, Volume 16, Issue 2, Apr-Jun 1999 Pages:17-25

[29] Teichert, T., and Mittermayer, M.A., "Text Mining for Technology Monitoring,"*Proceedings of the IEEE International Engineering Management Conference (IEMC),* Volume 2, pp. 596- 601, 2002.

[30] Walsh, Steven T., Roadmapping a disruptive technology: A case study: The emerging microsystems and top-down nanosystems industry, *Technological Forecasting and Social Change,* Volume 71, Issues 1-2, Roadmapping: From Sustainable to Disruptive Technologies, January-February 2004, Pages 161-185.

[31] Willyard, C.H. and McClees, C.W. (1987) "Motorola's technology roadmap process",Research Management, Sept.-Oct., pp. 13-19.

[32] Zhu, D., Porter, A., *et al*., “A Process for Mining Science & Technology Documents Databases, Illustrated for the Case of ‘Knowledge Discovery and Data Mining’.*Cienc Inf.,* Volume 28, Issue 1, pp. 1-8, 1999.

[33] Zhu, D., and Porter, A.L., “Automated extraction and visualization of information for technological intelligence and forecasting,” *Technological Forecasting and Social Change*, Volume 69, Issue 5, pp. 495-506, June 2002.