LIFE CYCLE EXTENSION STRATEGIES FOR LEGACY SYSTEMS

By

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CHAPTER I

INTRODUCTION

Purpose of the Study

For years, the rapid growth of technology has fueled business expansion and success. Vast improvements in speed, materials, processes and size of systems have created an issue affecting everyone from commercial business to the US government. These organizations are struggling not always to stay ahead, but to sometimes just stay in touch with the ever-changing technology world of increasing speed, increasing memory requirements, & improved technologies. In the midst of this struggle, these organizations may find themselves dealing with legacy systems, systems that are vital to the organization, but with which they (the organization) do not know how to cope (Bennett, 1995). Not knowing how to cope with these systems means that the organizations are unable to deal with a system that has decreasing reliability from degrading structure, and increasing cost due to rising maintenance requirements as the system ages (Bennett, 1995). There are other reasons for legacy systems to be considered legacy and these will be discussed below. There are solutions for managing the problems of legacy systems and this paper will present a method of finding a satisfactory solution.

. The first step in resolving the problem is determining if the system is a legacy system. A legacy system is considered a bequeathed system that no one wants to deal with but is too important to ignore (Adolph, 1996). Legacy systems have become a problem to an organization that possesses them for one or more reasons. These reasons could include technical obsolescence, high maintenance costs (Bray et al., 1995; Sage, 1995; Sneed, 1995), or the system could have simply reached the end of its design life (Prescott, 1995; Reinertsen, 1996).

One reason these systems are a problem is that they are approaching or have already reached a state of technical obsolescence. Technical obsolescence is defined by other researchers as deterioration of the technical knowledge of engineers (Glass, 2000; Kahn, 1990). From this definition it can be assumed that since these previous engineers are lacking technical knowledge of the new systems, new engineers are lacking the technical knowledge of the old systems. From this assumption, these older systems are becoming technically obsolete due to the fact that the knowledge base needed for these systems is either no longer present or is quickly declining. Technically obsolete systems may still be performing the tasks for which they were originally made, but in order to continue performing at a level at which it was originally designed they need to incorporate new and/or better technologies (Aiken et al., 1993). These technical changes will aid in the deterrence of obsolescence upon the system, because the newer engineers will be able to understand this newly implemented technology. Technically obsolete systems can remain operational as long as they do not become functionally obsolete. A functionally obsolete system no longer functions in a way that is meaningful for the organization. Therefore it has already become unnecessary or obsolete and can be discarded. However, Technically obsolete systems can have their lives extended in order to avoid functional obsolescence.

One example of technical obsolescence are NASA space shuttles (Vedantam, 2003). The space shuttles, which once boasted as being futuristic, have reached a state where they are bound by outdated technologies, some of which run vital parts of the space shuttle. One example of such a vital component is the IBM computers which are considered the main computers for the shuttles. They have not been updated since 1988-89 and astronauts have to carry laptop Windows computers to run high-speed science experiments. NASA has had to create a network of suppliers to obtain these older technologies. These parts are becoming increasingly unobtainable, which is what has forced the NASA space shuttle into a state of technical obsolescence. Since the shuttle still functions as it was designed, it has not reached a state of functional obsolescence. For this reason, the space shuttle could be considered a legacy system.

Some companies may try to deter the inevitable decline of a system into obsolescence by maintaining the system. While effective maintenance of a system will more than likely let the system continue operating at its normal capacity (Chockie et al., 1992), this can be a very expensive option and may have already been ruled out because of unacceptable maintenance costs (Bray et al., 1995). Maintenance costs are very high when compared to the other costs of a systems life (Buede, 2000). A discussion of maintenance costs is given later in this section. Also continued maintenance, especially on software systems, has been known to cause degradation that can lead to larger problems (Bennett et al., 1999).

Another challenge to business finding personnel that have the skill set and are willing to maintain older systems (Bennett, 1995). One reason for this is that these skills may not have been passed on to the next employee that is in charge of the system. The previous employees, who knew and understood the system, have moved on to other tasks. The present employees often do not know enough about the system to perform the more specialized procedures, and past employees may not be available or willing to aid in the maintenance of an older system because it is a less desirable job (Adolph, 1996).

One example of this type of legacy system is the IBM's CICS (Alderson et al., 1999). It is defined as a legacy system because it requires skills to maintain it that are considered legacy skills. Finding the people with these skills is difficult and can cause problems when facing the maintenance of these systems.

The cost associated with legacy system maintenance is another issue. The development costs of a system can be substantial, but are usually small by comparison to the mass amounts of money spent during maintenance (Buede, 2000). The costs can range from 60% to 90% of the technology budget (Ahrens et al., 1995; Aiken et al., 1993; Bennett et al., 1999). Figure 1 shows the cost of maintenance when compared with the costs incurred during various stages of development. The numbers in parenthesis represent the ranges of average costs of each phase found in a study presented by Buede (2000). The units are generic average units relative to each case in the study. While this graph was meant for a software system, the impact of the graph does not lose any strength when applied to other systems.

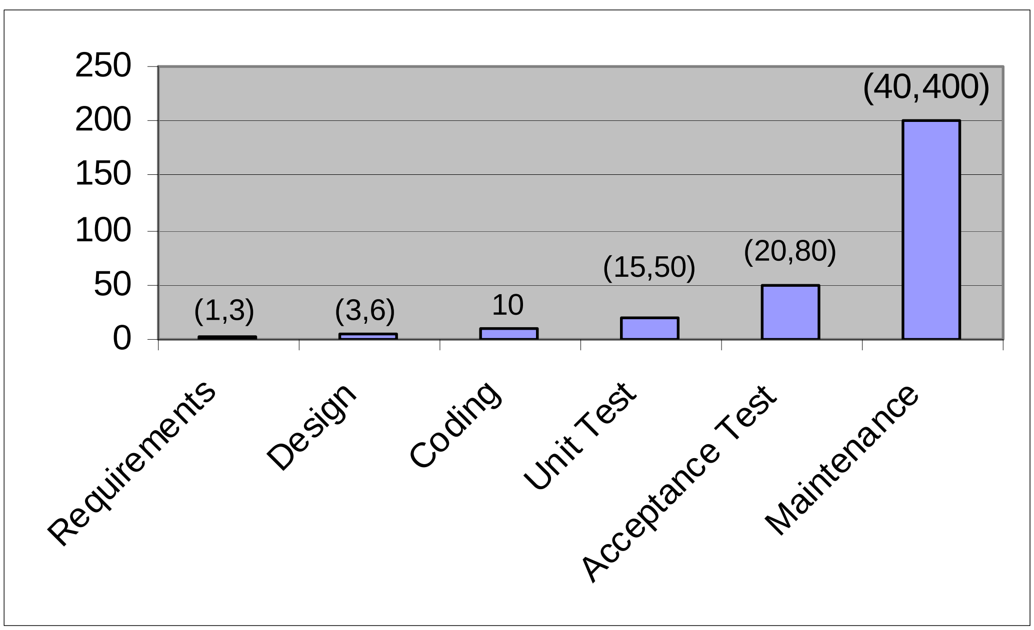


Figure 1. Relative costs of phases in product life cycle (Buede, 2000)

It is apparent from this graph that the maintenance cost of a system is the most substantial cost of the life cycle. This high maintenance cost is part of the reason that legacy systems are a problem. Legacy systems have operational and maintenance costs that have reached unacceptable levels (Bray et al., 1995) and the systems continue becoming more expensive as they age due to increasing maintenance demands (Bennett, 1995). This is one of the main motivations for defining legacy systems and finding solutions to the problem.

Systems can be considered legacy simply for the reason that they have reached the end of their design life (a.k.a useful life) (Prescott, 1995; Reinertsen, 1996). The design life is the intended life of the system, based on the requirements provided during development. For example, when the nuclear power plants in the Norwegian sector of the North Sea were first built around 40 years ago, their design life was 40 years (Reinertsen, 1996). Now there are safety and design problems based on factors including that it had reached the end of its design life and system degradation for extended exposure and use. These power plants have been labeled legacy for these reasons.

Legacy systems are also very important to study because they are often linked directly to the organization's core competency or core business(Liu et al., 1998). These systems can contain valuable data, functionality and expertise that can not be ignored. Legacy systems may hold information that encodes the organization's business processes (an example is an ERP – Enterprise Resource Planning systems). For this reason these systems have become part of the backbone of the organization. If these systems fail or begin to lose capabilities they can cause business loss. These systems have become so vital to the operation of the company that the replacement of the system would be too risky and the down time of the system could not be endured.

Organizations that find themselves with a legacy system are now becoming interested in extending the life of these systems instead of the more time consuming and costly method of replacing the system altogether (Madisetti et al., 2000). The process of extending the life of a system will be referred to as life cycle extension. Life cycle extension projects are usually sought for reasons of either wanting to keep these legacy systems in a state of "operational readiness" (Littlejohn et al., 2000), or in order to maintain "operational objectives" (Mahaffey et al., 2000). Although there are many suggested methods of life cycle extension, i.e. reengineering, reverse engineering, design recovery, etc… (Chikofsky et al., 1990), there is a lack of guidance for the managers of these systems to help in making decisions on what method to use (Brooke et al., 2001). This lack of guidance is what led to the undertaking of this study.

Organizations must be sure that they will achieve a significant benefit in reducing costs and increasing value without a disruption to the systems services when extending a system's life (Sneed, 1995). Choosing the correct method of life extension from among many options could aid in the project benefits such as reduced cost and time. Having an approach to making a decision about legacy systems would be invaluable to management faced with this very interesting, understudied and critical problem. This study presents a model that was developed for that reason. This model, the Life Cycle Extension Model, is a tool that will aid in the decision of how to extend the life of a legacy system.

The Study

This study will explore how the characteristics associated with a system can determine the solution methods that could best be used for life cycle extension of that system. The paper explores many different methods that can be used for life cycle extension and presents a model for deciding when one method of extension is advantageous over another. The literature that was reviewed for this paper presented only minimal explanations of when one method should be chosen over another, and a significant portion of that literature focused on software and information systems. This paper not only points out the missing pieces in the literature by providing examples of literature deficiency, but it also explains the model, how it was developed, and how it is used.

The Life Cycle Extension model will be developed using characteristics and methods collected from many sources to bring together a consolidated guide for managers to follow when extending the life of a legacy system. The systematic review of the literature as well as expert opinion was used to present an extensive list of characteristics and methods that are each analyzed and presented in a table form. The model compares the characteristics of a legacy system with the characteristics associated with the methods that are presented for life extension. This provides a way for the users of the model to analyze their legacy system and see the associated method that could be used for life cycle extension.

The model was tested for validity using a case study involving a guidance system of a missile. This system was used because it was deemed a legacy system by the system management and was in the process of having its life extended. Also the academic advisor had access to interview participants. The interviews conducted during this study were with decision makers involved directly with the legacy guidance system and the life cycle extension project. The questions that were asked aimed at obtaining the characteristics of the legacy guidance system that were needed in order to fill in a matrix model for comparison to the developed Life Cycle Extension Model. The interviewees were also asked what method they were using for this life cycle extension project. The characteristics of the legacy system obtained from the interviews were compared with the Life Cycle Extension model to determine what method the model presented as the correct life extension strategy to use. This method was compared with the method given by the interviewees during the case study. Since the life extension method determined by the model agreed with the method chosen by the interview participants in the case study, the model has successfully predicted the method used for life extension and can be considered a useful tool.

Outline of Thesis

The first chapter includes the purpose of the study and explanations of why it is important to study legacy systems. It gives examples of legacy systems and how these systems have presented problems to the organizations. Chapter I also gives an explanation of how this paper is designed to help with this problem by aiding in the life cycle extension project decision.

To understand this model and its intended purpose, a background of systems and legacy systems will be presented in Chapter II. Chapter II presents the background after an explanation of the systematic review process. It also explains system life cycles and life cycle extension to give further explanation of the model.

The remainder of the paper is dedicated to the Life Cycle Extension Model. Chapter III will present the model and discuss the concept of how it is used. The case study that was performed will be discussed in Chapter IV, which provides an example of how to perform the legacy system analysis using the model. The analysis and results of the case study research are also presented in this chapter. The major conclusions, including conclusions about the model and the literature, are discussed in Chapter V. Areas for future research will also be covered within Chapter V.

CHAPTER II

LITERATURE REVIEW

Systematic Review

The literature review was conducted in a manner known as systematic review. A systematic review is 'the application of scientific strategies that limit bias to the systematic assembly, critical appraisal and synthesis of all relevant studies on a specific topic' (Magarey, 2001). This method of literature review ensures a comprehensive, unbiased collection of all resources available on a topic. The intensive searching methodology provided a means for the researchers to find all relevant papers on the subject of legacy systems, life cycle extension and other topics pertaining to this research.

The traditional method of literature review does not attempt to obtain all papers written on a particular subject (Magarey, 2001). This automatically subjects the research to bias as the reviewer may include articles that support the research topic and leave out the papers that do not. Magarey suggests that the use of this traditional method of literature review should not be used in research where evidence is being gathered regarding the effectiveness of an intervention.

Many methods of intervention have been developed for the area of obsolescence management and many studies have been conducted with these interventions, but no study takes into account all of these interventions into a single study. This research was conducted in order to produce that single, unified study and for this reason a systematic review of the literature was needed in order to perform a complete analysis of the available sources.

Literature Review Process and Statistics

The literature review began with the researchers (who included the author of this paper and a masters colleague, with aid from the academic advisor) compiling a comprehensive list of key words and phrases that could be appropriate for the research. The list of key words/phrases originally included many legacy system characteristics and associated topics and several of the methods that were ultimately used in the model. The remaining methods used in the model were found during the literature review and the methods were included in the key words list in order to have a complete list of methods researched in each database. The final list of key words used for the literature review, which included words and phrases found during the initial review of the documentation, included all of the methods used for the model and many other key words/phrases that were necessary to give the literature a thorough review. The list of words/phrases can be seen in Table 1.

Table 1. Key words/phrases for literature review

Key Words for Literature Review	
- Legacy System	- Functional Discovery
- System	- Decision Methods/Making
- Legacy Components	- Reverse Engineering
- Obsolescence	- Redesign
- Obsolescence Management Strategy	- Re-engineering
- Life Extension	- Design Recovery
- Product Life Extension	- COTS – Component Off The Shelf
- Life Cycle Extension	- DMSMS – Diminishing Manufacturing Sources and Material Shortages
- Expected Life	- Operational Readiness
- Life Cycle Costs	- LOT – Life Of Type buy
- Non-recurring Engineering	- System Engineering
- Operational Effectiveness	- Outsource
- Migration	- Maintain
- Spare Parts	
- Wrapping	

This list of key words and phrases was the building block upon which a number of documents, books, and papers were compiled using a variety of databases, libraries, and online journals. The decision of what type of journal, databases, and libraries to use was made by the researchers before the search began. A complete list of the locations used for the search is listed in Table 2. The search returned documents going back more than 20 years, specifically to 1981. These resources were the supply of the characteristics, examples, and definitions used throughout this research.

Table 2. List of locations searched in literature review

Databases, Libraries and Online Journal used in Literature Review	
- ACM digital library – Association for Computing Machinery - DDRS - Declassified Documents Reference System - United States - ProQuest Digital Dissertations - DOD - http://www.defenselink.mil - GPO - Government Printing Office Access - IEEE Xplore - Web of Knowledge - Web of Science - Wiley Interscience - Tennessee Electronic Library	- InfoTrac - Journal Citation Reports Web (JCRWeb) - Science and Social Sciences Editions - JSTOR – Journal Storage: The Scholarly Journal Archive. - Lexis Nexis Academic - PAIS: Public Affairs Information Service - ProQuest - Science Direct - ATHENA – The Virtual Library of Many Members of the Nashville Area Library Alliance

The initial search of all locations using the keywords in Table 1 yielded over 90,000 documents, books, and papers. This was a combination of all searches performed at each location. Many of these were repeated documents common to multiple databases or documents that were not applicable to this research and were discarded after reading the titles. The remaining results were filtered by initially scanning the titles and summaries of every resource. This resulted in removing many more from the initial search because of a lack of pertinence to the subject or because the subject matter was too specialized. An example of a return that lacked pertinence is a paper that dealt with the securing of online credit card payments without disclosing private information. An example of subject matter that is too specialized is an article that discusses mathematical equations associated with how to perform systems engineering. These articles, while interesting and could be relevant to other situations, were not applicable to this study being conducted for legacy systems. The remaining irrelevant articles were dismissed by reading deeper into the summaries and introductions of each source to discover if it would be of any use for this research. The remaining sources were then analyzed on the basis of reliability. This means that the publication for which the source originates needed to be refereed or accepted by engineers as valid data. The only exceptions to this rule were newspaper articles that gave examples of legacy systems or pertinent concepts that are only just now coming into the legacy system scene. An example is a newspaper article from the Washington Post about the Space Shuttles (Vedantam, 2003). An example of a new pertinent concept would be Functional Discovery, which is just now being developed and researched (Mahaffey et al., 2000).

Once these resources were sorted through and the irrelevant articles discarded, the documents' bibliographies were analyzed to find any resources that might not have been found in the initial searches. This analysis also provided a means of ensuring that the researchers had obtained all the papers that are commonly used in papers on this subject. This made the systematic review of the documents more thorough and ensured that the most respected papers on this subject were found and used for this research.

These few remaining sources were then analyzed, in detail, to discover what, within its context, would be useful information. Some of these sources only mention in passing legacy systems or the methods of dealing with them. This means that some only mention that their system is legacy, or that they used a method, maybe reengineering, to correct the problem with their system, but did not give a definition or explain the concept behind their actions. Since these sources could not give a reason for why they used reengineering or even a definition of reengineering, the paper was considered a useful resource only in the fact that the system in question could be considered a legacy system and could be used as an example of one. This was shown in a paper that spoke of a legacy computer system that was reengineered by the staff for the project (Adolph, 1996). The paper never gave a definition of reengineering and the process that was undertaken almost matched the definition of building a new system. For this reason, this article was saved for an example of a legacy system and further research on the method that was used for their project.

After all of the sources were sorted through and analyzed for context, 60 resources were available for further review and inclusion in the systematic review of the literature. The following table shows a breakdown of the references that were used and what its main focus was for inclusion in this study. The duality of the key concepts results in the totals adding to larger than 58.

Table 3. Summary of systematic review

Key Word	**Total**		**Key Word**	**Total**
System			**Methods**	
Legacy System (1993 – 2004)	16		Reengineering (1990 – 2002)	24
Life Cycle (1981 – 2000)	10		Reverse Engineering (1985 – 2002)	19
			Build New System (1995 – 2002)	16
Research Aids			Spare Parts (1992 – 2004)	14
Case Study (1989 – 98)	4		Design Recovery (1989 – 99)	11
Systematic Review (2001)	1		Migration (1992 – 2003)	7
			Wrapping (1999 – 2002)	6
Others			Outsourcing (1998 – 2004)	5
Maintenance costs (1981 – 2000)	9		Ignore Problem (1995 – 1999)	4
Obsolescence (1999 – 2003)	6		Maintain (1992 – 2002)	3
Design Life (1995 – 96)	2		Functional Discovery (2000)	1

This table shows how the references used for this research was focused and in what areas each one presented useful information. For example, there were 16 resources that were helpful in describing legacy systems or providing a thorough example of what a legacy system is and/or is not. While there may have been other examples of systems within some sources, these 16 provided the basis for the explanation of legacy systems and the characteristics used within the Life Cycle Extension Model. Each of the other key words listed were analyzed for their final counts in the same manner. Some were detailed papers explaining concepts and theories of legacy systems and their life extension characteristics and methods, as with Chikofsky and Cross's explanation of legacy systems and methods of life extension (1990). Others were examples of legacy systems or methods of correcting a legacy system, as with the description of a legacy information system and the reengineering of a replacement system for modification (Aiken et al., 1999). A list of resources that were used as examples for the different methods can be found in the table in Appendix A. Since these examples could be very numerous if un-refereed or all newspaper articles about legacy systems are included, future searches for this same base of key words could result in numbers that do not exactly match those shown in Table 3. Also since bias can be involved in any literature search, regardless of the efforts made to avoid bias, certain resources could be removed from the resources provided here while others, that were removed, could be included. While the researchers were aware of these issues, all bias might not have been removed from the literature review, but in an effort to control bias both the author of this paper and a fellow colleague conducted the same literature review. Each resource is listed in the References of this paper.

Legacy Systems

To get an understanding of what a legacy system is, the definition and concept behind a system needs to be explained. A system is defined as a collection of different things, related to create a result greater than the parts could produce separately (Rechtin, 1992). For example, an assembled automobile provides transportation while its separate components cannot. Taking the definition a little farther, a system can be defined as an open set of complementary, interacting parts with properties, capabilities, and behaviors emerging not only from their parts, but from their interactions as well (Hitchins, 1998). External factors can effect the system no matter where the boundaries of a system are drawn (Rechtin, 1992). This is because one system is always part of a larger system. Systems do not operate in isolation and must comply with outside restrictions placed upon them (Hitchins, 1998). Legacy systems are a system as defined here, but they are being analyzed because of the need to correct obsolescence issues and to extend the system's life.

The exactly definition of a legacy system is not as easily obtainable as the definition of a system. Actually the exact definition is currently a subject of some debate among academics and practitioners (Brooke et al., 2001). Even though practitioners have an understanding of what constitutes a legacy system, it is still difficult to find an adequate definition (Gold, 1998). The concept of a legacy system is easier understood by looking at many different definitions and discussing them together. A discussion of legacy systems and some traits that characterize legacy systems was discussed previously in Chapter 1. This discussion continues with that explanation of legacy systems and elaborates. More examples of legacy systems are also given for better understanding.

A legacy system is defined in Chapter 1 as a system that is vital to the organization but that the organization is incapable of coping with (Bennett, 1995). Not knowing how to cope with these systems means that the organizations do not know how to manage a system that has decreasing reliability caused by degrading structure, and increasing cost due to increasing maintenance requirements as the system ages (Bennett, 1995). These systems are often bequeathed from previous generations and have reached a point in which they are no longer meeting the needs of the business environment (Brooke et al., 2001). An example of this is an outdated information system that the Air Force fleet uses for its supply and demand of spare parts (Erwin, 2004). This system provides inaccurate data that results in parts shortages. This system is no longer meeting the expanding needs of this environment. These needs could include the interfaces of the system with its external systems. The environment in which these systems operate may have changed and have become incompatible with the system interfaces(Liu et al., 1998). The system could also be degrading physically and replacement components might be hard to come by for reasons of manufacturer discontinuance. The scope for these systems have ranged from a large software system(Bennett, 1995) to a much wider description that includes the people, expertise, hardware, data, business processes, approaches to maintenance and development, and its relationship to the business environment(Brooke et al., 2001).

Legacy systems may have reached or are approaching technical obsolescence (Solomon et al., 2000). A technically obsolete system is defined as a system that needs new and/or better technologies in order to continue performing at the level for which it was originally designed. Obsolescence issues could arise from a manufacturer no longer making a particular part, manufacturer went out of business, or a part no longer meets the needs of the system (Brooke et al., 2001; Solomon et al., 2000). For example, The Castle Peak Power Station, Hong Kong's largest power plant, could no longer get the parts that were necessary an existing boiler control system, because the vendor was no longer in business (Peltier, 2003). This led to a legacy system decision. The DoD often runs into obsolescence issues due to long life cycles of weapon systems (Young et al., 1999). This could be brought about by the fact that the technology that defines the part is no longer used either to manufacture the part, or as a solution for the functionality of that specific part (Solomon et al., 2000). This could cause problems when attempting to incorporate a new part into an old design. Also the manufacturers of some replacement components may have decided to discontinue the part because it is no longer useful in commercial systems. Consumers of these commercial systems demand the latest and greatest technologies and the old components get pushed aside to make room for the new products. This forces the DoD system management into an obsolescence decision. These obsolescence issues do not necessarily mean that the system is no longer functioning at is originally designed level, just that steps need to be taken to resolve the issues that have brought it to legacy status.

It is important to realize that the obsolescence issue mentioned here is technical obsolescence. If a system has reached a state of functional obsolescence, it is no longer functioning as it was originally designed. Legacy systems may not be meeting business needs, or they may be technically obsolete, but this does not mean that it is not functioning as it was originally designed. If it is not functioning or performing the tasks for which it was originally designed, then the system is functionally obsolete. Functionally obsolete systems can be discarded because the function it provided has become obsolete or the system itself is not longer functioning in its designed manner.

While it appears from the above descriptions that legacy system can have a destructive or at least a negative presence in an organization, this is not always the case. These systems could be considered the core business or core competency of the organization and perform crucial tasks (Bennett, 1995; Brooke et al., 2001; Liu et al., 1998). Legacy systems sometimes contain valuable data, functionality, and expertise that can not be ignored. This could be an ERP system that holds the keys to business operations. These systems have become indispensable to the organization and this makes the complete replacement of these systems inadvisable from an operational and economical viewpoint (Liu et al., 1998). This adds to the urgency behind finding a solution for the legacy system.

At some point, organizations must make a decision about legacy systems. Is the system a legacy system? Will this system endanger the operation of the company? Many other questions can be asked. While a description of a legacy system is presented here, it does not cover everything that could be considered a legacy system because legacy systems are not clearly defined. At one extreme, the management needs to decide if the system is legacy. At another extreme, legacy is decided by the fact that a newer version of the system has been produced forcing the other into obsolescence. In either case, once this decision is made, action should be taken to correct the legacy issue. This thesis is a step toward that process of correcting the legacy problem with the best method possible.

Life Cycle of a System

To better explain life cycle extension, the life cycle of a system needs to be defined and explained. A system life cycle can be defined as the system from “birth to death” (Buede, 2000). This life cycle has many phases and a system can become legacy during any stage of its life cycle. As shown in Figure 2, adapted from Solomon, et al. (2000), there are six main stages that a system can go through. Although this graph was originally made for an electronic product and not a generic system, it is presented here as a good representation of a generic system life cycle. This life cycle representation is used because of its simplicity and the fact that it can characterize the life cycle of many different systems.

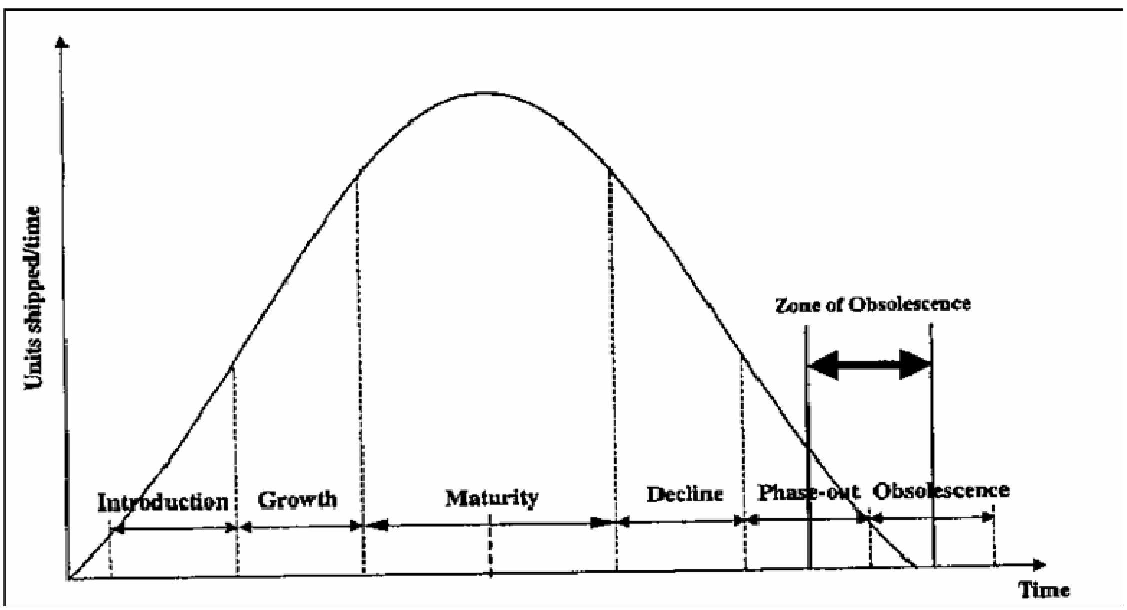


Figure 2. Life cycle of a system. (Solomon et al., 2000)

This figure shows several stages of a system during its life cycle. A systems life cycle begins with the Introduction phase (Solomon et al., 2000). This phase is characterized by high production and development costs. The system could be modified several times before the final version is accepted. A system could be classified as legacy during this phase if the system takes a long time for design and production (Madisetti et al., 2000). The system could have issues with part obsolescence from manufacturer discontinuance or could have required functionality changes that make it no longer acceptable for the organization.

The next phase is the growth phase, which is usually characterized by the product gaining market acceptance (Solomon et al., 2000). The system continues to function correctly but could be forced into a legacy system situation due to obsolescence as described for the introduction phase.

Next, the maturity phase signifies the maturation of the system but the system may be beginning to degrade, which would signify increasing maintenance costs (Solomon et al., 2000). Then decline is the beginning of the end of the system life cycle. This phase shows an increase in maintenance and part replacement of the system and a sharper decline into imminent obsolescence (Solomon et al., 2000).

This stage is followed by the phase-out and obsolescence stages. These stages are signified by the manufacturer discontinuing the support of the system (Solomon et al., 2000) or the system could be reaching the end of its design life (Reinertsen, 1996). This can mean that the technology used for the system is no longer implemented and the manufacturer has moved onto bigger and better technologies. Once a system has reached this stage in its life cycle decisions about the system must be made. Should there be an extension of the life of the system or should the system die and the user start anew with a different system? This research will help with that decision.

Figure 2 shows that the zone of obsolescence is in the phase-out and obsolescence stages. With a system, the zone of obsolescence can be in any of the stages of the life cycle, as explained in the previous paragraph. Systems can be deemed legacy before they are even placed in use due to long design and testing phases associated with their complexity (Madisetti et al., 2000). This can be cause by improvements in technologies or other issues that compel manufacturers to discontinue system parts. The Air Force has experienced problems with their long weapon system development cycles. They are experiencing part obsolescence during development and production (Stogdill, 1999).

The last stage mention was the obsolescence stage. This name can be misleading. Obsolescence can occur in any stage of the system life cycle. The problem with the system reaching obsolescence is not that the system no longer functions properly. It is the fact that the parts, or the technical components are reaching a state of obsolescence that needs to be corrected. The method of correcting this problem is known as life cycle extension.

Life Cycle Extension

While there are many methods that have been developed in order to extend the life of a system, it has been noted that there is little methodology behind selecting the correct method for life extension (Bennett et al., 1999; Brooke et al., 2001; Reinertsen, 1996). Five methods are presented in detail in this paper. These methods are Reverse Engineering, Spare Parts, Migration, Outsourcing, and Maintenance. A discussion of the advantages, disadvantages and an example of each will be given. These methods are summarized in a table in Appendix A. More methods of life cycle extension are described in a 2004 thesis paper by the colleague who jointly performed this research (Sellars, 2004). The methods discuss in that paper are Reengineering, Build a new system, Design Recovery, Wrapping, Functional Discovery, and Ignoring the problem. There is one category of methods that will be used later in this paper for discussion purposes. This category, the Redesigning methods, is based on similarities in the methodologies of some of the methods presented in the model. The redesigning methods are reengineering, reverse engineering, design recovery, and functional discovery. They are considered redesigning methods because they obtain a higher level of understanding about a system to create a new design. Further explanation of these methods and the remaining methods can be found in this thesis paper and the one mentioned above. The next sections of this chapter will discuss the five methods featured in this paper.

Reverse Engineering

Reverse engineering is the process of developing a set of specifications for a complex system by examining the specimens, or parts, of the system (Rekoff, 1985). This process analyzes a subject system to identify the system's components and their interrelationships and create representations of the subject system at a level of abstraction (more generalized structures that contain fewer details than found in the advanced level of designs (Biggerstaff, 1989) higher than that of the original system (Chikofsky et al., 1990). It takes a system in its highest form and continually breaks it down into its subsystems until it reaches the component level (Rekoff, 1985). This examination is usually done by someone other than the original designer and without the benefit of the original drawings (Rekoff, 1985). While this process usually involves a system that is currently functioning, it can be performed at any level of the system engineering process (Chikofsky et al., 1990).

This process in and of itself is not complete. It is only a method of creating a design from an existing product. Reverse engineering is "a process of examination, not a process of change or replication." (Chikofsky et al., 1990) Reverse engineering would need a process of forward engineering to obtain a final functioning product. To get a better understanding, Figure 3 shows the forward engineering process along with the reverse engineering and reengineering processes. Forward engineering is the name given to system engineering in order to distinguish the direction which the system is taking. This means that a higher level of abstraction has been obtained for the system and the system is being developed from that design. It also shows that reverse engineering does not have a process of forward engineering built into the definition. Therefore, it needs a process of forward engineering to obtain the final product.

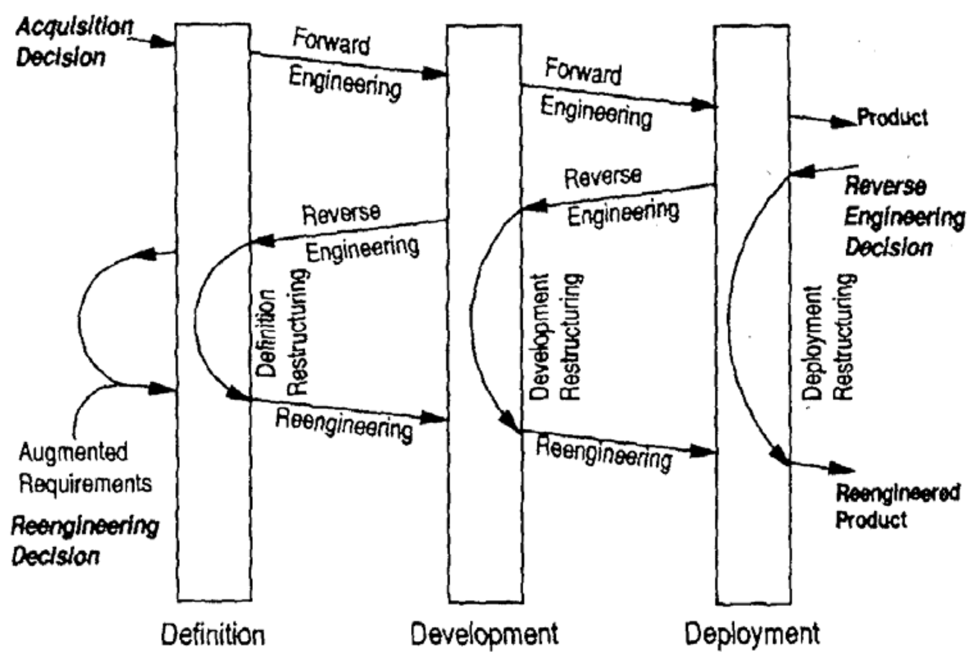


Figure 3. Visual representation of Forward and Reverse Engineering (Sage, 1995)

This method facilitates the increase of overall comprehension of a system and its functionality. The objectives of this method include trying to find missing or undocumented functionality among other objectives. This undocumented functionality can make a considerable difference in the forward engineered system if it is not found and included in the design. Since this method focuses on finding functionality, it is not suggested that functional changes be made to the system undergoing reverse engineering. Thus nothing is missed or accidentally altered which could remove functionality.

In order for reverse engineering to be performed a functioning system needs to be available for disassembly and analysis (Rekoff, 1985). During a disassembly of a functioning system, care must be taken so that valuable information about the system and its characteristics are not altered before they can be correctly analyzed and recorded. This fact needs to be kept in mind whenever this method is performed. Also one must recognize the fact that there are functional and dimensional specifications for a system and its subsystems. Functional specifications describe how the system and its subsystems work and interact. Dimensional specifications establish the dimension of the system and its parts. Both of these specifications need to be obtained when performing this method, although functional specifications are the most important. The system dimensions can be altered when forward engineering the system, but that is not part of this method. To obtain functional specifications, the item should be decomposed enough that the operational detail of the item is understood well enough that the significant mechanisms of operation are obvious. The dimensional specifications can be obtained by simple measurements of the parts as far decomposed as they can be without physically destroying the item itself.

Reverse engineering can be used to understand a new system in order for the legacy system data to be accurately moved to the new system. That is the case in the Commonwealth of Virginia's department of Personnel and Training (DP&T) and Accounts (DOA) (Aiken et al., 1999). They undertook a project to replace the existing payroll and personnel information systems, because of outdated technology, lack of integration of databases, and untimely information. For the replacement, they purchased the PeopleSoft Human Resources, Benefits, and Pay modules. The problem was the system was not tailored to fit the organization's needs. To solve this, they reverse engineered the PeopleSoft system in order to get a better understanding of how it works. They used this information to tailor the PeopleSoft system to fit their organization and to aid in transfer of the data that needed to be moved over from the old system. This article explained in detail how they performed the reverse engineering process and how this process aided in the smooth implementation of the new system. The reverse engineering process used in this example provided valuable system and background information that made the project successful.

Spare Parts

When a specific part of the system, not the entire system, becomes obsolete, a spare parts strategy may be used (Solomon et al., 2000). Obsolescence can occur when a manufacturer decides that it will no longer make a part, or when materials and/or technologies necessary to produce it are no longer available. Again, it is important to remember that this is technical obsolescence and not functional obsolescence.

The spare parts method is used when an obsolete part needs to be replaced so that the system can continue to function . Almost every article that discussed spare parts solutions described multiple methods of providing spare parts (Prescott, 1995; Reinertsen, 1996; Solomon et al., 2000; Stogdill, 1999). Most of these articles described the same set of solutions for spare part management. This includes lifetime buys (buying and storing a system lifetime supply of spare parts), part substitution (using a different part with identical or very similar form, fit, and function), redesign (upgrading the system to make use of newer parts), aftermarket sources (using a third party that will still provide the part), emulation (using parts that are fabricated using newer technologies to produce the same form, fit, and function), reclaim (using salvaged parts from other products), and uprating (using parts outside the manufacturer specified environmental range) (Solomon et al., 2000). While these solutions probably do not cover all of the possible methods, they do present an idea of what can be done to obtain spare parts.

A spare part solutions such as COTS (Commercial Off the Shelf) can be useful for a quick relief of an aging system (Prescott, 1995), but can compromise the life of a system if the usage of the COTS part and the part that is needed is not similar. These solutions can also be very expensive if acquiring a lifetime buy of the part is necessary (Stogdill, 1999). This solution means a high initial cost with a continual storage and maintenance cost. Also redesign costs can be very expensive and need to be taken with a consideration for future obsolescence issues.

Many organizations, from defense to commercial, struggle with spare parts management. The Navy and Air Force have recently confronted the issue that no domestic supplier can be found for a third of its spare parts because of manufacturing issues (Zylstra et al., 2004). This has presented them with an obsolescence problem that they are handling by seeking out foreign manufacturers for production of these missing parts. This is an example of finding an aftermarket source for the needed spare parts when confronted with an obsolescence issue brought about by the manufacturer discontinuing the production of parts.

Migration

Migration is the process of moving the system to a more flexible environment, while retaining the original system functionality (Bisbal et al., 1999; Sneed, 1995). While migration could be used on a hardware system, it is applied to software and information systems within the literature. A hardware system could use this method to migrate a subsystem of a mechanical device into another environment. This approach can be used as a intermediate step between the legacy system and the target system (Aiken et al., 1993), or it can be the long term approach to solving the legacy system problem (Bisbal et al., 1999). Using it as an intermediate step, a set of derived requirements are developed that can be implemented in the target system for increased reliability and functionality (Aiken et al., 1993). If the migration system is the permanent solution, it is not advisable to introduce new functionality (Bisbal et al., 1999). In either case, intermediate or permanent, this solution provides a method that is meant to cause as little disruption to the existing operational system as possible.

An example of migration is the migration of the cellular providers moving from the existing 2G networks to the new 3G networks (Buckley, 2003). This migration exists with a move onto CDMA by Sprint and Verizon and has AT&T and Cingular moving over to a new GSM networks. This migration includes improvements for voice services and new data services. It is taking place while trying to cause as little disruption to the existing operational system as possible. The apparent increase in functionality is something that was actually stated in the literature as being inadvisable (Bisbal et al., 1999). Nevertheless, the migration is underway and seems to be progressing without too many publicized problems.

Outsource

Outsourcing is a method of contracting a specialist organization that can handle the task that the legacy system was performing (Bennett et al., 1999). This method is used to mitigate the risk of performing a different life extension option that could be disastrous if it is not handled correctly (Brooke et al., 2001). This option can be unfavorable because the company would then lose control of the task of the legacy system and may end up losing a valuable part of the firm’s core competency. Outsourcing can be a wise choice if it helps to concentrate efforts on the firm core business as is demonstrated by United Services in the following example.

United Services, which is United Airlines' maintenance arm, announced in 2004 their plans of outsourcing all of its heavy maintenance. This was done in an attempt to focus on areas where it feels most competitive (Ranson, 2004). The firm is going to concentrate on their core competency and remove extraneous tasks. They are removing 13 maintenance line systems and outsourcing this business to two firms, Singapore Technologies and Timco.

Maintain

The maintaining method refers to continuing the course of frequent maintenance, and possibly improving maintenance practices in hope that it will improve the problem (Chockie et al., 1992). While system maintenance can aid in reducing the degradation of the system, it can also be overlooked which can cause system degradation (Reinertsen, 1996). A legacy system normally has maintenance costs that are extreme when compared with the development costs (Buede, 2000; Madisetti et al., 1999). Therefore when the system maintenance is ignored, the system subsequently degrades. It is important to remember the increasing cost of maintaining a system if this method is used.

The main theme of the maintain method is basically do nothing and maintain current course, which is a little less drastic than ignoring the problem altogether. So this method is another example of a do nothing option, but with more attempts to decrease system degradation. While this also sounds a great deal like spare parts, it is less in-depth than that method and does not deal directly with immediate obsolescence issues as with the replacement of obsolete spare parts.

Airbus uses maintenance in order to keep up with the threat of an aircraft becoming unsafe to fly. Airbus announced in 2002 their plans to create a network of partnerships to handle upgrades, conversions, maintenance, and overhaul services (Taverna, 2002). This network would handle the maintenance of the aircraft in order to keep the system in a state of operational readiness. These systems are not having their lives extended by a method similar to reverse engineering in which the system would be taken apart. This process is more of a method of ignoring the need for redesign, if such need exists, and carrying on with the continual maintenance of the system.

Summary

This chapter has presented the method of literature review, systematic review, used for this study and given all relative information and statistics from the review process. The definitions and details about the main concepts used in the research were then laid out. This chapter has given the definition of a system and a legacy system and explained examples of legacy systems. It has shown the life cycle of a system and how it leads to life cycle extension. Finally five methods for life cycle extension were explained in further detail and examples were given. The summary of these methods can be seen in Appendix A. The chapter has presented the background for this thesis that will aid in the understanding of the Life Cycle Extension Model and the uses of the model. The next chapter presents this model and related areas of the research.

CHAPTER III

LIFE CYCLE EXTENSION MODEL

The Model

The Life Cycle Extension Model was a joint development that included the author, one other master's program colleague, and faculty members. The model is a consolidation of characteristics of various systems that were gathered using a systematic review of the literature available on this subject and expert opinion. The methods that were included were gathered in the same manner as the characteristics. The complete model is shown in Appendix B. The methods that were included in the model are listed across the top while the characteristics are listed down the left side and grouped into major area headings. The next few sections give details about the development and use of the model.

Model Development

The development of the model was a lengthy and involved task that included many steps. Once the literature from the systematic review was compiled and all relevant articles and books were found, each one was thoroughly reviewed for clues as to the characteristics of legacy systems and the methods used during life extension. Some of the articles were descriptive in that they gave definitions for legacy systems and life cycle extension methods. Others were valuable because of their focus on an example of life cycle extension of a legacy system. Either way the articles had to be carefully reviewed for contextual clues as to the characteristics associated with legacy systems and life cycle extension strategies.

The researchers reviewed every article and recorded every characteristic or method that was mentioned or defined within. For ease of review, the researchers used EndNote, a referencing program that allows descriptions of resources by keywords, abstracts, or notes entered by the researchers. Once finished, the researchers came together to compare lists of characteristics and methods and created a master list. This list was presented to an expert to get feedback on anything that may be missing for complete analysis or anything that may be superfluous.

This master list of characteristics was then sorted by the most popular traits. The most popular traits were the ones that were referenced most often in the literature. These are the characteristics that seemed to turn up in almost every description or example of a legacy system so these are traits designated as being the 'most popular'. These 'most popular' traits were used later as a guideline for further development of the model.

Just as the characteristics were ordered in the most popular, so were the methods. The method counts were presented earlier in the systematic review section. These methods were listed from left to right on the model with the left being the most popular method and continuing down the line to the right. Figure 4 shows a portion of the completed model. The numbers underneath the methods and next to the characteristics represent how many times each method or trait was mentioned in the literature. This row and column is represented by the heading of 'Total'.

		Methods							
Characteristics		Reeng.	Rev. Eng	Build New	Spare Parts	Des. Rec.	Mig.	Wrap	…
	Total	23	17	15	11	10	6	4	
Scheduled Maint.	21	These characteristics were the most referenced in the literature. They were included in the creation of the categories for the final model. (Total Characteristics = 28)							
Unscheduled Maint.	21								
Tech. Insertion	17								
…									
Modify functions	7								
Skilled employees	7								
Operational costs	6								
Core Competency	5								
Regulatory Issues	4	These characteristics were the least referenced in the literature. They were placed into the created categories from above. If no category was available for a particular characteristic, one was created. (Total Characteristics = 37)							
Limitations	4								
Type of organization	4								
…									
Economic Impact	1								
System Engineers	1								
Simple system	1								

Figure 4. Example of partially prepared model

As can be seen from this figure, the most popular methods combined with the most popular characteristics produce a situation that is repeatedly described in the literature. The further down the model the less referenced the characteristics in literature, as is the further right the less referenced methods. In the bottom right of this model would be the combination of characteristics and methods that were rarely ever mention in literature. The result of this analysis gave a general understanding of what was considered the most important areas according to the literature that was available.

The top portion of the model shown in Figure 4, the most popular characteristics, was used in creating the final model categories. This portion of the model allowed for the most important characteristics about legacy systems to surface for analysis of categories. Any characteristic that was mentioned five or more times in the literature was included in the category analysis. The result was a list of categories into which each characteristic could be grouped. The remaining characteristics, the traits below the cut off of the most important, were sorted into the categories created. If there was not a category already created for some characteristic, a new category was created to supply a location (i.e. Organization Issues and Schedule). A description of the characteristic categories is given in the next section.

The final step for the creation of the characteristics list was converting the characteristics into questions. These questions are the guideline for using this model. Each characteristic was converted from a word or phrase (for example ‘functionality added’), to a full question (‘Will you add functionality?’). This allowed for the ease of use of the model that was not present when the characteristics were just phrases. This final list of categories and characteristic questions is shown in the model in Appendix B.

Now that the characteristics have been categorized, the next task was to fill in the model with ‘y’ (for yes), ‘n’ (for no), or ‘n/m’ (for not mentioned) depending on what the literature says about that characteristic with that method. To explain further, a ‘y’ was given to any characteristic that the literature mentioned or suggested as being important to a legacy system that needs life extension using a particular method. An ‘n’ would be entered for any method that does not need that characteristic or in which that characteristic is not important. An example of this is with the question of ‘Will you add functionality?’ For Reengineering a ‘y’ is entered because adding functionality is something that can be done or is suggested if reengineering is to be used. For Reverse Engineering, an ‘n’ is entered because it is ill-advised, by literature, to add functionality to the system while performing the Reverse Engineering method. An ‘n/m’ is entered whenever a characteristic is not mentioned in the literature involved with that particular method. This is the case with Outsourcing for the previous example.

This last step was the final step in the development of the model. The model was reviewed for completeness and then finalized. The methods used in the model have already been defined, so the characteristics should be described as well. The next section gives a general overview of what the characteristic categories provide for the analysis of a legacy system.

Characteristics of Legacy Systems

As mentioned before, the characteristics of legacy systems in this model were gathered from an extensive literature review. The list attempts to cover everything that is important and that needs to be included in order to make a conclusive evaluation of the subject system. The characteristics have been broken down into major categories and then presented in the form of a question in order to aid in the evaluation process. These major categories are: Cost/Benefit Analysis, Documentation, Changes, Maintenance, Organization Issues, People Issues, System Attributes, and Schedule.

The Cost/Benefit Analysis category deals with the various costs of a system that could arise during an extension of the life of that system and costs that are currently incurred on the subject system. It also deals with some questions about the system availability and importance of the system to the company. Costs deal strictly with the operational, acquisition and retirement costs because these were the only costs that came up in the literature as important to life cycle extension. Operational costs cover one of the most important issues of maintenance costs. Maintenance cost is covered in this category while the issues of obsolescence and system degradation are dealt with in the Maintenance category. The importance of the maintenance cost was described in detail in Chapter 1. The acquisition cost helped to differentiate between the methods that featured redesigning over building a new system or other methods.

The Documentation category includes the availability and accuracy of documents for the subject system. The documents mentioned in this category are vital to the understanding of the system. If these are present, a situation could be created where it is easier to use one method over another. This category also mentions the presence of the original designers of the system. This was a very important characteristic in the literature, because of the knowledge base that the original designers possess may not be included in any of the documentation that is available. These designers may hold the key to information about parts and functionality which could be missed if the system is, for example, reverse engineered. The missing or hidden functionality needs to be recovered for complete understanding of the system.

The Changes category deals with whether or not the proposed extension is going to change the functionality of the system or insert any new technologies. It also deals with limitations and regulatory issues that may have arisen since the building of the original system. The functionality and technology changes were the most popular issues that were placed in this category because of the number of times each was referenced in the literature. The functionality changes in particular are characteristics that can make a method more recommended than another. An example would be the fact that functionality changes are not recommended for reverse engineering while functionality changes are possible when using reengineering.

The next section involves maintenance and part obsolescence issues. The maintenance costs were covered in the Cost/Benefit category because of its relationship to operational costs. The maintenance and part obsolescence characteristics did not hold high importance in the literature based on the fact that they were not mentioned as often as other characteristics. It is the opinion of this researcher, however, that this is an area that needs to be researched further because of the link of these characteristics to the definition of a legacy system. Legacy systems were defined, in part, by technical obsolescence, which is part of this category of characteristics. This suggests that literature considers obsolescence to be important in defining legacy systems but not in differentiating between life cycle extension methods. This seems to be an assumption that needs further research to be fully understood.

The remaining categories are:

- Organizational Issues - has the type of organization within which this system is running and being extended.
- People Issues - deals with the current employees and whether or not they are skilled enough to handle legacy systems.
- System Attributes - deals only with the type of system, being hardware or software, and whether it is simple or complex.
- Schedule - asks questions about the time schedule and whether or not a market opportunity will be missed or an economic impact will be felt by the company.

While these last four categories were not emphasized as much here, do not let that imply unimportance of these characteristics. These were the traits that were not covered as thoroughly or covered at all in the literature. Further research should be conducted to analyze how useful these categories could be. It might turn out that they are very important or maybe they are not needed at all.

Using the Model

The first step in using this model is to answer all of the characteristic questions that are listed in the far left column. This is the full list of questions and each one needs to be answered in order to get a full analysis. The questions can be answered with a 'yes', 'no', or 'don't know' if the answer to the question is not known. These answers should be recorded in a blank model with each answer in a column next to the question.

Once all of these questions have been answered and recorded, the answers are compared with the model to see which method has the most number of characteristics in common with the system that is being extended. Using the model presented in this paper, each answer needs to be compared with the model's answer. If they match, a mark needs to be placed in the blank model in the spot where the answer was found. Since this might be somewhat confusing, Figure 5 shows an example of this task using a portion of the actual Life Cycle Extension Model.

	METHODS					
CHARACTERISTICS	**Answers**	**Re-Eng. (Model)**	**Re-Eng.**	**Reverse Eng. (Model)**	**Reverse Eng.**	**. .**
Cost/Benefit Analysis	---------	------	------	---------	--------	
Operational Cost	---------	------	------	---------	--------	
Poor design contributes to excessive cost?	Yes	Yes	Match	Yes	Match	
Scheduled maintenance contributes to excessive cost?	Don't know	Yes		Yes		
Unscheduled maintenance contributes to excessive cost?	No	Yes		Yes		
Customer service/support contributes to excessive cost?	Yes	Yes	Match	N/M		
…	…		…		…	.
Total			# Match		# Match	.

Figure 5. Example of model analysis

This figure shows how the blank model can to be completed. The answers column is where the recorded answers are written. In this case, these answers are examples. The next two columns are for the first, and most popular, method, reengineering. According to the Life Cycle Extension Model, for question 1 (Do you feel poor design contributes to excessive operational costs?), reengineering has a ‘Yes’. This means that for reengineering, the answers to question 1 match so a ‘Match’ is entered into that space. For question 2 (Do you feel that scheduled maintenance contributes to excessive operational costs?), reengineering has a ‘Yes’ entered in the model. Since the answer from the questioning is ‘Don’t know’, nothing is entered into this space because the answers do not match. This process is continued until the entire model is filled out for each method. The method that contains the most ‘Match’ entered into the column is the most highly suggested method for life cycle extension. The ‘Total’ row at the bottom of the model reflects the total number of ‘Match’ in each column. If more than one option is desired, the most highly suggested methods can be included for consideration. The analysis of the case study performed for this paper provides another example of using this model and shows examples of completed table analyses. It also explains how more than one life extension method can be used in the analysis to find the best possible method.

CHAPTER IV

THE CASE STUDY

Methodology

The case study design and methods followed Yin (1994) and Eisenhardt (1989). Yin (1994) provided a very detailed description of how to carry out each phase of the study while Eisenhardt (1989) provided details of theory development from case study research. The combinations of these two helpful guides were incorporated throughout the research in order to generate a meaningful and well-designed study.

Case study research is used for this situation because of the type of question that needed to be answered: how to correctly pick a method for life extension of a legacy system. As described by Yin, when the question to be answered is a ‘how’ or ‘why’, case study research is a correct research method to use (1994). This problem is also an “organizational and management study” which is one of the many situations where case study research can be useful. Yin also states that when little control over the situation is given to the investigator and when the focus is on contemporary phenomenon with real life context it is best to use a case study approach. In this research no control was given to the investigator because the research was not involved in making the project decisions, only in observing the choices of a particular life extension project. A final verification for case study research is that a method was being developed by the researchers that needed a qualitative study to test validity, which Yin also uses as qualities of a study that should use case study research.

While Yin’s book on case study research was the basic guideline for the case study, Eisenhardt’s paper on building theories from case study research was also useful. According to Eisenhardt, the case study approach is especially appropriate in new topic areas (Eisenhardt, 1989). The development of this new model is a new topic area in the management of legacy systems, so it seemed appropriate to take some advice from Eisenhardt and use case study research. She also emphasizes the importance of the role that literature can play in building theories, which literature is a major contributor to the rationale and basis of this study.

Yin’s method of simple pattern matching was used in the analysis of the data (Yin, 1994). This is a useful analysis method for this research because it compares an observed pattern to a predicted one. The observed pattern was the answers to the interview questions conducted for the research. These answers were matched against the existing model (the predicted pattern) to analyze any continuity in the results. The analysis of the data in this chapter shows how the pattern matching method works in the situation given in this research.

The Case Study Process

This section provides the entire process of the case study research conducted. The guideline for this section is based almost solely on Yin's recommendations (1994). This section describes everything from the unit of analysis, to the interviews conducted for the case study. This chapter ends with the analysis and results of the study.

The System

The first step in the process was to decide upon a legacy system that could be analyzed. This system needed to be in the process of, or already have completed, a life cycle extension project. Through the academic advisor's professional connections, a system was chosen that meet the needed requirements. The organization that participated in the study is in the aerospace/defense industry. The system was a guidance system for a missile that had been determined to be legacy. The guidance system is crucial to the missile efficacy and needs to be extended in order to maintain its operational objective of defending the US. The missile was approaching the end of its original design life. It was the decision of management (which in this case was Congress) to extend its life. The entire missile was to be extended an additional 40 years to the year 2042. This meant that the guidance system within the missile also needed to be analyzed and extended. The organization in charge of this project had already started on extending the life of the guidance system. The decision makers for the system already had a method of life extension decided upon and in place. This method was analyzed in this study to verify that the Life Cycle Extension Model "correctly" predicts the method used for life extension of this guidance system.

Preparation

Once the organization and the system had been decided upon, a method for gathering evidence was needed. It was decided by the researchers that a one-on-one open-ended interview was the most appropriate method (Yin, 1994). This allowed the participants to give the facts of the system and provide an atmosphere for the participants to give their opinion about the events.

Since this research was going to use living subjects, an IRB (Institutional Review Board) exemption was required. The IRB was given, along with the exemption application, a letter to the participants stating the purpose of the interview and a list of the general questions that were going to be asked. Both of these can be viewed in Appendix C. The letter contained a request to participate in the study and a request for the researchers to use an audio recorder. The participants could deny the use of an audio recorder, and 3 out of the 4 did. Only one participant allowed the use of a recorder. The letter is written from the point of view of my colleague, Autumn Sellars, because of IRB requirements, but the letter was created by both the author and Autumn Sellars. The IRB was also informed of the fact that all information would be kept confidential and would be destroyed within 2 years. The IRB approved the study on February 11, 2004 (#040118).

The next step was the development of an interview guide that would direct the questioning in a manner that would be appropriate for this method. This guide can be seen in Appendix D. The guide shows how the interview began with introductions and confidentiality statements. Then the purpose of the research and an explanation of why it is important were given so that the participant would know to what he/she was contributing. This was followed by background questions for the purpose of understanding what the qualifications and responsibilities of the individual were for the project at hand. The rest of the interview guide shows directional questions that were included to keep the interview on topic and to make sure that all relevant questions were covered. It ended by thanking the participants and getting contact information for future questions.

The next step, as suggested by Yin (1994), is to conduct a pilot case study. In the interest of time and for lack of funding, this pilot study could not be conducted. Instead the researchers spent extra time ensuring that the interview guide was well prepared and that the interviewers (the researchers) were also well prepared.

The Interviews

The interviews were conducted at the organizations' offices on March 24, 2004 and April 21, 2004. The individuals that were asked to participate were decided upon by their position and responsibilities in the life cycle extension project. These individuals included a technical director for systems engineers, a program manager, a project manager, and a system engineer. The technical director had worked in this position for the life extension project for a year and half. The technical director was responsible for system engineering in the project. The program manager worked in this position for life extension for five years. The project manager was in charge of the guidance system life extension project. The system engineer worked mostly on reliability issues. The system engineer had been with the organization since previous versions of the guidance system were produced. Table 4 summarizes the interview participants' demographics.

Table 4. Summary of Interview Participants

	Interviewee #1	**Interviewee #2**	**Interviewee #3**	**Interviewee #4**
Position	Project Manager	Technical Director	Program Manager	System Engineer
Years w/ System	19	1.5	5	20
Primary Responsibility	In charge of guidance system life extension project.	Responsible for system engineering in the project.	Responsible for system engineering in the project.	Reliability engineer

The interviews were conducted on a one-on-one, open-ended basis. Each of the four interviewees was asked questions from the interview guide and the model to determine the characteristics of the legacy system. They were also asked what method they considered themselves and the organization to be using in this life extension project. Since the interviewees were in different positions in the project and some were in different groups, it was assumed that the methods described by the interviewees would not be identical. This was assumed because each group could be using their own method of life extension in order to produce the needed result. In order to make sure that their methods fit with the definitions of the model presented here, they were asked to describe the method that is being used. Each interview lasted around 45 minutes. The shortest was about 30 minutes and the longest was 55 minutes.

The interviewers comprised of a primary interviewer and a scribe. The primary interviewer (the author of this paper) was meant to guide the questioning and try to encourage free expression of opinions. The scribe (the author's colleague) was there to take notes and ensure that all of the questions were answered. The two interviewers made sure that all relevant information was recorded and analyzed within two hours of the interview. This was done to ensure that the data would not be lost or misinterpreted if analyzed at a later time.

Analysis

The results were analyzed using the simple pattern matching method that is described by Yin (1994). As was mentioned earlier, the pattern matching method compares a theoretical (predicted) pattern to an observed one. The theoretical pattern is the characteristics in the Life Cycle Extension model and the associated methods that the model recommends. The observed pattern is the characteristics of the legacy system as uncovered from the interviews conducted and the method(s) that was described by the interviewee.

The first comparison to make was that of the characteristics observed from the interviews and the characteristics in the model. To start with, a matrix model was made that had all of the characteristics and methods listed, but none of the matrix filled in. To alleviate any confusion, this matrix model will be called the analysis model, while the completely filled in Life Cycle Extension model that was developed for this research (model is in Appendix B) will be called the comparison model. An extra column is given to the right of the characteristic questions in the analysis model to record the answers given by the interviewees. The answer to the first question in the analysis model was compared with the 'y', 'n', or 'n/m' in the comparison model for the first question under the first method, Reengineering. If a match was made then 'Match' was entered in the blank for the first question under Reengineering in the analysis model. This was repeated for the next method, Reverse Engineering, and on until the last method, Functional Discovery, was compared. This continued for each question in the model recording matching answers as the analysis continued down the model. Once this analysis was completed, every answer given in the interview was compared with every answer in the comparison model. The final analysis models for each interview are given in Appendix E.

The very last row in each column of the interview results is the total number of 'Match' for each method. The highest number of matches shown in this row is the suggested method of life cycle extension that the model gives for that interview. Table 5 shows the combined results for each interview. The numbers in parenthesis next to each method is the number of characteristics out of the 65 total characteristics in the model that matched up. For example, for Interview #1 Reengineering had 23 characteristics that match with the Life Cycle Extension Model. This interviewee also had only 4 characteristics matched for Outsource and Ignore Problem. The reason that the total number of matching characteristics is given is that it provides a manner in which to analyze the results and see which method was preferred over another. The larger the number, the more preferred the method is according to the model. The last column in Table 5 shows the total of all interviews. This column in given for reference and will be used later in the discussion.

Table 5. Methods suggested by Life Cycle Extension Model

Interview #1	Interview #2	Interview #3	Interview #4	Total
-Reengineering (23) **-Reverse Engineering (23)** **-Build New System (22)** **-Design Recovery (20)** **-Functional Discovery (18)** -Maintain (15) -Migration (14) -Wrapping (11) -Spare Parts (10) -Outsource (4) -Ignore Problem (4)	**-Reverse Engineering (23)** **-Build New System (23)** **-Reengineering (22)** **-Design Recovery (20)** **-Functional Discovery (16)** -Migration (12) -Maintain (12) -Wrapping (10) -Spare Parts (9) -Outsource (5) -Ignore Problem (4)	**-Reengineering (25)** **-Reverse Engineering (25)** **-Build New System (24)** **-Design Recovery (21)** **-Functional Discovery (18)** -Maintain (14) -Migration (13) -Spare Parts (11) -Wrapping (11) -Outsource (6) -Ignore Problem (4)	**-Build New System (24)** **-Reverse Engineering (23)** **-Reengineering (22)** **-Design Recovery (21)** **-Functional Discovery (16)** -Migration (13) -Maintain (12) -Wrapping (11) -Spare Parts (9) -Outsource (6) -Ignore Problem (4)	**-Reverse Engineering (94)** **-Build New System (93)** **-Reengineering (92)** **-Design Recovery (82)** **-Functional Discovery (68)** -Maintain (53) -Migration (52) -Wrapping (43) -Spare Parts (39) -Outsource (21) -Ignore Problem (16)

The most recommend methods are those shown in bold lettering in Table 5. The choices for the most highly recommend methods were made by analyzing the number of characteristics that matched during the previous analysis. The analysis used a difference of 5 matches between each method with a maximum of 5 methods for analysis. This is because this number included all of the most matched methods while not including too many options for analysis. This also created a situation where multiple methods could be chosen so that a detailed analysis of the options could be possible. Since this model is new and has never been tested before, this detailed analysis seemed necessary for further validation of the model.

The maximum allowable number of methods recommended by the model for this analysis was five unless the fifth method matched the following method in total number of matching characteristics. As this situation never arose, the maximum number was five for each interview. Also the method after the preceding method needed to be within five matching characteristics to be included. To give an example, Interview #4 has 21 matching characteristics out of 65 total characteristics with Design Recovery. The next method is Functional Discovery with 16 matching. This is within five of the previous method, Design Recovery, so it is included in the recommend methods set. It is also the fifth method to be chosen and no more methods were allowed.

Results show that the methods suggested in each interview by the Life Cycle Extension model were the same. All four sets include reengineering, reverse engineering, design recovery, functional discovery, and build a new system. This ensures the validity of the model by triangulation. Each of the interviews produced results that were identical in content but somewhat different in the order in which the methods were recommended. This order does not matter since each of the methods earned a spot in the top five recommended methods. Had these sets of methods been different, the results of the model would have to be analyzed independently and the validity of the model would be in question. As it is, the results of the model can be analyzed together since the interviewees completely agreed on the top five methods that can be used for life cycle extension in this situation.

The next step in the analysis process was to compare the methods described by the interviewees to decide if they matched with the model suggested methods. The methods described by the interviewees seemed to be combinations of several method definitions that were part of this research. For this reason it was not possible to state only one technique that was used for life extension by the interviewees. This is the reason that Table 6 has more than one for each interviewee. These were the methods that best fit with the descriptions given by the interviewees and so it seemed that they were using them in combination. Also, the exact technique that was being used for the life extension project was not agreed upon between interviewees. This is most likely because each individual was performing the technique that he/she was most comfortable with or possibly the only way that was known by him/her. Each interviewee did agree that a form of reverse engineering, design recovery, or functional discovery was being used. This is an understandable collision of descriptions since these methods could be considered very similar. Each one produces a higher level of understanding by analyzing the documentation or the system itself. It was agreed upon that there was a technique being used that produced a level of abstraction that could then be used to forward engineer the system. This could be because they are still in the stages of reaching a higher level of understanding of the system and have not started the forward engineering process yet. The remaining analysis of the results is presented in the next section. The following table shows the interviewee suggested methods.

Table 6. Methods used by Interviewees

Interview #1	Interview #2	Interview #3	Interview #4
-Reengineering -Spare Parts -Reverse Engineering	-Design Recovery -Functional Discovery	-Reverse Engineering -Functional Discovery	-Reverse Engineering -Design Recovery

This table shows the methods that were described by the interviewees. As was said earlier, since the descriptions given by the interviewees did not match exactly with the definitions given in this research, it was more appropriate for multiple methods to be named in order to cover all methods that match the descriptions given. The interviewee may have given a description that inferred the use of Design Recovery and Functional Discovery (as is the case in Interview #2). Since characteristics of both methods were being used, both were included in this analysis so that each one can be analyzed further in the next section of this paper.

Results

The analysis shown in the previous section has suggested five methods from the Life Cycle Extension Model and five methods from the interviewees. Table 7 shows a combination of the methods described by the interviewees (consolidation of Table 6) and the main choices selected by the model. The number of times that each one was described by the interviewees is in parenthesis as is the total number of characteristics matched in the model (obtained from

Table 5 in the ‘Total’ column). The rest of this section will discuss these methods chosen by the interviewees and the model to determine which method is the best option. The discussion will be supported by interview comments. Since three of the four interviews did not allow audio recorders, the interview support will come in the form of second hand comments. While these comments were recorded with the utmost care of being precise, exact quotes are not available so wording may not be completely accurate.

Table 7. Comparison of methods chosen by interviewees and model

Methods Chosen by Interviewees	**Methods Chosen by Model**
-Reverse Engineering(3) -Design Recovery(2) -Functional Discovery(2) -Reengineering(1) -Spare Parts(1)	-Reverse Engineering (94) -Build New System (93) -Reengineering (92) -Design Recovery (82) -Functional Discovery (68)

To begin, Reverse Engineering was the most popular method chosen by the interviewees and the model. Reverse engineering uses a subject system to discover the physical and functional characteristics (Rekoff, 1985). This was a suggested method by most of the interviewees because of the availability of a subject system for disassembly and analysis. The interviewees mentioned things like ‘tear down systems for a year’ and ‘learned about the old system by simulation, testing, and taking it apart’. This analysis of a subject system by disassembly suggests that reverse engineering was being used. Also the model supports reverse engineering in the fact that a duplicate system is available and that the system can be disassembled. This is a key element of reverse engineering and this method is the only one that the literature mentions as being a necessary characteristic.

The one characteristic that does not support the reverse engineering method is the functionality changes. Reverse engineering does not support the ability for changes in functionality (Rekoff, 1985). The interviewees all mentioned functionality changes. Half of the interviewees respond to the functionality change questions with answers of ‘no, not here to improve performance just to extend its life’ and ‘no, but will be adding new technology’. The other two interviewed said ‘adding functionality to keep up with new technologies’ and ‘yes, add different functionality to make it adaptable for optional missions'. These differencing of opinions make it a draw as far as functionality changes. Since reverse engineering does not support change and reengineering does, this could be one reason why these two options were so closely matched. Since the interviewees were split on the matter of functionality changes, neither reverse engineering nor reengineering can be ruled out as appropriate options because of this characteristic.

Another difference between these two methods within the model is that limited third party support for components suggests the use of reengineering in the model. Since the interviewees seemed to agree that vendors were hard to find for support of their spare parts (i.e. 'vendors for components are not available' and 'factory does not exist anymore to replace parts') reengineering is supported by the model as being an option for life extension. The literature did not suggest anything for reverse engineering on this characteristic so the model reflects this with a 'n/m'.

Reengineering was only suggested by one of the participants, but it is so closely related to reverse engineering that it still could be a viable option. One reason for this method only being suggested by one interviewee is that the project used in this case study was still underway. The project appeared to be in the process of obtaining a final design which means it is not yet in the process of forward engineering. If this is the case, it is hard to distinguish between reengineering and reverse engineering, since reengineering has a form of forward engineering while reverse engineering does not (Chikofsky et al., 1990). Also these methods have been considered very similar in literature. Literature also suggests that reverse engineering could be a part of reengineering (Chikofsky et al., 1990). An increase in research for these two methods could result in an opinion of whether these two methods are one in the same or if they are just similar. If these methods are considered separate options, then the Life Cycle Extension model is flawed and these methods need to be combined.

There are also very few differences in the model that distinguish between reengineering and reverse engineering. These differences include the main characteristics of availability of analogous system, functionality changes, and third party component support. The availability of an analogous system suggests that reverse engineering should be used since this system can be disassembled for analysis. Functionality changes are suggested within the reengineering method as is third party component support. Other differences include customer support contributing to excessive cost, missed market opportunities, and economic impact, all of which are differences only because the literature had no suggestions for these characteristics when associated with reverse engineering. These limited differences are another reason why these methods are so closely associated in the analysis.

One of the other methods of life extension suggested in both the interviews and the model was Design Recovery. This method is very similar to the two previously analyzed methods especially in the answers to the characteristics question within the model. This method attempts to gain a higher level of understanding of the system by using documentation, modeling, or other available information (Biggerstaff, 1989). In this way it is like reverse engineering, except that this method does not need a system to disassemble. The reason that this method was suggested by the interviewees was because of the emphasis on documentation availability. These participants made comments including 'there is an immense amount of documentation that was helpful' and 'the documentation was adequate for analysis'. Since some of the documentation was adequate and helpful to the analysis, this suggested design recovery. The model supports this by suggesting that the documentation needs to be available and adequate for design recovery. Design recovery also suggests that the presence of the original designers for information was necessary for this method. The interviewees all agreed on the availability of original designer. Their comments included 'old designers (available) that are useful for team', 'plenty of people who understand system', 'brought old designers back as consultants', and 'surprising number of original designers available'. This characteristic and the documentation characteristic are the supporting factors for design recovery.

Design recovery, like reverse engineering, runs into a problem within the model and this analysis with the functionality changes. It does not allow the functionality of the system to be altered. As was mention earlier, the interviewees were split on the characteristic of functionality changes. Since there was not a consensus on the question, design recovery can not be ruled out as on option. This method can be included with reverse engineering and reengineering as viable options for life cycle extension.

Functional Discovery was also a suggested method by both the model and the interviewees. This is an interesting result since this is a new method and only one source was available for analysis. The main reason for this method even making the cut in the highest recommend methods from the model was because of the documentation section. This method suggests that documentation is not a necessity, but it can be useful (Mahaffey et al., 2000). This concurs almost exactly with the interviewees who said ‘adequate documentation available’, ‘documentation available but some things not documented or wrongly documented’, and ‘documentation available, but not complete’. Since this was the main supporting characteristic that made this method a suggested option by the model, further research should be conducted in order to have a better understanding of this method. The fact that the documentation characteristic provided most of this method’s support also suggests that this characteristic may be over represented in the model. This will be discussed later in the section.

As with design recovery and reverse engineering, functional discovery does not support the ability to make functionality changes. Since this characteristic has already been determined to be split down the middle with the interview subjects, it is not reason enough to eliminate this method as on option. Functional discovery can break down because of lack of literature support. There is a large amount of ‘n/m’ associated with this method that might restrict it from being a major competitor. It also might force it off the top five list altogether. This answer will not be known until more research is done on this method.

The last method suggested by the interviewees for life extension was spare parts. This method was mention by only one interviewee as being a method used in this project. The interviewee mentioned ‘replace expensive parts with newer, cheaper ones’ and ‘replace electronic parts also’. This method was mentioned in the other interviews, but was mentioned only in the fact that they use this method for maintenance and daily operational readiness and not for a life extension project. These interviewees said ‘maintenance is handled with lifetime buys of spare parts’ and ‘dedicated storage facilities for the spare parts’. Some mentioned the cost of these spare parts and the maintenance philosophy was too costly for it to continue (i.e. ‘repair philosophy contributed to high costs’ and ‘procurement philosophy too expensive for life extension’). This seemed to suggest that the spare part method was not only too expensive for life extension but that it is part of the problem. Since most of the interviewees did not suggest this method for life extension and the model did not support the method either, it is safe to suggest that this method is not a valid option.

Spare parts may not be an option in this project because it may be a better maintenance philosophy than it is a life cycle extension method. The literature implies that parts must be available to replace aging components which can maintain reliability (Solomon et al., 2000).

This seems to fit the spare parts method with the maintain method which is, in reality, an option of ignoring the problem and continuing with the system maintenance. These two options may need to be reconsidered and possibly removed from the model and considered options of avoiding life cycle extension projects. This option needs to be researched further in order to obtain an answer. For now, it might be better to continue with spare parts being an option for life cycle extension, separate from maintain, until further research is done.

The only other method in Table 7 that has yet to have been discussed is building a new system. This option was not suggested by the interviewees for several reasons. One interviewee suggested that the system was ‘mandated by Congress to have its life extended’. Also it was suggested by the interviewees that ‘funding was adequate for life extension’ but they did not seem to think the option of a complete rebuild was possible. It was implied that most of the interviewees believed that there would not be enough money for that sort of project. It was also implied that due to fluctuations in the budgets from year to year, rebuilding the system from the ground up was not something that could be accomplished. For these reasons building a new system should not be considered an option in this case.

The fact that building a new system is supported by the model suggests that the model could be flawed. If the money is not available for a project of that cost, then this option is usually not even considered. The model needs to be able to eliminate this option when funds are not available. It is difficult to base an elimination method with literature support since literature does not specify a monetary value for a project because all projects are different. In order for the build a new system method elimination to work, more emphasis needs to be placed on the question ‘Do you feel that it is feasible for your organization to cover the cost of rebuilding the system’? In order to accomplish this, a weighting system could be placed on this question. This weighting system could also be placed on other questions that need more emphasis within the model. More research needs to be conducted in order to decide how this would work.

It was discussed earlier that the documentation characteristics was the major contributing factor for the functional discovery method to be included in the model suggestions. This also appears in the building a new system method. The above mentioned weighting system may need to be put on particular kinds of documentation or the documentation section needs to be consolidated into a single set of questions instead of four sets so that it does not carry so much weight. Since the majority of the interview subjects talked about documentation in general, the answers to these questions, in the analysis of the case study, were identical for each type of document. This created a weight for this characteristic that could unfairly produce a result that should not have been presented. Correcting this flaw could eliminate building a new system and functional discovery as options for life cycle extension. Since this change could also greatly effect the other options for life extension, this suggested change should be researched with another case study to discover any benefits or shortcomings with this correction.

The discussion of each of the methods above provided reasons why the chosen methods were supported or not supported in the literature and in the interviews. While the supporting reasons for the method provided by the literature are as complete as possible for this research, there are holes that need to be filled. Each method has a large number of 'n/m' associated with it which shows where the literature has not addressed one of the questions included in the model. Since some of the methods had more 'n/m' than others, these methods (including wrapping, outsource and ignore problem as the highest number of 'n/m') may not have been fairly represented in the analysis. The model presents the suggested methods under assumptions that are based on limited information obtained in the literature. This is a flaw of the model and further research should be conducted to complete the model and take out any unnecessary bias put in by this limited literature support.

CHAPTER V

CONCLUSIONS

From the discussion in the previous chapter, reengineering, reverse engineering, design recovery, and functional discovery were presented as options for life extension for the sample organization. The methods of spare parts and building a new system were eliminated. The methods presented as life extension options are all very similar and one common difference among them is that reengineering includes a forward engineering process, while the others do not. All of these methods use a process that gains a higher level of understanding of the system so that a new design can be created. Since this project called for a 'design refresh' to a more 'modular design', as was mentioned by the interviewees, these methods could all produce favorable results. While reverse engineering and reengineering were the most highly suggested by the model, it can be assumed that this may be only because of the lack of support by the literature for the other methods but this is not necessarily the case. This chapter will give some reasons how the model and the literature support could be improved to help with the completion of the Life Cycle Extension Model.

This chapter presents conclusions about the Life Cycle Extension Model and the literature associated with development of this model. The case study showed that the model predicted a successful life extension project, but the model and literature could have problems which may have skewed the results. These issues and a discussion about them are presented below. It is followed with a discussion about future research which could help resolve these issues.

Conclusions on the Model

The Life Cycle Extension Model is a development that brings the characteristics of legacy systems together with the methods of extending the life of that system to aid with the decision process involving legacy systems. A model of this sort has never been published before and could be helpful to academia and practitioners. This model creates a basis of study for future researchers to continue and provides practitioners with a method of deciding on life cycle extension projects. Throughout the analysis of the case study suggestions of pros and cons of this model were stated. This section will reiterate these suggestions and present other areas that could be improved.

This model contained eleven different methods of life cycle extension. These methods may not be exhaustive and mutually exclusive. This means that there could be other methods that should be included or some of these methods may be identical. Additional methods could be included during further research of this model or during the development of a new method of life extension, such as with functional discovery. Functional discovery, which was recently identified in a paper by Mahaffey (2000), was an under researched approached that was included for completeness. The arguments for the mutually exclusive methods were made during the discussion of reengineering/reverse engineering and spare parts/maintenance. Literature suggested that reverse engineering may be a component of reengineering rather than a separate method. For this reason these two methods could be combined to make the model more accurate. The discussion in the previous chapter of the spare parts method being a form of maintenance also falls under this mutual exclusion. Spare parts may be a maintenance practice and therefore should be combined with maintenance. However, to exclude any method, further research and testing needs to be conducted to ensure that these methods are not mutually exclusive. Also the definitions of these methods would need to be modified to accommodate the addition workload of the surviving method.

The characteristics list could have problems that caused an inaccurate conclusion to be reached in the testing of the model. These issues include characteristics that were missing, undervalued, over valued, or characteristics that were unnecessary. These characteristic problems could have caused a false negative or a false positive of a method recommendation. As was discussed in Chapter 4, the method of building a new system was inaccurately recommended as a valid life cycle extension method for the case study. This problem could have been avoided had the characteristic list put more emphasis on the question of funding for the rebuilding method. Only one question was presented in the model that focused on the cost of completely rebuilding the system. This question should be a preliminary question that would immediately remove the method of building a new system if the funding was not available, thus solving the problem of the inaccurate recommendation of building a new system.

The previous example showed a problem with an undervalued characteristic: overvalued characteristics can also cause problems. This was shown with the inclusion of the functional discovery method with all four of the interview analyses. The literature on this method focused on documentation. This created a situation where the method matched almost exactly with each interview and made the documentation characteristics overpower the other characteristics, forcing a recommendation of functional discovery. There were 13 documentation questions out of the 65 total. With the small number of total matches for each method in the analysis, none going over 25 (reference table 5 for totals), this gave an unfair advantage to functional discovery. For this reason the documentation section needs to be reworked to create a better analysis. This result could be obtained by consolidating the documentation section into a general question about the availability of all documentation. Since, in the case study, most of the interview participants made comments on documentation as a whole and not on particular documents, this seems like a valid solution to the problem. Further testing of the model with this change could help in discovering if this is an acceptable fix.

Some of the characteristics within the model did not seem to make a difference between methods because of the 'n/m' being present for each method associated with that characteristic. That was the case with retirement costs, which did not make a difference among methods according to the literature used. Other characteristics that fell into this category were the type of organization and the availability of system engineers within the organization. While these characteristics could make a difference between methods, it was not apparent with the literature that was found during the systematic review for this study. These methods need to be researched further to determine if they need to be removed from the model. Practitioners could provide information about these characteristics and explanation whether these traits are influential in life cycle extension projects.

While it seems that the model performed as it was designed to, it may have predicted the methods under the pretences of incomplete information. The methods that seemed to be most highly recommended by the model were the methods that had the most literature on the subjects. These methods included reengineering, reverse engineering, build a new system, and design recovery. These methods were four of the top five most referred to methods within the literature. They were also the top four of the least 'n/m' within the method. This means that the method contained more characteristics that were mentioned within the literature which provided a situation for more characteristics to match with the methods. This gave an advantage to these methods that could have been the reason for the model suggesting these particular methods. The fact that it matched with the methods described by the interview participants could mean that these engineers and managers knew these terms and their definitions. This could make them tend to describe these terms more than the other methods that are less supported in literature. It could also mean that since they know the processes of these methods, they use them because of this knowledge. Regardless, the heavily supported methods in the literature seemed to be the more supported methods in both the Life Cycle Extension method and in practical use.

Conclusions on the Literature

This study proposed not only the development of the model but also that it would provide an explanation of the shortcomings of the literature. These shortcomings include unspecified definitions and characteristics of legacy systems, inadequate and disputed definitions of methods, lack of complete examples of legacy system life extension, and no arguments as to why one method was used over another. These gaps relate directly to the 'n/m' that are rampant throughout the Life Cycle Extension Model. This section will described these shortcomings.

The problem with defining a legacy system for this study is that academia has not agreed upon a definition. One way of trying to define a legacy system is to present numerous characteristics and examples to paint a picture of what a legacy system is. This is how this research paper presented legacy systems. The examples were further restricted because the literature used software or information systems in most of their examples of legacy systems. While this is great for defining a legacy software system, it does not aid in describing a legacy hardware system. The goal of this research was to be able to use this model for any type of system, be it hardware or software. This placed a restriction on the definition of legacy system and could have affected the model in a negative way. These negative affects could be represented in the fact that the characteristics for each method were obtained mostly from software examples. These characteristics may not be the same for hardware systems. This problem needs to be researched and included in the model for added accuracy.

The method definitions had a similar problem since the literature did not always use a common definition for each method. This problem forced the researchers to agree on definitions for each method so that the case study could be accurately analyzed. But even though this was the case, the examples within literature where one method was used, never stated why the authors decided to use one method over another. The examples would describe a system that they called ‘legacy’ and present the method of extending the life of that system. Since it was shown in this study that the methods of life cycle extension can be very closely associated with each other with regard to this case study, literature should make more of an effort to include a discussion of why a particular method was chosen. It can be seen from Table 5 in Chapter 4 that the methods of reverse engineering and reengineering were always very close in the number of matching characteristics. This means that either of these methods could have been a good choice for life extension according to the model. Literature needs to put forth a better effort to include the argument for why one method was used over another. Perhaps academia can use this model to begin to understand how this discussion could be structured.

Areas of Future Study

Future research for this area of study includes further literature expansion, additional case studies, more in-depth case studies, and continued review of the literature. To begin with, the literature has gaps that need to be filled. These gaps were discussed throughout the paper and most recently in the previous section. With more extensive research done on legacy systems, the Life Cycle Extension model could grow to become a more defined and valid decision tool. The literature needs papers similar to Chikofsky and Cross (1990) who presented a paper that was respected by academia for definitions of some life cycle extension methods. Continued research needs to be conducted with other examples of legacy systems to include hardware, software, and systems that are a combination of the two. More research needs to be conducted in order to help define when one method is preferred over another. Continued research in this area of study could lead to a decision tool that will help to save money and time on projects of this nature.

Further research could also include more case studies using this model to address validity problems associated with this study. Such studies could focus on particular areas of the model and modify it so that it could be more accurate in predicting life cycle extension methods. These studies could be conducted using a wider range of interview participants. This range could include people that deal with every aspect of the life cycle extension project, from the original decision to the retirement of the old system. Additional studies could include participants from all areas that the Life Cycle Extension model incorporates and focus on different systems that are from a different industry. The focusing of this study on a system in one industry creates a situation where the findings may not be generalizable to all systems in every industry.

Additional studies need to be conducted with other systems so that the results can be generalized across multiple industries and system types

The final suggestion for future research is to incorporate new and improved search routines into a continued effort of the systematic review. A new search routine could be one that increases the span of the literature search to include other sources of information not used in this research. The routine could also include additional keywords and combinations of keywords that were not used. With a new search routine, more literature could be uncovered that could improve the Life Cycle Extension model. Also this continued effort of literature review should bring about changes to the model whenever new research is done. These changes could include adding/subtracting life extension methods and adding/subtracting characteristics to describe methods. These additional literature reviews could also aid in completing the model by removing the 'n/m' that are present throughout the model. With this continued effort to improve upon the literature base of this study, the Life Cycle Extension model could grow into a decision tool that would be invaluable to academia and practitioners.

APPENDIX A

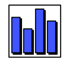
SUMMARY OF METHOD DESCRIPTIONS

Reverse Engineering Characteristics -Develop a set of specifications for a preexisting system. -Develop design from the finished product. -Examines pieces of the system from disassembling the system. -Gathers information about the functional and dimensional specifications of a system and its subsystems.	Advantages -Can be used to overcome defects in or to extend the capabilities of a system. -Can be used to analyze a competitor's product. -Can be used to analyze any enemy equipment obtained.	Disadvantages -A currently operational system needs to be available for disassembly. -Possible to destroy valuable design information with disassembly. -Performed without the benefit of original designers. -Is not used to change or replicate the system, only to obtain an original design.	Example -The Commonwealth of Virginia used reverse engineering to analyze the PeopleSoft system in order to understand it enough to tailor the system to fit with their organization. The tailored system was then used to replace the existing legacy system.	References - Aiken, et al., 1999 - Chikofsky and Cross, 1990 - Rekoff, 1985
Spare Parts Characteristics -Includes options such as lifetime buys, part substitution, redesign, or reclaiming. -Can solve part obsolescence problems	Advantages -COTS products can bring quick relief to an aging system. -Many different options to choose from in order to correct the legacy issue.	Disadvantages -May be forced to store a system lifetime supply of a part which can be expensive. -Can have problems with performance if COTS product is not similar.	Example -The Navy and Air Force have an obsolescence issue with spare parts. They can not find a domestic supplier. They are handling the problem by finding a foreign manufacturer.	References - Prescott, 1995 - Solomon, et al., 2000 - Stogdill, 1999 - Zylstra, et al., 2004

Migration Characteristics -Refers mostly to software systems. -Process of moving software and data to a new system that provides the required essential functionality.	Advantages -Provides an intermediate step that can be used to derive functionality and data requirements. -Can also be used as a long term solution. -Mitigates the risk of system shutdown.	Disadvantages -Adding functionality is not advised if being used for a long term solution. -Current system has to remain operational during migration.	Example -The migration of the cellular providers from the 2G network to the 3G network is a good example of this method. These providers are trying to do this without disturbing the existing network.	References - Aiken, et al., 1993 - Bisbal, et al., 1999 - Buckley, 2003 - Sneed, 1995
Outsource Characteristics -Contract with a specialist organization to handle legacy system tasks.	Advantages -Can mitigate the technology risk to another company.	Disadvantages -Will lose control of the task of which the legacy system performed. -This lost task could be part of firm's core competency.	Example -United Services is outsourcing heavy maintenance to two other companies so they can focus on areas where they are more competitive.	References - Bennett, et al., 1999 - Brooke and Ramage, 2001 - Ranson, 2004
Maintain Characteristics -Continue to maintain system either as was previously done or with some change in maintenance methods.	Advantages -Can help to reduce the degradation of the system	Disadvantages -Does not help if maintenance is causing the continued degradation. -Excessive maintenance cost.	Example -Airbus uses a partnership method to handle the maintenance of their aircraft in order to keep them in safe working condition.	References - Bisbal, et al., 1999 - Buede, 2000 - Chockie and Bjorkelo, 1992 - Laverna, 2002 - Madisetti, et al., 1999 - Reinertsen, 1996

APPENDIX B

LIFE CYCLE EXTENSION MODEL



APPENDIX C

IRB DOCUMENTS

Interview Letter

Date

Dear [Potential Interviewee],

My name is Autumn Sellars and I am a graduate student in Management of Technology at Vanderbilt University. A fellow graduate student, Ben Matthews, and I are conducting research under Dr. William Mahaffey in system engineering. We are currently analyzing a model that can be used for life cycle extension of legacy systems. This research project is being conducted in partial fulfillment of a Master's thesis in Management of Technology.

We would like to ask for a face-to-face interview at your earliest convenience. For your familiarity, attached is a copy of the model that has been developed and the questions you will be asked. All individual responses will be treated as confidential. The information will not be reported in a way that enables others to identify the respondent or the respondent's organization. Additionally, you will be provided with a copy of the results to this study.

With your permission, the interview will be audio taped, as it would assist in recalling details of our conversation. Please respond to this email to indicate whether or not you are willing to participate in this study. Also, please respond in the email and indicate if your interview may be audio taped. You do not have to respond to any of the questions asked if you do not wish to. You will be contacted to verify your willingness to participate in this study and to establish a mutually convenient time to conduct the interviews. If you agree to have the interviews audio taped, the tapes will be kept no longer than two years after completion of the study, at which point they will be destroyed.

If you have any questions or comments, you can reach Autumn at autumn.sellars@vanderbilt.edu or 615-500-5357; you can reach Ben at b.matthews@vanderbilt.edu or 615-268-4178**,** or you may contact my academic advisor at william.r.mahaffey@vanderbilt.edu or 615-322-2964. For additional information about giving consent or your rights as a participant in this study, please feel free to contact the Vanderbilt University Institutional Review Board Office at 615-322-2918 or toll free at 866-224-8273.

Thanks in advance for your assistance,

Autumn Sellars
Ben Matthews

Possible Questions for Interviewees

Following is the outline of the questions intended to be asked, which are derived from the model and their sources within the literature review:

1. System Characteristics

Describe your system? - Is the system hardware? - Is the system software? - Do you consider the system to be complex?	1. Brooke, C., Ramage, M. (2001). Organizational Scenarios and Legacy Systems. *International Journal of Information Management*, 21, 365-384 2. Rekoff, Jr., M.G. (1985). On Reverse Engineering. *IEEE Transactions on Systems, Man, and Cybernetics*, 15(2), 244-252. 3. Welch, L.R., Samuel, A.L., Masters, M.W., Harrison, R.D., Wilson, M., Caruso, J. (1995). Reengineering Computer-Based Systems for Enhanced Concurrency and Layering. *J. Systems Software*, 30(1-2), 45-70.

2. Maintenance

Tell me about your maintenance practices? – Repairing or replacing anything that relates to performance of system - Is your system currently operational ready? - Do you have scheduled maintenance plans you follow? - Do you service the system only when it is necessary? - Do you think maintenance costs are excessive based on previous maintenance budgets? - Do you think constant maintenance is contributing to system degradation? - Are employees available who have the skill set to maintain system? - For example you may have trouble finding people wanting to work on maintenance issues	1. Adolph, W.S. (1996). Cash cow in the tar pit: reengineering a legacy system, *IEEE Software,* 13(3), 41-47. 2. Bennett, K. (1995). Legacy Systems: Coping With Stress. *IEEE Software,* 12(1), 19-23 3. Bray, O., Hess, M.M. (1995). Reengineering a Configuration-Management System. *IEEE Software,* 12(1), 55-63 4. Brooke, C., Ramage, M. (2001). Organizational Scenarios and Legacy Systems. *International Journal of Information Management,* 21, 365-384 5. Blanchard, B. (1998). System Engineering Management. John Wiley and Sons: New York, New York, 38-42.

3. Documentation

Do you have documentation associated with this system? What type? - Is the documentation available? - Is the documentation inadequate? - Are the original designers available for consultation that could explain documentation?	1. Alderson, A., Hanifa, S. (1999). Viewpoints on Legacy Systems. *Communications of the ACM*, 42(3), 115-117. 2. Bisbal, J., Lawless, D., Bing, W., Grimson, J. (1999). Legacy information systems: issues and directions. *IEEE Software*, 16(5), 103 – 111. 3. Chikofsky, E.J., Cross II, J.H. (1990). Reverse Engineering and Design Recovery: A Taxonomy. *IEEE Software*, *7*(1), 13-17. 4. Rekoff, Jr., M.G. (1985). On Reverse Engineering. *IEEE Transactions on Systems, Man, and Cybernetics,* 15(2), 244-252.

4. Obsolescence

Do you consider the obsolescence of your system to be one of the driving factors behind addressing legacy system issues? - Is your supplier no longer making parts for the system? - Is obsolescence one of the reasons you are inserting technology into your system? - Is obsolescence preventing you from adding to the functionality of the system? - Is obsolescence preventing you from modifying the functionality of the system? - Will you not change the functionality of the system? - Do current design team/employees understand legacy system?	1. Chikofsky, E.J., Cross II, J.H. (1990). Reverse Engineering and Design Recovery: A Taxonomy. *IEEE Software*, *7*(1), 13-17. 2. Madisetti, V.K., Jung, Y.-K., Khan, M.H., Kim, J., Finnessy, T. (1999). Reengineering legacy embedded systems. *IEEE Design & Test of Computers*, 16(2), 38 – 47 3. Sage, A. (1995). Systems engineering and systems management for reengineering. *Journal of Systems and Software*, 30(1-2), 3-25. 4. Sneed, H.M. (1995). Planning the Reengineering of Legacy Systems. *IEEE Software*, 12(1), 24 -34. 5. Welch, L.R., Samuel, A.L., Masters, M.W., Harrison, R.D., Wilson, M., Caruso, J. (1995). Reengineering Computer-Based Systems for Enhanced Concurrency and Layering. *J. Systems Software*, 30(1-2), 45-70.

5. Cost/Benefit Analysis

Did you perform a cost benefit analysis and what were your findings? - Is the system used as part of your organizations core competency? - Do you feel it is feasible for your organization to cover the cost of rebuilding the system? - Do you feel it is feasible for your organization to cover the cost of redesigning the system? - Do you feel customer service/support contributes to excessive operational cost based on previous budgets?	1. Adolph, W.S. (1996). Cash cow in the tar pit: reengineering a legacy system, *IEEE Software*, 13(3), 41-47. 2. Brooke, C., Ramage, M. (2001). Organizational Scenarios and Legacy Systems. *International Journal of Information Management*, 21, 365-384 3. Blanchard, B, Fabrycky, W.J. (1981). Systems Engineering and Analysis. Prentice Hall: Upper Saddle River, New Jersey, 557-602. 4. Chikofsky, E.J., Cross II, J.H. (1990). Reverse Engineering and Design Recovery: A Taxonomy. *IEEE Software, 7*(1), 13-17. 5. Sneed, H.M. (1995). Planning the Reengineering of Legacy Systems. *IEEE Software*, 12(1), 24 -34.

APPENDIX D

INTERVIEW GUIDE

Introduce ourselves

- Explain who will be conducting the interview while the other is taking notes.

Confidentiality

- Everything will be kept confidential with everyone inside and outside the company.
- Any documents and recordings that are given to us will be destroyed within 2 years.
- You will be provided with a copy of the results or a short summary.

Purpose of research

- Research will analyze models that can be used for the life cycle extension of a legacy system
- What the end product should be

Explain to them why this is important and how it could be beneficial

- Large cost of legacy systems – very expensive to maintain and can hinder organization performance if not handled correctly
- No one has done this before – after an extensive literature review we have found that no one has divided the methods according to system characteristics
- Can help save money and improve efficiency and effort expended when addressing legacy systems
- This could also illustrate whether or not you are performing the correct method of dealing with your legacy system according to academic management and system engineering resources
- Could help you generate new ideas of how to handle legacy systems
- Trying to bridge the gap between academics and practical applications.

Initial Questions

- Find out the interviewee's position

- Find out the interviewee’s responsibilities.
- What is their formal training.
- How long have they been working on this project.

Model Questions

- What do you think was the major factor for making the decision to do this life extension project?
- System description and characteristics

  Describe your system?

  - Is the system hardware?
  - Is the system software?
  - Do you consider the system to be complex?

  - Organizational
  - People Issues
- Cost/Benefit Analysis

  Did you perform a cost benefit analysis and what were your findings?

  - Is the system used as part of your organizations core competency?
  - Do you feel it is feasible for your organization to cover the cost of rebuilding the system?
  - Do you feel it is feasible for your organization to cover the cost of redesigning the system?
  - Do you feel customer service/support contributes to excessive operational cost based on previous budgets?
- Maintenance / Changes

  Tell me about your maintenance practices? – Repairing or replacing anything that relates to performance of system

  - Is your system currently operational ready?
  - Do you have scheduled maintenance plans you follow?
  - Do you service the system only when necessary?
  - Do you think maintenance costs are excessive based on previous maintenance budgets?

- Do you think constant maintenance is contributing to system degradation?
- Are employees available who have the skill set to maintain system? - For example you may have trouble finding people wanting to work on maintenance issues

- Obsolescence

  Do you consider the obsolescence of your system to be one of the driving factors behind addressing legacy system issues?

  - Is your supplier no longer making parts for the system?
  - Is obsolescence one of the reasons you are inserting technology into your system?
  - Is obsolescence preventing you from adding to the functionality of the system?
  - Is obsolescence preventing you from modifying the functionality of the system?
  - Will you not change the functionality of the system?
  - Do current design team/employees understand legacy system?
- Documentation

  Do you have documentation associated with this system? What type?

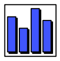
  - Is the documentation available?
  - Is the documentation inadequate?
  - Are the original designers available for consultation that could explain documentation?
- Time / Schedule

Conclusions

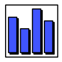
- Get contact info
- Thank them and tell them we may be contacting them for additional information.

APPENDIX E

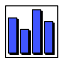
INTERVIEW RESULTS



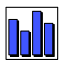
Interview #1 Results



Interview #2 Results



Interview #3 Results



Interview #4 Results

REFERENCES

1. Acquisition Management System. (n.d.). *OMS(Obsolescence Management Strategy)*. Retrieved December 29, 2003 from United Kingdom Ministry of Defense: http://www.ams.mod.uk/ams/content/docs/obsolete/oms.doc.

2. Adolph, W. S. (1996). Cash Cow in the Tar Pit: Reengineering a Legacy System. *IEEE Software*, 13(3), 41-47.

3. Ahrens, J. D., N. Prywes, et al. (1995). Software Process Reengineering - Towards A New Generation of Case Technology. *Journal of System Software*, 30(1-2), 71-84.

4. Aiken, P., A. Muntz, et al. (1993). A Framework for Reverse Engineering DOD Legacy Information Systems. *FIM/TIM Conference*, Monterey, CA, http://www.defenselink.mil/nii/bpr/bprcd/mhone.htm, 1-12.

5. Aiken, P., O. K. Ngwenyama, et al. (1999). Reverse-Engineering New Systems for Smooth Implementation. *IEEE Software*, 16(2), 36-43.

6. Alderson, A. and S. Hanifa (1999). Viewponts on Legacy Systems. *Communications of the Association for Computing Machinery*, 42(3), 115-117.

7. Asker, J. R. (1995). Boeing station work set at $5.6 billion. *Aviation Week & Space Technology*, 142(4), 63-64.

8. Bennett, K. (1995). Legacy Systems: Coping With Stress. *IEEE Software*, 12(1), 19-23.

9. Bennett, K. H., M. Ramage, et al. (1999). Decision model for legacy systems. *IEEE Proceedings Software*, 146(3), 153-159.

10. Biggerstaff, T. J. (1989). Design Recovery for Maintenance and Reuse. *IEEE Computer*, 22(7), 36-49.

11. Bisbal, J., D. Lawless, et al. (1999). Legacy Information Systems: Issues and Directions. *IEEE Software*, 16(5), 103-111.

12. Blanchard, B. and W. J. Fabrycky (1981). *Systems Engineering and Analysis*. Upper Saddle River, New Jersey, . Prentice Hall.

13. Bray, O. and M. M. Hess (1995). Reengineering a Configuration-Management System. *IEEE Software*, 12(1), 55-63.

14. Brooke, C. and M. Ramage (2001). Organizational Scenarios and Legacy Systems. *International Journal of Information Management*, 21, 365-384.

15. Buckley, S. (2003). Are We There Yet? *Telecommunications Americas*, 37(13), 6.

16. Buede, D. M. (2000). *The Engineering Design of Systems*. New York, NY: John Wiley & Sons, Inc.

17. Chikofsky, E. J. and J. H. Cross II (1990). Reverse Engineering and Design Recovery: A Taxonomy. *IEEE Software*, 7(1), 13-17.

18. Chockie, A. and K. Bjorkelo (1992). Effective Maintenance Practices to Manage System Aging. *Annual Reliability and Maintainability Symposium Proceedings*, IEEE, 166-170.

19. Eisenhardt, K. (1989). Building Theories from Case Study Research. *Academy of Management Review*, 14(4), 532-550.

20. Erwin, S. I. (2004). Computer System Helps Lower Spare Parts Shortages at Air Force Depots. *National Defense*, 89(609), 17.

21. Gannod, G. C. and B. H. C. Cheng (1999). A framework for Classifying and Comparing Software Reverse Engineering and Design Recovery Techniques. *Sixth Working Conference Proceedings on Reverse Engineering*, Atlanta, GA, 77-8.

22. Glass, R. L. (2000). On Personal Technical Obsolescence. *Communications of the Association for Computing Machinery*, 43(7), 15-16.

23. Gold, N. (1998). *The meaning of 'Legacy Systems'*. Retrieved 1/06/04, 2004 from EPSRC - Systems Engineering for Business Process Change SABA: http://www.dur.ac.uk/CSM/SABA/legacy-wksp1/meaning.html.

24. Hitchins, D. K. (1998). Systems Engineering in search of the elusive optimum. *Engineering Management Journal*, 8(4), 195-207.

25. Holland, C. P., B. Light, et al. (1999). Focus Issue on Legacy Information Systems and Business Process Change: Introduction. *Communications of the Association for Information Systems*, 2(9), 1-11.

26. Holtzblatt, L. J., R. L. Piazza, et al. (1997). Design Recovery for Distributed Systems. *IEEE Transactions on Software Engineering*, 23(7), 461-472.

27. Kahn, A. (1990). Technical Obsolescence. *American Psychologist*, 45(11), 1272.

28. Littlejohn, K., M. V. DelPrinciple, et al. (2000). Embedded Information System Re-Engineering. *IEEE Aerospace and Electronics System Magazine*, 15(11), 3-7.

29. Liu, K., A. Alderson, et al. (1998). Using Semiotic Technology to Derive Requirements from Legacy Systems. *Systems Engineering for Business Processes Change workshop*, Durham, N.C, 1-9.

30. Lott, S. (2004). Korean Air to Provide Engine Maintenance for UA, LH. *Aviation Daily*, 356(12), 6.

31. Madisetti, V., Y.-K. Jung, et al. (2000). On Upgrading Legacy Electronics Systems: Methodology, Enabling Technologies and Tools. *IEEE Proceedings on VHDL International Users Forum Fall Workshop*, IEEE, 7-14.

32. Madisetti, V. K., Y.-K. Jung, et al. (1999). Reengineering Legacy Embedded Systems. *IEEE Design & Test of Computers*, 16(2), 38-47.

33. Magarey, J. M. (2001). Elements of a Systematic Review. *International Journal of Nursing Practice*, 7, 376-382.

34. Mahaffey, W. R., J. S. Tomlinson, et al. (2000). Functional Discovery to Enable Confident Change. *15th International Conference on Systems Engineering*,

35. Manzella, J. and B. Mutafelija (1992). Concept of Re-engineering Life-Cycle. *2nd International Conference on Systems Integration*, 566-571.

36. Meredith, J. (1998). Building operations management theory through case and field research. *Journal of Operations Management*, 16, 441-454.

37. Peltier, R. (2003). DCS reinvigorates Hong Kong's oldest plant. *Power*, 147(7), 58.

38. Prescott, N. J. (1995). Equipment Life: Can We Afford To Extend It? *Proceedings Annual Reliability and Maintainability Symposium*, British Crown, 529-535.

39. Ranson, L. (2004). United Services Uses Chap.11 to Change Business Strategy. *Aviation Daily*, 356(17), 5.

40. Rechtin, E. (1992). The art of systems architecting. *IEEE Spectrum*, 29(10), 66-69.

41. Reinertsen, R. (1996). Residual life of technical systems; diagnosis, prediction and life extension. *Reliability Engineering and System Safety*, 54(1), 23-34.

42. Rekoff, M. G., Jr. (1985). On Reverse Engineering. *IEEE Transactions on Systems, Man, and Cybernetics*, 15(2), 244-252.

43. Rugaber, S. and J. White (1998). Restoring a Legacy: Lessons Learned. *IEEE Software*, 15(4), 28-33.

44. Sage, A. P. (1995). Systems Engineering and Systems Management for Reengineering. *Journal of Systems and Software*, 30(1-2), 3-25.

45. Sage, A. P. (1999). *Handbook of Systems Engineering and Management*. New York: John Wiley and Sons, Inc.

46. Sellars, A. (2004). *Life Cycle Extension Strategies For Legacy Systems*. Retrieved from Vanderbilt University website: http://etd.library.vanderbilt.edu/ETD-db/available/etd-07062004-151044/.

47. Serrano, M. A., D. L. Carver, et al. (2002). Reengineering legacy systems for distributed environments. *The Journal of Systems and Software*, 64(1), 37-55.

48. Sneed, H. M. (1995). Planning the Reengineering of Legacy Systems. *IEEE Software*, 12(1), 24-34.

49. Sneed, H. M. (1999). Risks involved in Reengineering Projects. *6th Working Conference Proceedings on Reverse Engineering*, Atlanta, GA, 204-211.

50. Solomon, R., P. A. Sandborn, et al. (2000). Electronic Part Life Cycle Concepts and Obsolescence Forecasting. *IEEE Transactions on Components and Packaging Technologies*, 23(4), 707-717.

51. Sowers, J. L. and P. E. Rubin (2001). Reversing course: Issues in modeling legacy systems. *Telecommunications Systems*, 16(1,2), 147-157.

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

53. Taverna, M. A. (2002). Airbus Unveils Aviation Support Services Plan. *Aviation Week & Space Technology*, 157(14), 52.

54. Unknown. (2003, December 22). Rolls-Royce Is Kept On. *The Washington Post* [Washington, D.C.]. p. E.02.

55. Vedantam, S. (2003). *Space Shuttles Bound to Technologies of the Past*. Retrieved February 26, 2003 from Washington Post: http://www.washingtonpost.com/wp-dyn/articles/A61971-2003Feb24.html.

56. Welch, L. R., A. L. Samuel, et al. (1995). Reengineering Computer-Based Systems for Enhanced Concurrency and Layering. *Journal of Systems and Software*, 30(1-2), 45-70.

57. Whetten, D. A. (1989). What Constitutes a Theoretical Contribution. *Academy of Management Review*, 14(4), 490-495.

58. Yin, R. K. (1994). *Case Study Research Design and Methods*. Thousand Oaks, California: Sage Publications, Inc.

59. Young, F. C. D. and J. A. Houston (1999). Formal Verification and Legacy Redesign. *IEEE AES Systems Magazine*, 14(3), 31-36.

60. Zylstra, S. G. and D. Thompson (2004). 'Virtual Supply Chains' Could Help Bridge Manufacturing Gaps. *National Defense*, 89(609), 68-70.