THE RELATIONSHIP BETWEEN LIFE-CYCLE COSTING AND PERFORMANCE: AN EXPLORATORY ANALYSIS

By

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To Mom, Dad, Lesley and Uncle Dan.

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CHAPTER I

INTRODUCTION

As the United States continues the war on terrorism, military spending continues to grow. In February 2005, President Bush asked Congress for an additional $82 billion to cover the costs of keeping troops in Iraq; much of this emergency request was to cover the costs of ensuring U.S. troops in Iraq and Afghanistan have the supplies they need (Jaffe, 2005). This request is in addition to the $402 billion Department of Defense 2005 Fiscal Year Budget (DoD Financial Summary Tables, 2005). As a result of this spending, the Defense Department is under pressure to control its costs. In response to this pressure, the Pentagon began a study to explore ways to reduce the maintenance costs of weapons systems, and improve the efficiency of maintenance operations (Erwin, 2005). Maintenance and other long term systems costs beyond the initial acquisition cost comprise a large portion of the DoD budget.

A method that is currently being used by the DoD in an attempt to manage and control costs within their systems is life-cycle costing. DoD Directive 5000.1 requires that a total systems approach be used in acquisition programs to optimize total system performance and minimized the cost of ownership (DoD Directive, 2003c). Ownership costs historically have accounted for 60 to 70 percent of life-cycle costs for weapons systems (Asiedu and Gu, 1998).

Life-cycle costing is a tool that is commonly used in conjunction with Systems Engineering (Fabrycky and Blanchard, 1991). A system is defined as a collection of hardware, software, people, facilities, and procedure organized to accomplish some common objective (Buede, 2000). Using this definition, a system could be anything from a subway system, to a university, to a missile defense system. For the purpose of this study, only government defense systems are going to be considered. A major characteristic of Systems Engineering is that the entire life of the system, from inception to disposal, is taken into consideration as decisions are made (Buede, 2000). Systems Engineering is based upon developing, matching, and trading off requirements, functions and resources to reach a cost-effective, life-cycle balanced product based on the needs of the stakeholder (Buede, 2000). Life-cycle costing is a costing technique that applies the pillars of systems engineering using a macro, long-term view of the system.

The process of life-cycle costing involves evaluating different design options, and determining the most cost-effective solution to meeting system requirements (Woodward, 1997). Life-cycle costing requires knowledge of anticipated system reliability, utilization and maintenance procedures because they help in understanding of the relationship between the capital costs of the systems design, acquisition and disposal, and the costs of operation and maintenance (Woodward, 1997).

A systematic review of the literature available on life-cycle costing demonstrated that there are few studies that explore the outcome of life-cycle costing, specifically from the perspective of experts in the field. (See Chapter II)

A major issue that needs to be addressed is what effect life-cycle costing has on a finished system. The longevity of the system, system performance, and the system costs may be affected by the application of life-cycle costing principles (Fabrycky and Blanchard, 1991). The longevity of the system is the length of time the system can physically remain operation, its useable life. The performance of the system, for the purpose of this research, is based on reliability, the time it takes to repair the system, and how well the finished system meets customer expectations. The effect life-cycle costing has on these factors, as perceived by the experts in the field is the purpose of this exploratory research. For example, if life-cycle costing requires more resources initially in the design phase due to trade studies and other tools being used, yet does not increase the system life, it may be argued that its initial incremental cost is not justified.

The exploratory research conducted to explore these issues increases the current body of knowledge that is available for life-cycle costing. There are four main objectives of this research: 1) to create and validate an instrument to measure the above mentioned issues (a survey); 2) to explore if certain types of business units are more likely to have success using life-cycle costing than others; 3) to explore the effect life-cycle has on the properties of finished systems; and 4) to explore whether if an overall consensus on the desirability of using life-cycle costing is system development exists.

There are five main chapters in this thesis. The first chapter is the introduction. The second chapter is the systematic review of the literature. A formal literature review was conducted to ensure a comprehensive collection of information pertinent to this research. The next chapter contains the research model and explains the goals of the research and how the survey instrument was developed. The fourth chapter of the thesis is the methodology which explains how the survey instrument was used to gather data. It also explains how the surveys were distributed and how the field studies were conducted. Following the methodology section is the results section. This chapter discusses the information that was obtained using the survey instrument. The last section of the thesis is the conclusion and opportunities for further study chapter. This section evaluates the results of the survey and ties them into the initial research objectives. Conclusions are made based on the pilot study, and suggestions for further research are discussed in this final chapter.

CHAPTER II

LITERATURE REVIEW

Systematic Review of Literature Procedure

A systematic review of literature was conducted to obtain sources pertaining to life-cycle costing and methods of life-cycle costing (Margery 2001). A systematic review of literature is an unbiased collection of all the data on a given topic, and a critical appraisal and synthesis of this information to answer the research question (Magarey, 2001). A thorough review of existing literature on a given subject matter creates a firm foundation for advancing knowledge by identifying the areas where a plethora of research already exists, while also uncovering areas where research is needed (Webster and Watson, 2002). The steps in a systematic review are to first formulate a research question, then identify the key words and pertinent databases, and lastly search for literature and research using the key words and databases. After performing a comprehensive search for information pertaining to the topic, the collected articles are narrowed down to the ones that are most relevant to the research question (Magarey, 2001).

The first step in conducting the literature review was to locate sources of information on lifecycle costing. A list of key words was compiled to use in searching the databases. Words that were frequently used in conjunction with life-cycle costing, such as cost modeling and life-cycle engineering, were included in the list of keywords. After doing an initial search of key words, and skimming the literature found, additional words and phrases commonly found in the relevant articles were added to the list of key words. For example, the phrase “design for ‘X’,” where ‘X’ is replaced by representative terms such as manufacturability and maintainability, was commonly used in conjunction with life-cycle costing so it was added to the list of terms searched. Different forms of key phrases and words were searched, for example in addition to cost model, the phrases cost modeling and cost models were searched. Also, life-cycle costing was searched hyphenated and unhyphenated because there does not seem to be a standard punctuation for the term. Table 1 lists the key words that were searched within the databases.

Once the key words had been identified, the appropriate search tools and databases were identified. Relevant articles for the past 45 years were collected, specifically from 1960 to present day. This time span was chosen because life-cycle costing was first used in the 1960’s (Gluch and Baumann, 2003). In order to cover business, engineering and economic literature pertaining to life-cycle costing, a range of search engines and databases were used. Extensive searches were conducted across the following databases: Business Source Primer, DoD Defense Link, IEEE Xplorer, JSTOR, Lexis Nexis Academic, ProQuest, Government Printing Office, Vanderbilt University Acorn Catalog, Web of Knowledge. The databases searched are listed in Table 2.

Business Source Primer provides database full text access to nearly 7,600 scholarly business journals dating back to 1922. The search engine on the DoD Defense Link (www.defenselink.mil) is a tool that locates military information online. It provides information on defense policies, organizations, functions and operations. The IEEE Xplorer searches IEEE and IEE Transactions, Journals, Magazines and Conference Proceedings published since 1988, and additional limited content dating back to 1950.

The diversity of databases searched provided extensive and thorough systematic search of literature. JSTOR is a journal archive that provides compete electronic back files of journals in a variety of subjects. Full text articles in this database typically begin at the first issue of each journal and end within five years of the present date. Lexis Nexis is a database that provides full text sources to current events in a variety of subjects including business and government information. The ProQuest search engine was used to find scholarly journal articles, dissertations and articles by various news sources dating back to 1985. The Government Printing Office resource is a catalog and index to U.S. government publications received by the GPO providing electronic versions of resources dating back to 1976. The Vanderbilt University Acorn online catalog was used to locate books and journals articles pertaining to life-cycle costing. This search engine explores literature available through Vanderbilt University Libraries, and also sources available from other university libraries via interlibrary loans.

The Web of Knowledge, Web of Science is a research database that contains citations to science journal articles dating back to 1965. One benefit of using this database is that it allows the researcher to go forward by identifying articles that cite articles previously found, and also to go backward by reviewing the citations for key articles (Webster and Watson, 2002). A physical search of government documents pertaining to lifecycle costing was conducted at the Vanderbilt University Jean and Alexander Heard Library. The indexes of journals in the Vanderbilt University Walker Management library were also searched to uncover any articles that were not available through the electronic databases.

A systematic search of literature, as described above should ensure that a relatively complete census of relevant literature was obtained (Webster and Watson, 2002). Once the same articles were repeatedly being found, and no new concepts or key words were being uncovered, the researcher was able to conclude that the relevant articles for the systematic review had been obtained (Webster and Watson, 2002).

The initial systematic search of literature returned over 17,000 potential sources. These articles were initially filtered based on their titles. Titles that were not written in regards to the life-cycle cost of an engineering system were discarded. For example, an initial search on ProQuest yielded several articles on the life-cycle cost of various medical conditions. This systematic review is concerned solely with life-cycle costs of engineering systems, so these articles were discarded. After paring down based on title, 865 sources remained.

The next step in filtering the collected literature was to eliminate articles based on the journal they were published in, and the date of publication. If the article was not found in a book, journal, or on a website that would likely be used by experts in the field of life-cycle costing, the article was discarded. Table 3 shows the refereed journals that repeatedly came up during the literature review. In addition to referred journals, information was also used from IEEE transactions and textbooks on life-cycle costing and systems engineering.

Articles published prior to 1960 were discarded because life-cycle costing for engineering systems was not used before then (Gluch and Baumann, 2003). In the same step as eliminating articles based on the journal and its publication date, duplicate articles were discarded. 156 sources remained after this step. The remaining sources were scanned to determine if they contained information that would be applicable to the systematic review. This was the final step in paring down the sources. This step eliminated 110 references. After the thousands of initial hits had been filtered, 46 sources remained. These are the sources that were used for references in this systematic review. The steps in performing the literature search are summarized in Figure 1.

Table 4 outlines the topic breakdown of the sources cited in the paper. The summary of sources indicates the most frequently occurring topics that were discussed in the sources obtained through the literature search.

The total of these sources is greater than 46 because some articles contained more than one of the topics below. For example, the journal article "Systems Life Cycle Engineering and DF 'X,'" discussed both trade studies the Design for 'X' methodology (Keys, 1990). A number of the sources listed below contained the same or similar information, therefore not all articles listed cited on the in the reference pages will be discussed in the literature review.

The results of the literature review will discuss life-cycle costing concepts and different views of the product life-cycle. Background information on life-cycle costing, including when and why the methodology was first implemented, and current uses for life-cycle costing on today's systems are described. Fundamental economic and engineering theories and ideas, which are the basis for life-cycle costing methodology, are explored in the literature review. Methods and examples of tradeoff studies are also discussed; life-cycle costing involves making optimal decisions based on cost and performance and trade studies compare different system alternatives.

Life Cycle Costing

Life-cycle costing was first used in the United States by the Department of Defense (US DoD) in the mid-1960's (Gluch and Baumann, 2003). The goal of life-cycle costing at that time was to assist the US DoD in the procurement of military equipment. The life-cycle cost concept and its application were initially motivated by US DoD findings that acquisition costs only accounted for a small part of typical weapons systems; the US DoD found that operation and support costs for typical weapons systems comprised as much as 75% of the total cost for the system (Asiedu and Gu, 1998).

In the 1970's, application of life-cycle costing spread to design decision making within the US DoD; it was used to assess and compare relative benefits of different energy design options in buildings (Cole and Sterner, 2000). By planning for the system life-cycle, decisions could be made early on in the design of the system to help alleviate the operations and support costs down the road.

One of the approaches, suggested by Apgar and Keane (2004), to lower operating costs in the DoD is to rigorously manage maintenance and repair. Operating and support costs are the most significant portion of the life-cycle costs, and are usually the most difficult types of costs to predict (Asiedu and Gu, 1998). In 2003, the Department of Defense spent $4 billion on wheeled vehicles, parts, and construction equipment, and about $500 million each on fuel and maintenance. With over 350,000 Humvees, trucks, and sedans, the Army operates the Nation's largest vehicle fleet and second largest construction equipment fleet (Apgar and Keane, 2004). The War in Iraq is wearing out the fleets and straining the maintenance systems. US government records have historically shown that the cost of operating and supporting an item may exceed the initial purchase price of that item as much as ten times (Asiedu and Gu, 1998).

Although companies in the private-sector have chosen to design with the life-cycle in mind, the concern for the entire life-cycle remains especially strong within the DoD (Asiedu and Gu, 1998 & Fabrycky and Blanchard, 1991). A reason for this could be that the US defense systems are owned, operated, and maintained by the DoD, whereas in most situations in the private sector, the producer is not the user of the system, and therefore does not incur costs associated with the later stages in the system lifecycle.

Private-sector defense contractors who build systems for the government, however, are usually obligated to design and develop in accordance with DoD directive specifications and standards, and therefore have to follow life-cycle costing procedures (Fabrycky and Blanchard, 1991).

In researching life-cycle costing and interviewing experts in the field, it is important that a consistent definition is used as to make sure each of the respondents interpret the questions the same way. No exact definition has been agreed upon for lifecycle costing amongst experts in the field. However, for this research the definition provided by Fabrycky and Blanchard (1991) will be used because they are the authors most frequently cited in the literature. In their articles they provide the following definition of life-cycle costing.

> "Life-cycle cost refers to all costs associated with the product or system in its defined life
> …Life-cycle costing is employed in the evaluation of alternative system design configurations, alternative production schemes, alternative logistic support policies, and so on. The analysis constitutes a step-by-step approach employing life-cycle cost figures of merit as criteria to arrive at a cost-effective solution. The analysis process is iterative in nature and can be applied to any phase of the system of product life cycle." (Fabrycky and Blanchard, 1991, pg. 23)

Blanchard and Fabrycky (1991) define the life-cycle of a system as the time period spanning from the acquisition phase through the utilization phase, beginning with conceptual designs, and ending with product disposal. The system life-cycle is represented in Figure 2, with identification of the need shown at the start, and the phases from conceptual design through product disposal shown within the arrow. This is the definition of they system life-cycle that will be used in the research.

Technical and economic considerations are continually given throughout the life-cycle development phases shown in Figure 2. This is done by comparing the cost of the product design with a reliability level (warranted period, useful product life, expected product life) and the support costs for some period of time after delivery to the customer for maintaining a certain performance level (Blanchard, 1988). Life-cycle costing and engineering differs from other cost and engineering procedures because the complete life-cycle of the system is considered in each phase of the system development when using life-cycle costing (Blanchard, 1988).

The underlying theory of life-cycle costing is to minimize the total amount of money that is spent on a given system from the conceptual design thorough disposal of the system, i.e. over the system life-cycle. As stated by Cavalierei et al (2004), "…in the life cycle theory the overall objective resides on the minimization of the cumulated costs." (pg. 167). The key part Cavalieri's statement is 'cumulated costs.' Life-cycle costing encourages a long-term outlook to the investment decision-making process rather than trying to save money in the short-term by simply purchasing assets with lower initial acquisition costs (Woodward, 1997). Physical performance measures and initial acquisition costs have historically tended to be the overriding factors in procurement decisions. However, present trends show that life-cycle costs are becoming more important (Sherif and Kolarik, 1981).

Life-Cycle Costing and Design Phase

Despite the fact that the majority of costs of a finished good are generated in later phases such as manufacturing and distribution, life-cycle costing theory suggests that most of the costs are implicitly determined in the early phases of development.

(Woodward, 1997). Debardelaben et. al (1997) stated that emphasizing cost-related issues early on in the design phase is the most effective phase within the product's life-cycle to control costs. A key task for product and system designers is to determine the relationship between cost information available and the decisions they make (Asiedu and Gu, 1998).

In the phases of design and development a large commitment to costs is made (Blanchard, 1991). This is because design decisions that are made prior to manufacturing implicitly define the majority of costs (Asiedu and Gu, 1998). A statistic given by Cooper and Slagmulder (2004), is that 80% to 95% of a products long-term cost is determined in its design phase. The survey that was developed and tested for this research was designed to capture whether using life-cycle costing in the design phase has been successful in controlling costs throughout a given systems lifecycle.

An example of a system having the total life-cycle costs committed early on is shown in Figure 3. The product under consideration in this example is an embedded microsystem (Debardelaben et al, 1997). Front end design processes usually involve less than 10% of the total prototyping time and cost for the system, yet account for more than 80% of a system's life-cycle cost (Debardelaben et. al, 1997).

Awareness that that cost commitments are being made early on in the system lifecycle prompts engineers and managers to explore decision making during the design phase and how certain decisions they make may control total life-cycle costs (Cavalieri et. al, 2004). This presents a challenge in estimating costs because there is an inverse relationship between the accuracy of the cost estimate and the span of time between the estimate and the event. (Cavalieri et. al, 2004). In the early phases of the life-cycle of a system, there is less information and definition in the system plans so production cost data is hard to estimate (Cavalieri et. al, 2004).

In designing and forecasting costs for the life-cycle of a system, the projected life of the product is considered; this includes product and market research, design phases, manufacturing process, reliability, and maintenance and support issues. Different articles provided different views of what costs are considered in the system life-cycle. For example, in some articles costs such as marketing and disposal costs were captured in the life-cycle costing methodology, however in others they were not (Fabrycky and Blanchard, 1991 & Sherif and Kolarik, 1981). Therefore, the survey will include a question for the respondent on what phases and costs are included in their life-cycle cost forecasts. Interactions between these different issues are complex; as a result, trade studies are conducted to allow engineers to compare alternatives throughout life-cycle phases. (Keys, 1990).

Trade Studies in Life-Cycle Costing

Trade studies in life-cycle costing are concerned with quantifying different options to ensure the implementation of a favorable system configuration. Tradeoff comparisons are typically made throughout life-cycle costing procedures. A characteristic of life-cycle costing is that the complete life-cycle of the product is kept in consideration and treated in each phase of the product development (Keys, 1990). As a result, both technical and economic considerations must be continually given throughout the product life-cycle development phases, comparing the cost of the product design with its reliability level and support costs (Keys, 1990). The length of a products expected life-cycle is taken into consideration while performing the studies.

An example of a typical cost tradeoff study for a system is shown in Figure 4. The trade space is a set of program and system parameters, attributes, and characteristics required to satisfy performance requirements (Keys, 1990). Decision makers define and redefine the a system by making tradeoffs with regard to cost, schedule, risk and performance, all of which fall within the systems trade space (Brantley et al, 2002). .

An example of a cost tradeoff comparison is shown in Figure 4. The area above the parabola represents possible system configurations. The x-axis represents the reliability metric, mean time between maintenance (MTBM), and the y-axis represents the life-cycle cost of the system. The minimum allowable MTBM is shown by the vertical line intercepting the x-axis at the minimum MTBM; any point to the right of this line would meet the MTBM requirements. The maximum system life-cycle cost is shown by the horizontal line intercepting the y-axis at the maximum allowable life-cycle cost; any point below this line would meet the life-cycle cost requirement. The trade space represented in Figure 4 is the area of possible configurations that would meet both the life-cycle cost and reliability requirements. The graph is used to show what design options are available that would meet the system requirement. The optimal configuration point for the microsystem cost trade off, represented by Figure 4, is at the intersection of the minimum allowable MTBM and the lowest life-cycle cost (Keys, 1990).

In general, the trade space is the set of system parameters, attributes, and characteristics that are required to satisfy performance standards. The decision makers theoretically define and refine the system being developed by making tradeoffs with regard to cost, schedule, risk, and performance. (Brantley, 2002).

Another example of a trade-study being used to compare system options was the process the military used in determining the most cost-effective hardening approach for a low-cost/high production volume munitions system (Millward, 1996). The trade study included a life-cycle cost tradeoff analysis for four different hardness assurance strategies. The results of the study indicated that for the requirements of the system, the conventional approach did not result in the lowest life-cycle cost. The study concluded that for the system being studied, attempts should not be arbitrarily made to substitute harder components, or to substitute radiation harness-assured components for the hardness critical items in the design if the unit production cost of the system would increase. The study concluded that for the category of system, components should be purchased at the lowest cost, and sample hardness assurance testing should be performed on each set of devices (Milward, 1996).

Tradeoff studies are a key component of life-cycle costing decision making. Available literature fails to provide many examples of whether or not trade studies have been successfully practiced in life-cycle costing. The survey developed in this research aims to uncover whether engineers using life-cycle costing are conducting trade studies, and the extent to which their suppliers are using life-cycle costing. Organizations weight the importance of different factors considered in their trade studies. Examples of these factors are initial acquisition cost, the environmental impact (Woodward, 1997). A goal of this research is to recognize what factors are most important to engineers in the defense industry.

Cost Modeling

In addition to weighing different system alternatives, it is important that costs are correctly accounted for in life-cycle costing. System costs need to be broken down to the level necessary to provide management with the visibility required in evaluating various facets of system design and development, production, operational use, and support (Blanchard, 1991). The purpose of this within the cost breakdown structure is to give management the ability to identify cost drivers, i.e. the factors that have the most impact on the price of the system. The cost breakdown structure, and the categories defined, should be coded in way that allows individual areas to be isolated and specifically analyzed without taking others into account (Blanchard, 1991). When the group that constructs the system is different than the user, the system builders pay for the resources required to bring the system to market, and the owners of the product pay for the resources required to deploy, operate and dispose of the system (Asiedu and Gu, 1998). Identifying major cost drivers allows both the users and builders to locate individual areas for cost reductions that could have the greatest impact on total life-cycle cost of the system.

Cost models used to forecast life-cycle system characteristics range from simple to complex in nature. The process being modeled, the life-cycle cost of a system, typically involves many parameters. Examples of these parameters are the system's physical environment, usage demands, reliability, maintainability, labor rates, energy rates, taxes rates, and inflation rates (Sherif and Kolarik, 1981). Using these parameters, there are many different approaches to developing cost models for life-cycle cost analysis. These models tend to fall into three general categories: conceptual, analytical, and heuristic (Asiedu and Gu, 1998)

Conceptual models typically are not highly formal or mathematical. Their purpose is typically to stimulate the thought process, though they are limited when it comes to formal analysis (Sherif and Kolarik, 1981). Conceptual models consist of a set of hypothesized relationships expressed in a qualitative framework. Generally, they are very flexible and can accommodate a wide range of systems. Figure 5 represents the life-cycle cost profile of a typical Department of Defense system acquisition (Kerzner 2001). This conceptual model example shows that the majority of life-cycle costs occur in the operation and support phases of the system life.

The second category of life-cycle cost model is the analytical model. Analytical models are usually based on mathematical relationships designed to describe a particular aspect of a system under certain conditions or assumptions (Asiedu and Gu 1998). These assumptions tend to restrict the ability of the model to represent actual system performance. The extent of the limitation is directly related to the complexity of the system (Sherif and Kolarik 1981). Heuristic models are less structured analytical models that use an approach that produces a feasible solution, although oftentimes it is not an optimal solution (Asiedu and Gu, 1998). These models are not as general as the analytical models, and usually are only applicable for the specific situation for which they are intended and cannot be used multiple times and applied to additional situations (Asiedu and Gu, 1998). Computer simulation and Monte Carlo techniques are typically used in heuristic models.

Techniques such as scenario forecasting, sensitivity analysis, probability analysis, decision trees, and Monte Carlo simulations are often used to reduce uncertainty of future costs. However, the problem with these techniques is that they presuppose that decision makers are aware of the nature of the uncertainties that can be expected during the building's lifetime (Gluch and Baumann, 2004).

All of these models have risks and potential areas for miscalculations. Datar and Gupta (1994) performed a systematic analysis of whether an activity-based costing system with multiple cost pools, activity drivers and allocation bases generates more accurate product costs. Their research can be applied to the life-cycle costing of a system because multiple cost pools, or groups of costs relating to systems functions, and estimates are taken into account when estimating the life-time cost of a system. In their systematic analysis, Datar and Gupta found that there were cost errors attributable to specification error, aggregation error, errors in measurement of overhead costs and errors in measurement of product-specific units of allocation bases. Increasing the number of cost pools in a costing system can actually increase specification and aggregation errors. Firms can reduce specification and aggregation costing errors by better specifying and breaking down costs into smaller components cost pools (Datar and Gupta, 1994).

Specification error occurs when the method used to identify costs to specific system components does not reflect the demands placed on resources by individual components. To the extent that building a system requires significant resources that do not vary directly with the volume of production, a volume-based cost system will misspecify demand placed on overhead resources by individual products (Datar and Gupta, 1994). Historically, cost systems have allocated overhead costs to products based upon drivers such as direct labor hours or machine hours. To the extent that manufacturing requires significant resources that do not vary directly with the volume of production, a volume-based cost system will not correctly identify the demands placed on overhead resources by individual products (Cooper 1988).

Aggregation error occurs when costs and units of a resource are combined over different heterogeneous activities to derive a single cost allocation rate. Heterogeneity arises when individual products use different amounts of resources across cost pools (Datar and Gupta, 1994). An example of this system used that could have this type of error was at John Deere. In the John Deere Component Works, department-wide setup costs were pooled into a single cost pool and were allocated using the total number of setup hours required by the products (Datar and Gupta, 1994). Since the accumulation and allocation of setup costs used only a single cost pool, the cost system was exposed to aggregation errors. The setup cost for one process used by one set of products may differ considerably from the setup cost per hour at another process used by another set of products. Therefore, one product may go considerably over budget, and one under budget with this type of setup system.

These two types of costing error, specification and aggregation, are important to keep in mind throughout the research, especially in the analysis of the results. These types of errors are potential causes for failures and shortcomings in systems using life-cycle costing.

Summary of Literature Review

A systematic review of literature has presented information on theory behind life-cycle costing, why life-cycle costing came into use, and the methods for using life-cycle costing to control system costs. The majority of articles included in this systematic review stated that decisions made in the design phase have a large effect on costs the system will incur in the later stages of its use. The articles stressed the importance of realizing that a lower initial acquisition cost does not necessarily result in a lower total life-time cost. Oftentimes, the money saved by choosing lower cost alternatives in the design phase may be negated by incremental costs in the future, especially for systems with long life-cycles. As discussed, these lower long-term cost alternatives are often uncovered through trade studies. Cost models are used to project future costs over the life oft the system. The three types of cost models discussed were conceptual, analytical and heuristic.

Although there is a substantial amount of literature available on the process of using life-cycle costing, and its potential benefits, little research has been done to explore whether experts that use life-cycle costing perceive it be a success or failure. The systematic review of literature, which filtered through over 17,000 references pertaining to life-cycle costing, demonstrated that further exploration and study is necessary in evaluating the effects of life-cycle costing on systems. Of the 17,000 potentially relevant references initially found in the literature review, 46 were found to be applicable to this thesis. Not one of those references, however, was focused on exploring the end result of using life-cycle costing as observed by those who have used it first hand.

The purpose of this exploratory study is to conduct a pilot study to develop and test a survey, which will be used to uncover the perceived successes and failures of life-cycle costing on a finished system. Capturing how life-cycle costing affects system performance, systems costs, and system longevity from the perspectives of those who used life-cycle costing first hand, are the goals of the survey. The characteristics that are the basis of system performance, for the purpose of this study, are defined to be reliability, system time to repair, and the ability to satisfy customer expectations. The survey will be tested by conducting field studies, and mailing the survey to respondents whom could not be met with in person.

Table 1. Summary of Key Words Searched in Literature Review

Key Words	
Concurrent Engineering	Life-Cycle Cost
Cost Model	Life Cycle Costing
Cost Modeling	Life-Cycle Costing
Design for 'X'	Life-Cycle Engineering
Life Cycle Assessment	Life Cycle Engineering
Life-Cycle Assessment	Time-Based Competition
Life Cycle Cost	Total Cost Assessment

Table 2. Summary of Databases and Search Engines in Literature Review

Databases and Search Engines in Literature Review	
Business Source Primer	ProQuest
DoD Defense Link	Government Printing Office (GPO)
IEEE Xplorer	Vanderbilt University Acorn Catalog
Scholarly Journal Archive (JSTOR)	Web of Knowledge
Lexis Nexis Academic	

Table 3. Summary of Refereed Sources Used in Literature Review

Refereed Source in Literature Review	
Internal Journal of Computer Integrated Manufacturing	International Journal of Production Research International Journal of Project Management
International Journal of Management Science (OMEGA)	Journal of the Operational Research Society
International Journal of Physical Distribution and Logistics Cost Management	MIT Sloan Management Review
International Journal of Production Economics	Proceedings of the Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture

Table 4. Summary of Sources

Summary of 46 Sources Cited in Thesis	
27 on LCC Methodology	5 on Design for 'X'
13 on LCC and Design Phase	6 on Tradeoffs/ Trade Studies
6 on LCC Models	4 on Theory Behind LCC
6 on History of LCC	3 on Potential Error in LCC
6 on Characteristics of System Life Cycle	.
**Total is greater than 46 because some sources contained more that one of the topics above*	

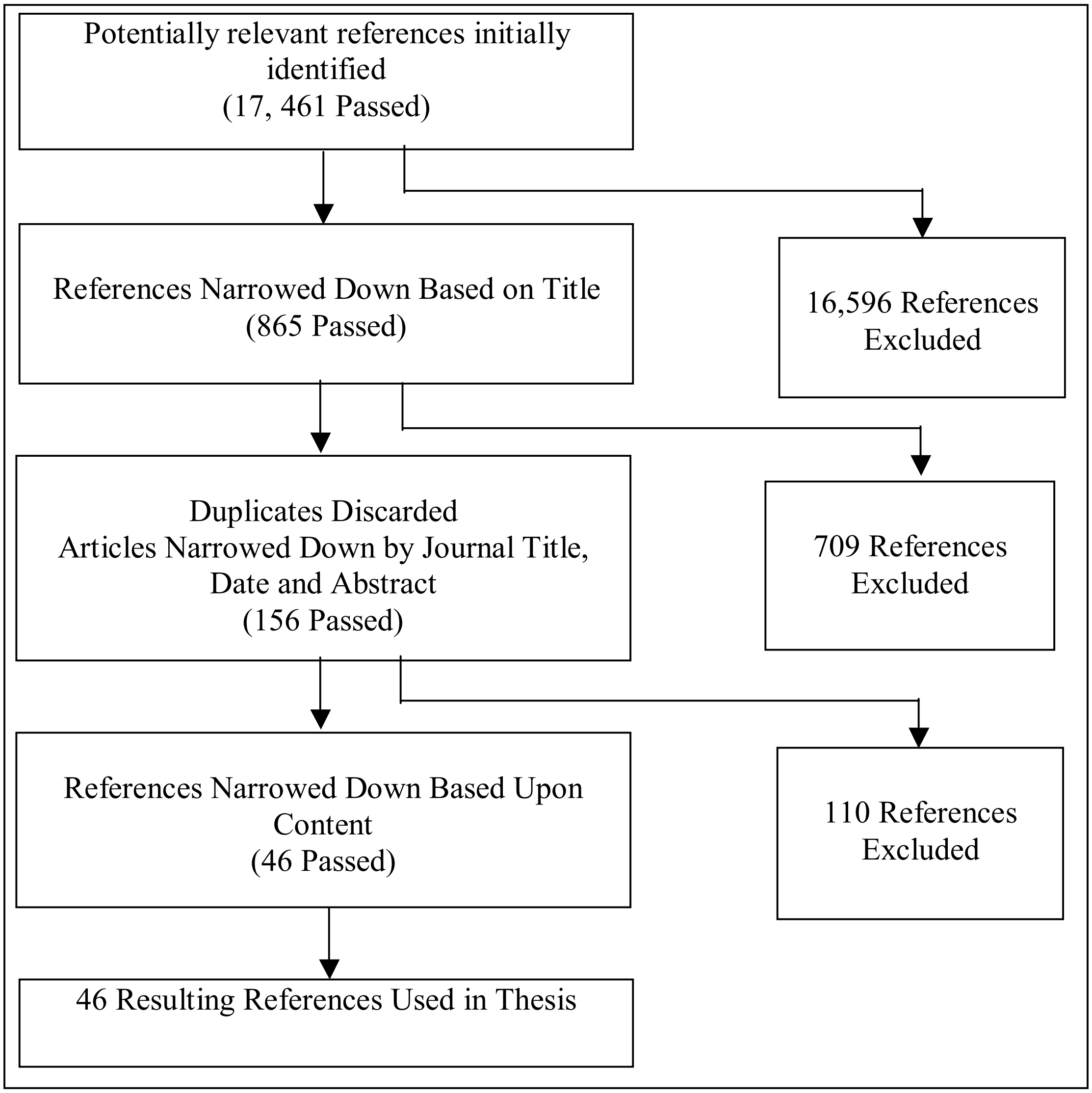


Figure 1. Search Method Flowgraph

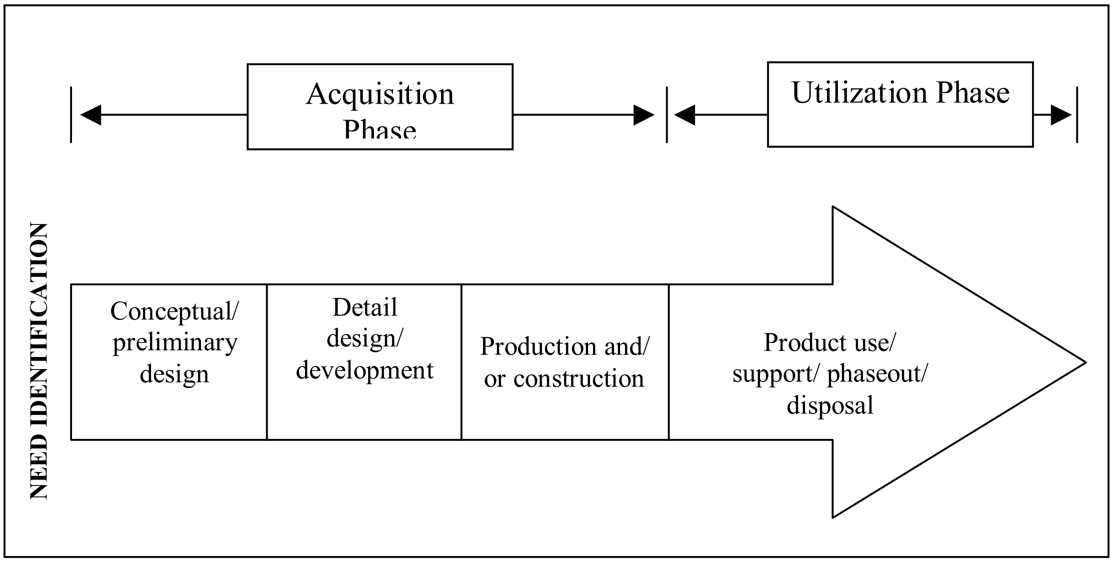


Figure 2. System Life-Cycle (Blanchard and Fabrycky, 1991)

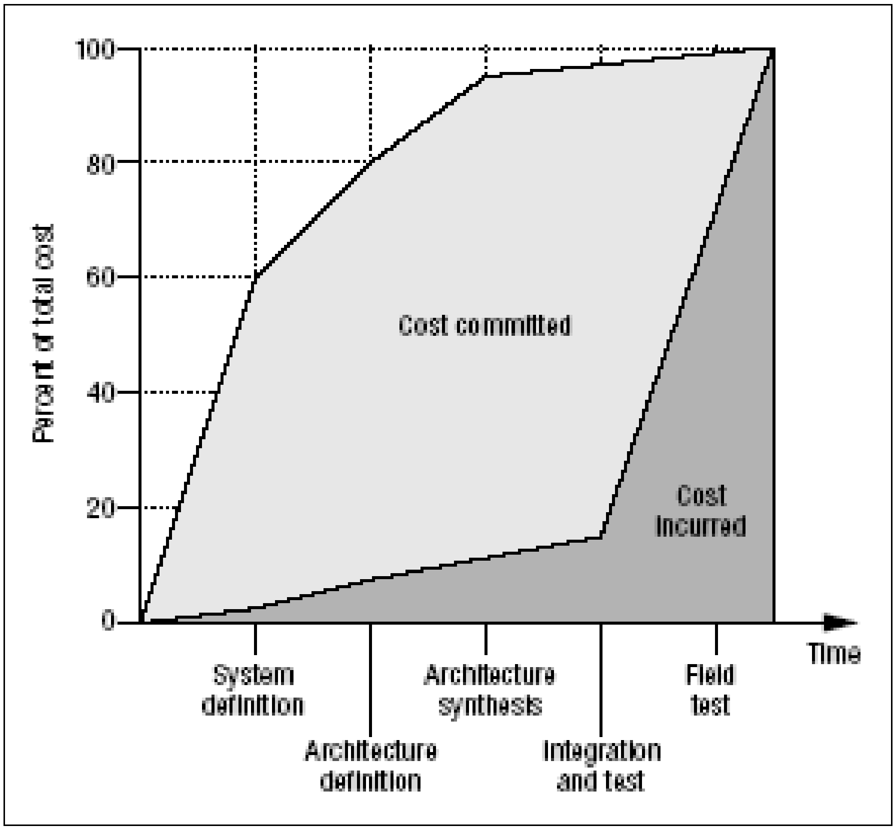


Figure 3. Cost Commitment Over the System Life (Debardelaben et. Al, 1997).

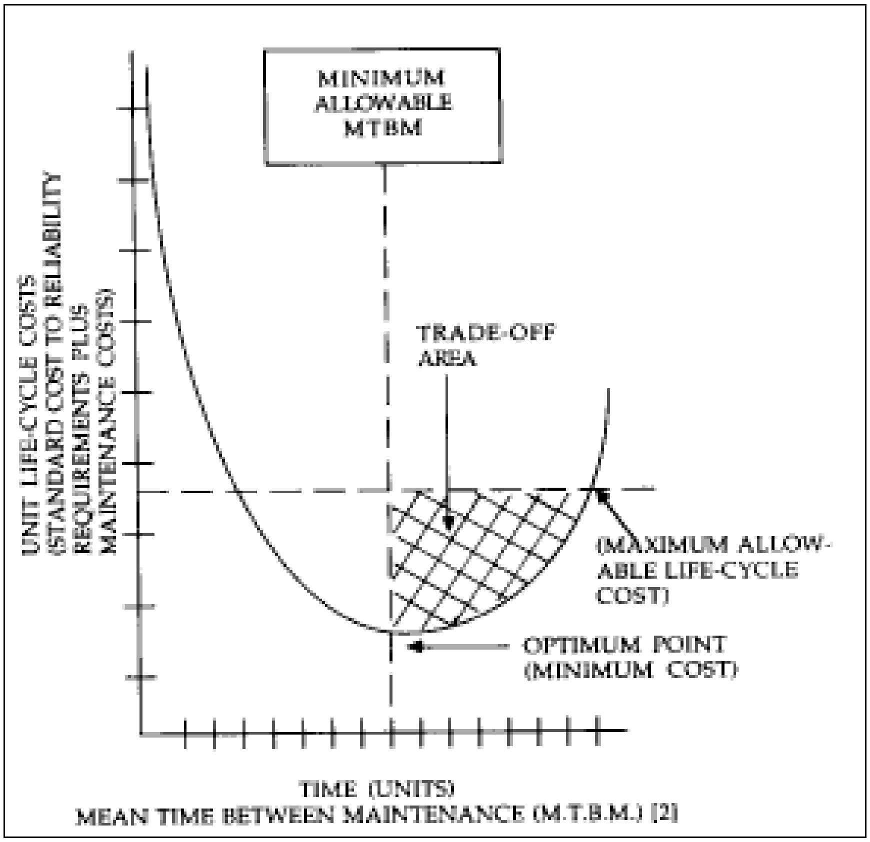


Figure 4. Tradeoff Comparison (Keys, 1990 pg. 84).

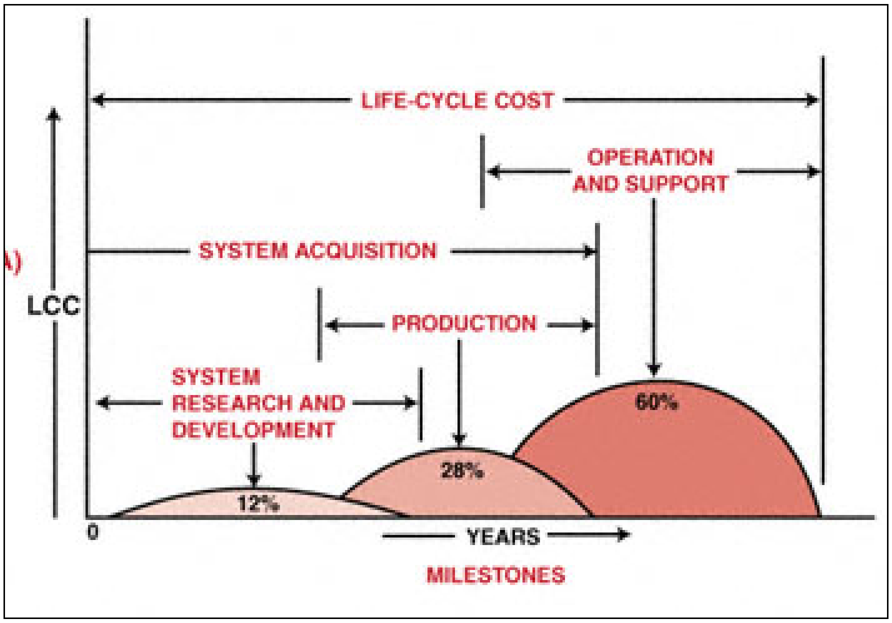


Figure 5. DoD System Acquisition Life-Cycle Cost Profile (Kerzer 2001, pg. 784).

CHAPTER III

RESEARCH MODEL AND DEVELOPMENT OF INSTRUMENT

Development of Research Model

As previously stated, the goal of this exploratory research is to develop and test an instrument for measuring the effects life-cycle costing has on the development of a system. To ensure that the survey captures the factors being explored in this pilot study, a model was first constructed to visually represent the relationship between the factors. (See Figure 6)

The characteristics of both the systems and business units being surveyed are first explored to help understand what factors contributed to the system development. The application of the life-cycle costing methodology to the system development is surveyed, and characteristics of the finished system are studied to explore the effects of life-cycle costing. The system development is the process of the business unit either creating a new system or conducting an upgrade on a preexisting system. The two factors that affect the system development in this model are the characteristics of the business unit, and the characteristics of the system itself (Buede, 2000).

System Development Factors

The characteristics of the system captured in this model are the system's size, time to develop, cost, expected life and status. The systems size, for the purpose of this research, will be quantified using the number of employees that were involved in its development. This is an important characteristic because the number of employees involved may have an effect on the success of life-cycle costing (Cole and Sterner, 2000).

The time to develop is the length of time it took the business unit to create the system from the system concept to the releasing of the system for production. A shorter time to develop may indicate that there was less time spent on doing trade studies and making future cost estimates. The cost of the system is the amount of money initially committed to the system. The status of the system characterizes whether it is a current system, retired system, abandoned system, or a system that has not yet been produced. Although life-cycle costing is most frequently used in the creation of new systems, it can be used for upgrades made to preexisting systems (Cole and Sterner, 2000).

Business unit characteristics captured by this model are its size, the type of industry it is in, and its objectives or priorities; these characteristics are important to know because of potential correlations they may have with the effects of life-cycle costing (Buede, 2000). The size of the business unit is measured by how many people are employed at the organization. The type of industry group is characterized by the primary products or services that the business unit produces. Examples of industry groups are transportation equipment and electronics. The industry group is important to know for this research because life-cycle costing may be more successful applied to certain types of systems than others.

The objectives of the business unit are based on the groups' goals and priorities. For example, these objectives may be guaranteeing speedy delivery of services, or beating competitors to the marketplace with new systems. It is important to know the priorities of the organization when attempting to understand the success of life-cycle costing. A business unit whose most important goal is to beat competitors to the marketplace with new systems may spend less time making life-cycle costing forecasts in order to minimize the time required to get their system to market.

Application of Life-Cycle Costing to System Development

After defining the factors that could inherently affect the system development, the model takes into account how life-cycle costing principles are applied during system development. The depth of implementation of life-cycle costing is explored; this includes how long life-cycle costing has been used at the business unit, and how much of the organization uses life-cycle costing (Cole and Sterner, 2000). (ex. throughout the corporation? only at the respondent's business unit?) Organizations that have been using life-cycle costing for a long time, or have implemented it throughout the organization may have a higher degree of training resources available than those who have not been using it as long.

The completed system characteristics are examined so possible correlations between these characteristics and the effects of life-cycle costing principles can be uncovered. System longevity, performance and cost are the three characteristics that are used to assess the effect of life-cycle costing on the system.

The cost of the system is based on the costs incurred to design, manufacture and maintain the system. One of the main objectives of life-cycle costing is to manage the long term system maintenance costs. If all of the given costs increase without any change in useable life or performance, then the results would suggest that life-cycle costing is not beneficial. However, if some costs go up and some go down, this would suggest a need for further research to uncover the magnitude of these changes. If all of the costs go down, then life-cycle costing would appear to be successful in the costing area. As previously mentioned, life-cycle costing principles are not concerned with costs alone; performance and the longevity of the system are also important considerations. For example, if the total cost of the system goes down and the expected useable life of the system is also reduced, from a cost point of view alone this may appear beneficial. However, if the reduced longevity of the system requires a new system or a system refresh within a shorter time span, the long term additional costs required would likely outweigh the short term benefit of immediate cost savings.

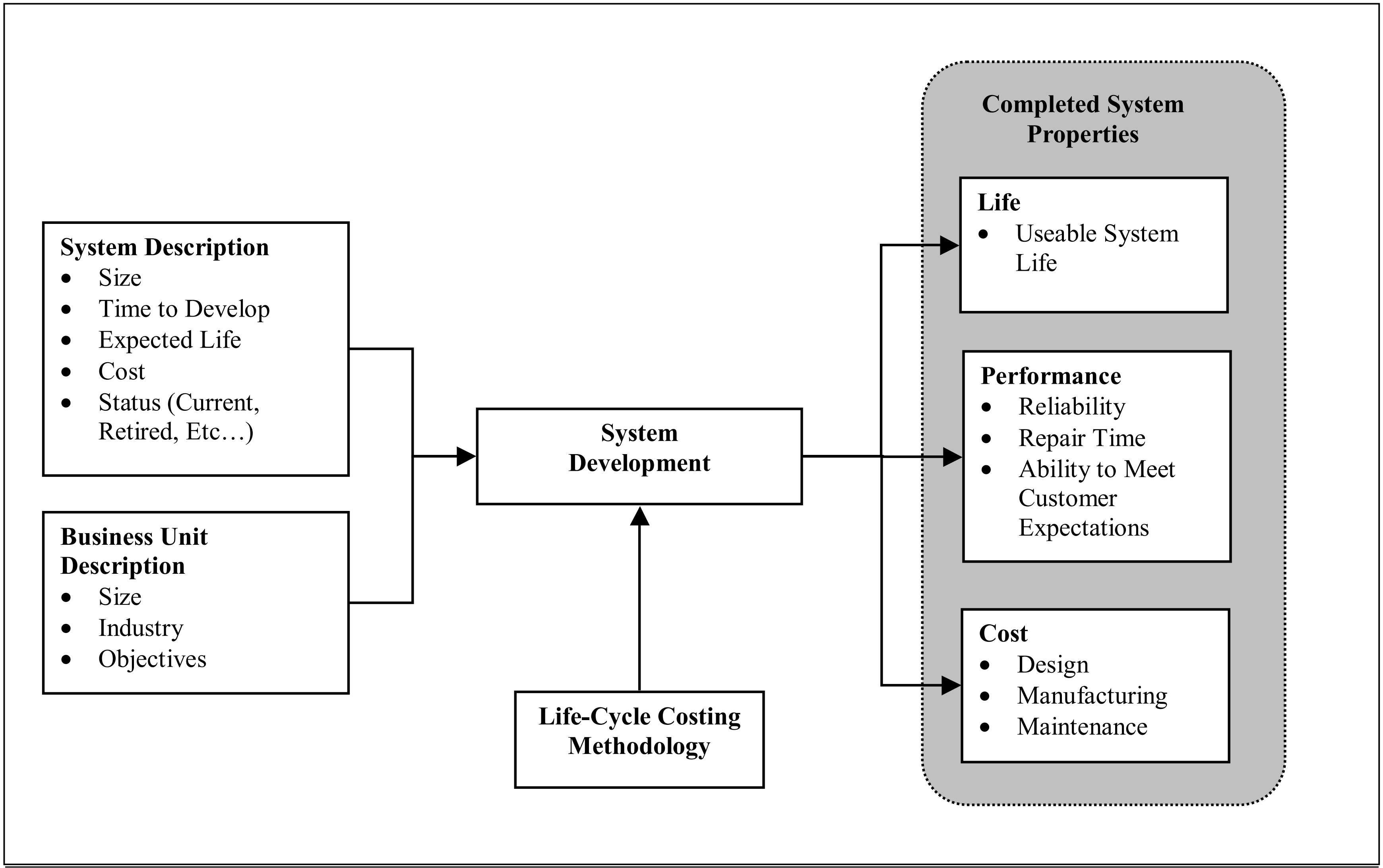


Figure 6. Research Model (Effect of Life-Cycle Costing on Finished Systems)

Development of Instrument

The survey instrument was developed to explore the four major areas captured by the model;

a) System Description
b) Business Unit Description
c) Life-Cycle Costing Methodology
d) Completed System Properties
    a. Life
    b. Performance
    c. Cost

System Description

The first section, designed to capture characteristics of the system the respondent based their answers on, included six questions. The respondent was asked what type of system they were referring to; whether it was a current, retired or abandoned system. To understand the size of the system, the amount of money initially committed to the system along with the number of people involved in the development of the system were considered. Time parameters were also included in this section; the time span from when system concept was developed to when it was released for production, the amount of time the system is or was expected to be operational, and the frequency of modifications and enhancements were included questions. These questions were based on information collected in the literature review. Generally, these were the characteristics that were included in their descriptions in the literature. The types of questions that were asked in this section were also derived from a CAM-I survey that was developed to capture similar characteristics of its respondents and the systems they worked on ("Target Costing--Best Practices Survey," available: http://www.cam-istandards.org/TC/survey.pdf). Table 5 provides references for the questions that were asked in the system information section.

Business Unit Description

The second section of the research instrument was developed to understand the type of business unit the system was created within. Questions included in this section were the number of people employed at the business unit, the primary products and services produced within the business unit, and the functional area of the respondent. This section asked the respondent how their business unit should be interpreted. Possible responses included a single department or function, a commercial product line, or multiple facilities. This section also included a question intended to capture the priorities of the business unit. This question asked the respondent to rate eight statements, such as 'beating competitors to the marketplace with new systems' and 'providing superior service and support to customers.' A scale from 1 to 5 was used to assess the importance the business unit placed on each of the statements, with 1 being not important, and 5 being very important. These questions were also derived from information collected in the literature review and questions in the CAM-I survey. Table 6 provides references for the questions that were asked in the business unit information section.

Life-Cycle Methodology

This section uses a filter question to determine if the respondent uses life-cycle costing. This question gives a definition of life-cycle costing that was found in the literature review, and asks the respondents whether or not they use life-cycle costing in their business unit based on that definition. Although many definitions of life-cycle costing were found through the review of literature, the one that was chosen to be used was that given by Fabrycky and Blanchard (1991) because it was the most often cited in the literature, therefore suggesting that experts in the field use this definition. If the respondent uses life-cycle costing they are asked to complete the remainder of the survey instrument.

This section of this survey instrument also explores how life-cycle costing was implemented in the respondent's system. A key characteristic of life-cycle costing found through the literature review is that cost estimates are made for system from the conceptual design phase through the product disposal. Questions in this sectioned asked the respondent to answer statements regarding what periods of the product life-cycle cost estimates are made. Life-cycle costing takes into account cost estimates that will be encountered throughout the product life-cycle. These costs range from production costs to disposal and recycling costs. This section of the survey asks the respondent what cost estimates were made for the system in their business unit.

This section considers what group made the decision to adopt life-cycle costing, how long it has been used within the business unit, and to what degree it has been implemented. This section also explores whether suppliers were required to use life-cycle costing.

The questions asked in this third section were based upon information gathered in the literature review. A summary of the questions and the references used is shown in Table 7.

Completed System Properties

The final section of the survey instrument investigates potential effects life-cycle costing may have had on the completed system. This section of the survey contains both open-ended and interval-level response questions (Trochim, 2001). There were two interval level response questions. The first of these two questions explores how trade studies were used in the development of the system. The respondent is asked to rate the importance of seven factors in their decision making; examples of these factors are initial acquisition cost, the relationship with supplier, and component reliability. The responses to this question are useful in providing information on what factors are perceived to be the most important.

The second interval level response question explored what, if any, changes in the system were caused by life-cycle costing. A list of factors were given, such as overall system performance and operating costs, and the respondent was asked to rate the effect life-cycle cost had on each factor. The scale was from -5 to +5, a -5 represented an extreme decrease, a 0 represented no change, and a +5 represented an extreme increase. The factors that were used in this section to evaluate the characteristics of the finished system were found in the literature review as shown in Table 8.

The survey also aims to capture any other potential effects of life-cycle costing that were not suggested in the literature review. The survey concluded with an open-ended question asking the respondent to comment on the successes and failures they have seen with life-cycle costing, and whether or not they would extend the use of life-cycle costing to other systems.

The survey was developed based on what characteristics and factors were necessary in the research model. The research model, as previously stated, was developed using the results of the literature review. Therefore, the questions are a direct result of the sources from the literature review. In addition to the literature review, a survey found on the CAM-I website was used as a model for the survey format and for the questions on the business unit and system information ("Target Costing--Best Practices Survey," available: http://www.cam-istandards.org/TC/survey.pdf). The CAM-I survey was targeted towards a similar group of respondents as the life-cycle costing survey, and CAM-I survey has previously been verified. The CAM-I survey efficiently and unambiguously gathered information on the respondent's business unit, and the system the respondent worked on. Therefore many of the questions in the first two sections of the questionnaire were directly taken, or adapted from the CAM-I questionnaire.

Table 5. References for System Information Questions

System Information	References
Development Length? People Involved? System's Expected Life? System Modifications/Changes? System cost?	"Acquisition Community Connection home page" Retrieved September 5, 2004 from http://acc.dau.mil/simplify/ev_en.php?ID=1433_201&ID2=DO_TOPIC Asiedu, Y. and Gu, P. (1998) "Product Life Cycle Cost Analysis: State of the Art Review," *International Journal of Production Research*, 36(4): 883-908. Cooper, Robin and Slagmulder, Regime (1997) *Target Costing and Value Engineering*. Portland, Or: Productivity Press "DoD Defense Link home page" Retrieved September 5, 2004 from http://www.defenselink.mil/search/ "DoN Acquisition One Source Home page" Retrieved September 5, 2004 from http://www.abm.rda.hq.navy.mil/navyaos/content/vw/full/128 Herald, Thomas E. (2000) "Technology Refreshment Strategy and Plan for Application in Military Systems – A How to Systems development Process and Linkage with CAIV" *IEEE Conference Proceedings* pp.729-736. Rush, Dr. Benjamin (1997) "Cost as an Independent Variable: Concepts and Risks" *Acquisition Review Quarterly,* (Spring): 161-172. "Target Costing—Best Practices Survey" Retrieved October 3, 2004 from : http://www.cam-istandards.org/TC/survey.pdf

Table 6. References for Business Unit Information Questions

Business Unit (BU) Information	References
Industry? Area? Actual BU description People in BU? Where BU places importance?	"Acquisition Community Connection home page" Retrieved September 5, 2004 fromhttp://acc.dau.mil/simplify/ev_en.php?ID=1433_201&ID2=DO_TOPIC Anasari, Shahid L., and Bell, Jan E. (1997) *Target Costing : The Next Frontier in Strategic Cost Management*. Chicago, IL: Irwin Professional Publishing Asiedu, Y. and Gu, P. (1998) "Product Life Cycle Cost Analysis: State of the Art Review," *International Journal of Production Research*, 36(4): 883-908**.** Cooper, Robin and Slagmulder, Regime (1997) *Target Costing and Value Engineering*. Portland, Or: Productivity Press "DoD Defense Link home page" Retrieved September 5, 2004 from http://www.defenselink.mil/search/ Fabrycky, Wolter and Blanchard, Benjamin (1991) *Life-Cycle Cost and Economic Analysis*, Englewood Cliffs, NJ: Prentice-Hall, Inc. "Target Costing—Best Practices Survey" Retrieved October 3, 2004 from : http://www.cam-istandards.org/TC/survey.pdf

Table 7. References for Questions on Life-Cycle Costing Application and Results

How Life-Cycle Costing Was Implemented	Reference:
Life Cycle Diagram Cost Estimate Phase? Elements of Cost Estimates? LCC Definition Reason for Never Using LCC? Reasons for Quitting Using LCC? Decision to implement LCC? Depth of LCC? Supplier Compliance? Perception of Success? Extend to other Business Units? Trade Studies?	Asiedu, Y. and Gu, P. (1998) “Product Life Cycle Cost Analysis: State of the Art Review,” *International Journal of Production Research*, 36(4): 883-908. Blanchard, Benjamin (1998) “The Measures of a System—Performance, Life-Cycle Cost, System Effectiveness, or What?” *Proceeding of the IEEE 1988 National Aerospace and Electronics Conference*, 4: 1434-1439. Emblemsvåg, Jan (2003) *Life-Cycle Costing: Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks*, Hoboken, NJ: John Wiley & Sons, Inc. Fabrycky, Wolter and Blanchard, Benjamin (1991) *Life-Cycle Cost and Economic Analysis*, Englewood Cliffs, NJ: Prentice-Hall, Inc. Kumaran, D. Senthil and Ong, S.K. (2001) “Environmental Life Cycle Cost Analysis of Products,” *Environmental Management and Health*, 12(3): 260-276. “Target Costing—Best Practices Survey” Retrieved October 3, 2004 from : http://www.cam-istandards.org/TC/survey.pdf Wanyama, W., Ertas, A., Zhang, H. and Ekwaro-Osire, S. (2003) “Life-Cycle Engineering: Issues, Tools and Research,” *Internal Journal of Computer Integrated Manufacturing*, 16(4-5): 307-316 Woodward, David (1997) “Life Cycle Costing—Theory Information Acquisition and Application,” *International Journal of Project Management,* 15(6): 335-334.

Table 8. Characteristics of Finished System After Using Life-Cycle Costing

Characteristics of Finished System After Using Life-Cycle Costing	Reference:
Cost of System Before Manufacturing Time Required for System Introduction System Features and Functions that Customers Value Customer Expectations for System Cost of Purchased Materials Projected Manufacturing Costs Projected Maintenance Costs Projected Operating Costs Number of Design Changes After Production Begins Overall System Profitability Overall System Performance Cost of Ownership System Repair Time System Reliability Useable System Life	Asiedu, Y. and Gu, P. (1998) "Product Life Cycle Cost Analysis: State of the Art Review," *International Journal of Production Research*, 36(4): 883-908. Blanchard, Benjamin (1998) "The Measures of a System—Performance, Life-Cycle Cost, System Effectiveness, or What?" *Proceeding of the IEEE 1988 National Aerospace and Electronics Conference*, 4: 1434-1439. Emblemsvåg, Jan (2003) *Life-Cycle Costing: Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks*, Hoboken, NJ: John Wiley & Sons, Inc. Fabrycky, Wolter and Blanchard, Benjamin (1991) *Life-Cycle Cost and Economic Analysis*, Englewood Cliffs, NJ: Prentice-Hall, Inc. Wanyama, W., Ertas, A., Zhang, H. and Ekwaro-Osire, S. (2003) "Life-Cycle Engineering: Issues, Tools and Research," *Internal Journal of Computer Integrated Manufacturing*, 16(4-5): 307-316 Woodward, David (1997) "Life Cycle Costing—Theory Information Acquisition and Application," *International Journal of Project Management,* 15(6): 335-334.

CHAPTER IV

METHODOLOGY

From the literature retrieved in Chapter II, it is evident that previous research on life-cycle costing failed to comprehensively address the effects life-cycle costing has on a finished system in terms of costs, performance, and time. As a result, exploratory research was conducted in attempt increase this area of knowledge.

The initial survey and the methods of collecting data were then sent to the Vanderbilt University Institutional Review Board (IRB) for approval. The IRB approved the initial survey on January 5, 2005, IRB#041108. The initial survey primarily contained open-ended questions to measure the effects of life-cycle costing on the finished system. The responses to these questions were diverse, and questions that would allow for quantitative measures were needed. As a result, an amendment to the survey was created which included several additional interval response questions that allowed for quantitative data to be collected. The amendment to the survey was submitted to the IRB for approval, and it was approved on February 9, 2005. The initial survey is attached in Appendix A, and the amendment to the survey is attached in Appendix B.

The exploratory research done for this study was conducted through a pilot study. A pilot study is typically used in two ways: as a feasibility study in preparation for a major study, or as a method of pre-testing a research instrument (Teijllingen and Hundley, 2001). The later of these two uses, to test a research instrument, is the purpose of this study.

The survey instrument that was tested for this research contained both structured and unstructured questions. The structured questions were useful because they allowed the research to more efficiently and quantitatively compare the responses (Trochim, 2001). The unstructured questions were helpful in understanding the views of the respondent, and in capturing ideas that were not included in the structured questions.

The questionnaire was tested using a pilot study. In this pilot study, field interviews were conducted to verify that the questions were clearly understood by the respondents.

There were several experts in the field who were willing to participate in the study, though it was not possible to interview them in person. The survey was distributed to these respondents via e-mail.

Respondent Sample

The respondent sample was made up individuals employed by organizations that use life-cycle costing in any, or all of their business units. Whether the respondent uses life-cycle costing was determined by their responses to the third section of the survey.

Two of the three respondents interviewed in the field studies were not involved with life-cycle costing. Although their organization uses life-cycle costing and they were willing to participate in the study, they were test and evaluation engineers and therefore not involved in the implementation of life-cycle costing. All of the potential respondents that answered the questionnaire via e-mail had experience using life-cycle costing first hand, thus bring the total sample size to six.

As previously mentioned, once the questionnaire was initially distributed, and the researcher began compiling data, it was realized that more quantitative data questions would be needed. This would enable the researcher to have a consistent measure to compare survey responses. An amendment to the questionnaire was distributed to the six respondents who used life-cycle costing. One of the respondents who initially responded via e-mail could not be contacted so there is a sample size of five for the questions in the amendment.

Data Collection Format

The researcher interviewed the field study participants in person at their place of employment. The questions were read to the respondents in the field interviews exactly as they appear in Appendix B. Two researchers were present while the interview was conducted to ensure the responses were accurately recorded. The e-mail surveys were sent the potential respondents, and the respondents completed the survey and retuned the survey to the researcher.

CHAPTER V

RESULTS

The results of the survey are described in this chapter. Appendix C provides data tables with comprehensive results. In this chapter, the results will in the order they appear in the survey:

1) System Description;

2) Business Unit Description;

3) Life-Cycle Costing Use and Implementation;

4) Possible Effects of Life-Cycle Costing;

5) Themes from Average Responses.

System Description

In developing and testing the survey instrument, it is important to understand the characteristics of the system the respondents are referring to. All of the system respondents except for one were referring to a current system in answering the survey questions. The other respondent was referring to a subsystem's life-cycle extension; the electronics of the system were undergoing a technical refresh.

The business units that the respondents worked with to create these systems spent 5-6 years, to over 25 years planning the system from the development of the system concept to its release for production. The majority of the systems required 10 years or less to reach the production stage. Most of the systems had fewer than 1,000 people involved in the development of the system, though one survey response said that the system they were describing had over 1,000 people working on the system development. The expected useful life of the systems ranged from 10-15 years to over 25 years. The majority of the systems were expected to be in operation for over 20 years, with modifications and enhancements most commonly occurring every six months or less. Half of the respondents said that major redesigns take place on their systems every 7 years or more.

The initial commitment of resources for these systems ranged from $50,000-100,000 to over $100 million, with over half of the systems having over $100 million initially allocated to them.

Business Unit Description

All of the survey respondents were from the Aerospace and Defense industry and worked for either the US Government or a US Government Contractor. About half of the respondents were in the engineering sector of their organization, and the other half in the program management area. There was a large variation in the size of the business units the respondents work for; about 40% were less than 250 employees, and about 30% had over 5,000 employees.

For this research it is important to understand what the objectives and values are of the business units. The survey gave a list of possible business unit objectives, and asked the respondent to rate their importance. Providing more reliable longer-lasting systems was consistently the highest rated objective; 57% of the respondents rated it as very important. Other factors important to the respondents were guaranteeing speedy delivery of the systems, being cost leaders and providing the lowest cost system, and being the performance leaders. Being the sole supplier of a certain technology and beating competitors to the marketplace with new systems were the least important objectives of the business units overall.

Life-Cycle Costing Use and Implementation

Subsequent to determining the characteristics of the system and business unit the respondents were employed by, data was collected on how the respondents use life-cycle costing and the extent of its implementation. The first question in the third section of the survey asked the respondent to identify the phases at which cost estimates were made. The entire respondent population made cost estimates prior to detailed design and development, during conceptual design, and during the design phase. Cost estimates during the production and construction phase were not relevant for two of the respondents, but the respondents that considered that phase in their business unit made cost estimates for it. Based on the responses to the first question, all respondents use life-cycle costing as defined by Fabrycky and Blanchard (1991).

All groups made cost estimates for research & development costs and service & support costs. The majority made estimates for production, construction and distribution. Marketing was not relevant for about a third of the respondents because of the nature of their business unit and/or system. Disposal and recycling costs was the cost category that was least often considered; 43% of the respondents did not make cost estimates for this phase.

The next question asked the engineers directly whether or not they are currently using life-cycle costing in their business unit; all of the respondent used life-cycle costing in their business unit except for two for whom it was not relevant. Those respondents were not directly tied into the design phase in their business unit; what they do as test and evaluation engineers does not drive design decisions. However, the respondents stated that their prime contractors use life-cycle costing trade studies to determine the best selection at the best price.

The length of time life-cycle costing has been used in the business unit is important to consider in this research. The majority of respondents that use life-cycle costing have used it for over 10 years, and have implemented the costing method throughout the entire corporation. This would suggest that business units have been using life-cycle costing long enough to have witnessed its impact on the organization. In half of the respondents, the decision to use life-cycle costing was made by the entire company; other responses indicated that the decision was made due to government projects and mandates. The depth of implementation of life-cycle costing within the organization ranged from within a group or division, to throughout the entire corporation; throughout the entire corporation was the most common response to the question.

All of the business units require trade studies to be completed for the majority of major design decisions within the organization. However, only one of the respondents indicated that their business unit mandates all suppliers use life-cycle costing.

In conducting trade studies, the factors that appeared to be the most important to the respondents were the long-term life-cycle cost of the system, and the component reliability. The salvage value of the system was by far the factor that was given the least importance in the trade studies.

Possible Effects of Life-Cycle Costing

The main focus of the survey was to explore possible effects life-cycle costing has on finished systems. The survey respondents were given a series of factors, such as the cost of owning the system throughout it life-cycle, and the system repair time. They were asked to rate the effect, if any, they perceived life-cycle costing to have had on a given factor. A scale of -5 to +5, -5 being extremely decrease and +5 being extremely increase, was used. A response of '0' meant that the respondent did not believe life-cycle costing had any affect on the given factor.

There was a lot of variation in the responses to these questions. The first question asked the respondents to rate the effect life-cycle costing had on the cost of the system prior to manufacturing. Two the respondents indicated that life-cycle costing moderately increased the cost of the system prior to manufacturing, one indicated that there was no change, and one indicated that the cost of the system prior to manufacturing moderately decreased.

The next question asked the respondents what effect life-cycle costing had on the time required for system introduction. Over half of the respondents indicated that the time required to introduce the system increased, one respondent indicated they saw no change, and one respondent indicated that they saw a moderate decrease in the time required.

The effect, if any, life-cycle costing had on the system features and functions that customers value, was the third question. The responses were split on this question, two of the respondents indicated that life-cycle costing moderately decreased system features and functions, two indicated that life-cycle costing moderately increased features and functions, and one respondent reported that they saw no change.

The responses showed that the majority of respondents saw no change in the costs of materials they purchased; three respondents reported no change, one reported a moderate increase, and one a moderate decrease in the price of purchased materials.

The next three areas the survey measured were how life-cycle costing affected the systems manufacturing, maintenance, and operating costs. There was a great deal of variation in the responses to these questions amongst the respondent population. However, if a respondent saw a positive or negative change in one of the factors, they tended to see it for all of three factors. For example, one respondent indicated that they saw a moderate decrease in the manufacturing, maintenance, and operating costs. Another respondent indicated they saw an extreme increase in all three cost categories.

Three of the respondents said they saw an increase in the overall cost of owning their system after implementing life-cycle costing. The degrees of increase ranged from slight to extreme. One respondent witness no change, and one indicated they had a moderate decrease in the cost of owning the system their business unit worked on.

The respondents also witnessed very different effects life-cycle costing had on the number of design changes after system production begins. Two of the respondents witnessed an extreme increase in the number of design changes after production, while two other respondents saw a moderate decrease, and one respondent saw no difference in the number of design changes.

Four of the five respondents saw a decrease or no change in the overall system performance after using life-cycle costing. One of the respondents indicated their system had a moderate increase in overall performance.

There was a lot of variation in the responses to system repair time and system reliability. Two of the responses indicated a moderate increase in system repair time, two indicated a moderate decrease, and one indicated no change. Three of the respondents indicated a decrease in system reliability, one saw no change, and one saw a moderate improvement in reliability.

The last question asked the respondents if they observed any changes in the usable system life of their system. Three of the respondents indicated that life-cycle costing moderately extended the useable system life of their system. Two respondents indicated that they saw a moderate decrease in the longevity of the system after using life-cycle costing.

The last portion of this question asked the respondent if there were any effect they observed that were not included in the factors they were asked to rate. One respondent said, "life-cycle costing is more expensive to manage. The trade studies consume a lot of resources."

Themes from Responses

The main theme that can be identified from the survey data is that there was little consistency in the responses. Some of the respondents seem have a positive overall view of life-cycle costing and believe that it has had a positive effect on the system they work with. However, other respondents seem to have the opposite viewpoint and view life-cycle costing as time consuming, with little results to show for their efforts.

The different viewpoints of the respondents came across in the open-ended questions. Several respondents viewed the cost estimation required as part of life-cycle costing to be inefficient and unreliable. One respondent stated that, "it is often [used] to determine the logistics tail of a system during the early stages of development although we need to determine those costs as well as associated training needs." That same respondent also stated that life-cycle costing is perceived to be a success and as a result it has become institutionalized within the Department of Defense.

Another respondent seemed to have mixed views. They stated that, “it is only with proper life-cycle costing that we are able to forecast our fiscal resource.” However, that respondent stated that a challenge of life-cycle costing is projecting those future demands on resources. They stated, “We are not there with ‘good’ cost estimating. This calls for cost readjustments and sometimes even asking for more resources than planned for.”

Frustration with the time required to perform life-cycle costing was another viewpoint that came across from several of the respondents. One of the respondents stated, “Aspects of [life-cycle costing] that are labor intensive are perceived to be of little value. Cost estimation is a legal mandate,”

Several of the respondents, however believed their system had benefited as a result of life-cycle costing. One respondent stated that after using life-cycle costing, they were finding the major costs encountered with their systems were in support rather than the design an initial build. They noted, “it’s important to focus on maintainability and obsolescence years. LCC will be extended more to other projects”

Another respondent said that their business unit will continue to apply life-cycle costing to other systems, “Yes [LCC will be extended to other business units/systems]. It is only through LCC that a true picture of “things” can be understood. Without LCC management will not have an accurate picture of initiatives to make decisions on what initiatives should be funded.”

One respondent was hesitant to draw any conclusions on the successes and failures of life-cycle costing because of the time required to realize the results. “In this program (and most military systems) the operating and containment cost far outweighs the initial development and production. The ultimate success or failure will not be known for many years, but the LCC played a large role in the direction the program went."

CHAPTER VI

CONCLUSIONS AND OPPORUNTUNTY FOR FURTHER STUDY

The purpose of this exploratory research was to create and test an instrument that could be used to understand the effects of life-cycle costing on systems. This research topic was chosen after conducting a literature review and observing a paucity of literature regarding whether engineers perceive life-cycle costing to be a success of failure in practice. The survey instrument was developed using information collected in the literature review and tested through field studies and survey mailings.

The results of the pilot study were discussed in the previous chapter. The major theme from the pilot study is that there is a high degree of variation in successes and failures of life-cycle costing as perceived by engineers. There was a large range of responses to all of the questions regarding the effect of life-cycle costing on the system in terms of performance, cost and longevity. This was shown in the results section. (See Chapter V and Appendix C)

The underlying reasons that may have caused the variability in responses are further discussed in this chapter. Five specific areas that need to be explored to aid in understanding why engineers viewed life-cycle costing as having the impact it did are:

- The definition and implementation of life-cycle costing among business units
- The life-cycle costing training procedures used in different business units
- The attitude of the respondent towards life-cycle costing
- The previous costing methods used by respondent

- Systems engineering maturity within the business unit

Through the literature review, the researcher discovered that there various was to interpret the definition of life-cycle costing.. Although the definition used in the survey was the commonly found definition written by Fabrycky and Blanchard (See Survey in Appendix A), the survey respondents may have been familiar with another type of costing method or definition of life-cycle costing and used that definition when answering survey questions. Certain sources found through the literature review mention other costing systems in conjunction with life-cycle costing (Emblemsvag, 2003). The respondents may have confused other current cost management systems, such as activity based costing, just-in-time costing, target costing, and strategic cost management for life-cycle costing.

Another factor that may have led to the differences in responses is the level of life-cycle cost training that was done before the costing method was implemented. Business units that underwent formal training in how to use life-cycle costing may have had a higher potential for positive life-cycle costing results as compared to business units that were given a manual to follow without any formalized instruction. The degree of life-cycle costing training is a characteristic that should be included in the research model. The level of training is a characteristic can be captured in the moderating variable "Life-Cycle Costing Methodology." This variable explores how the business unit implemented life-cycle costing (See Figure 7). Survey questions such as 'Did your business unit participate in a formal life-cycle costing training program?' and 'How was your business unit trained to use life-cycle costing?' are questions that would be beneficial to the life-cycle costing methods section of the survey.

The general attitude towards life-cycle costing is another factor that could potentially impact its perceived success or failure. If the engineer in the business unit was forced to use life-cycle costing and did not initially deem it to be necessary, respondents answers may have been negatively biased. If the engineer responding to the survey had a role in the training or the decision to implement life-cycle costing, they would have a vested interest in its success and therefore may have answered the questionnaire with a positive bias. From the pilot study interviews, it was apparent that some survey respondents had an overall positive perspective on life-cycle costing, and others had a very negative outlook on life-cycle costing. Possible questions that could be asked in the life-cycle costing survey to capture the view of the respondent are, 'Did you have any role in the decision to implement life-cycle costing?' 'What was your general attitude towards life-cycle costing when it was implemented?' and 'Did you feel life-cycle costing was necessary for the system?'

Another factor that the pilot study uncovered that needs to be included in the research model is the costing method that was used prior to life-cycle costing, and whether that costing method was perceived to be successful. Where the 'Preexisting Costing Method Description' fits into the research model is shown in Figure 7. Characteristics of the preexisting costing method are input variables that should be explored in conjunction with the business unit and system characteristics. If survey respondents had previously used a costing method that they viewed as a success in their business unit, they would have a tougher basis for comparison when answering questions on the success and failures of life-cycle costing than a respondent who had previous experience with an unsuccessful costing method.

One additional factor that should be included in the research model is the level of Systems Engineering maturity within the organization. Whether the business unit has well defined Systems Engineering practices and procedures could directly influence the results of using life-cycle costing. System Engineering methodologies and life-cycle costing methodologies go hand in hand and have many parallels, therefore experience with one may influence the success of the other.

In additional to factors that need to be added to the research model, and the questions that need to be added to the survey, there are several other recommended modifications to the survey. In the first section of the survey, which contains questions on system information, question six asks the respondent the amount of money initially committed to the system. (See Appendix A.) The majority of the respondents checked the “over $100,000,000” box, and therefore it is recommended that the scale be increased to included number in the billions.

The researcher discovered a significant amount of information through this pilot study. From the literature review, the researcher learned that there has been little research published regarding the end result of life-cycle costing when used for defense systems. Specifically, there is a lack of published research available based on the perspective of individuals that used life-cycle costing in designing systems.

After developing and testing the survey to explore the effects of life-cycle costing, the researcher realized that there is a large degree of variation in the perceived successes and failures of life-cycle costing. The researcher learned that there were underlying characteristics not included in the model and test instrument that were causing a disparity in the views of life-cycle costing. Based on the responses from the open-ended questions and observations made through field studies, several possible explanations for the differing views of the success of life-cycle costing were considered. These potential explanations were previously described in this chapter.

An interesting area for further research would be to use the survey instrument developed in this research, including the suggested modifications, to sample a larger population. A larger population would allow for data analysis and statistical tools to be used to analyze the survey responses. Knowledge gained from this research could potentially be usefully in predicting the success or failure of life-cycle costing in a given system and business unit, and thus could aid in decision making when determining when to use life-cycle costing.

The exploratory research conducted in this study was successful in developing and testing a survey instrument that can be used to measure the effects of life-cycle costing on a system. Where this research concludes, there is the potential for further research to begin. Using the test instrument that has been developed and validated, interviews conducted using a sufficient sample size have the potential to contribute additional information to the life-cycle costing body of knowledge.

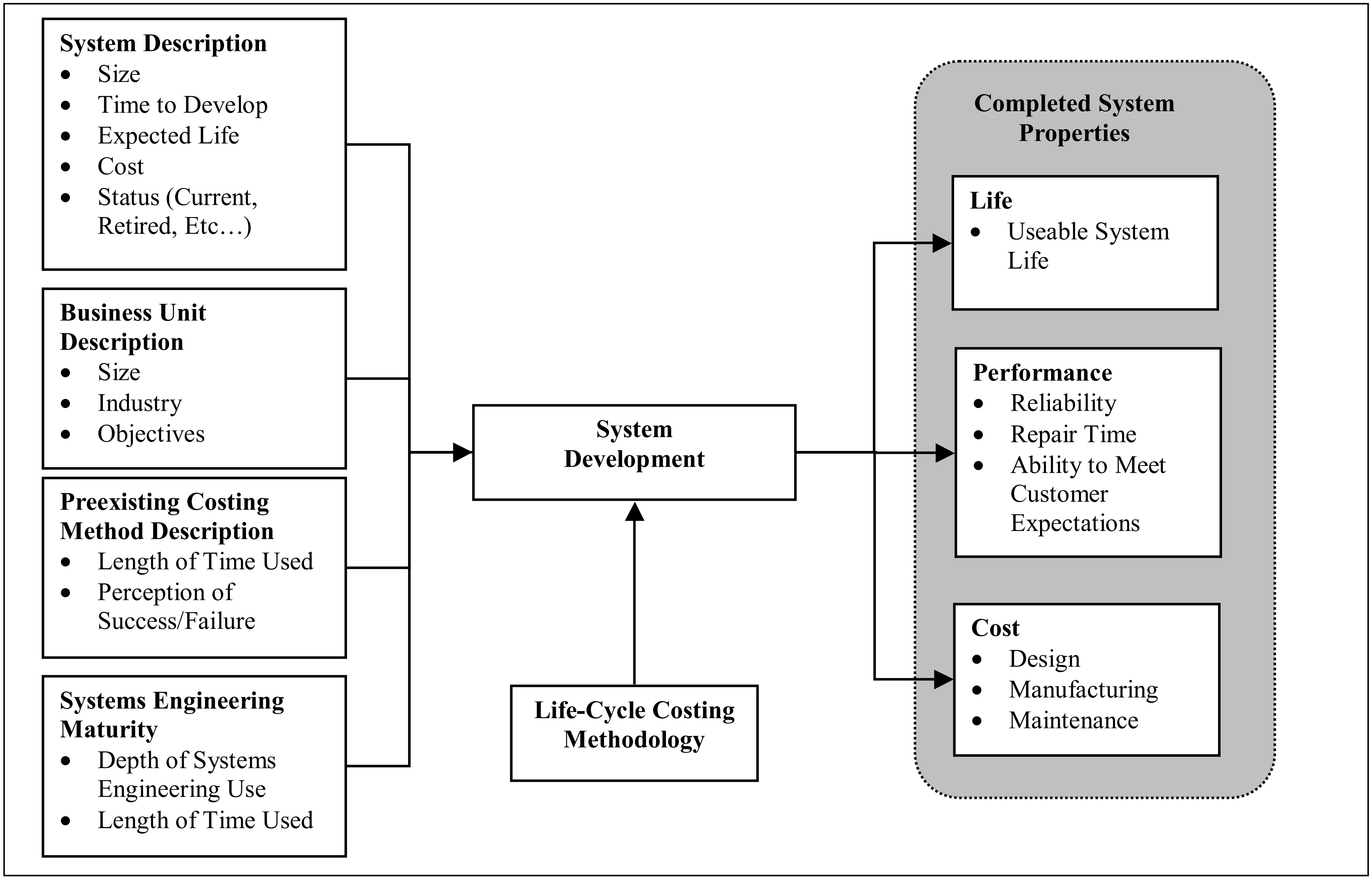


Figure 7. Revised Research Model (Effect of Life-Cycle Costing on Finished Systems)

Appendix A. Survey

LIFE-CYCLE COSTING SURVEY

RESPONDANT INFORMATION
Company Name ____
Name of person completing survey ____
Title ____
Address ____
____
Phone # _________________________ **e-mail** ___________________________________

I WOULD LIKE TO GET A REPORT OF THE STUDY'S RESULTS ☐

Section 1. System Information

For this survey consider the following definition:
<u>System</u>- a group of elements or components that work together to accomplish a common goal such a system can be physical objects and/or software. For example, landing gear, safety, wings, controls, computers, etc.. are the elements/components that make up the system of an airplane.

1. For the purposes of this survey the "system" you are referring to is: (check one)

- ☐ A current system
- ☐ A retired system
- ☐ An abandoned system
- ☐ A system that has yet to be introduced
- ☐ A system that has been produced before
- ☐ Other ____

2. How long did it take your business unit to create the system, from the development of the system concept to releasing of the system for production? (check one)

☐ Less than 1 yr.
☐ 1-2 yrs.
☐ 2-3 yrs.
☐ 3-4 yrs.
☐ 4-5 yrs.
☐ 5-6 yrs
☐ 6-7 yrs
☐ 7-8 yrs
☐ 8-9 yrs
☐ 9-10 yrs
☐ 10-15 yrs
☐ 15-20 yrs
☐ 20-25 yrs
☐ 25+ yrs

3. How many people were involved in the development of this system? (check one)

☐ 250 or less
☐ 251-500
☐ 501-1000
☐ 1001-2000
☐ 2001-5000
☐ Over 5000

4. How long is/was the system expected to be operational? (check one)

☐ Less than 1 yr.
☐ 1-2 yrs.
☐ 2-3 yrs.
☐ 3-4 yrs.
☐ 4-5 yrs.
☐ 5-6 yrs
☐ 6-7 yrs
☐ 7-8 yrs
☐ 8-9 yrs
☐ 9-10 yrs
☐ 10-15 yrs
☐ 15-20 yrs
☐ 20-25 yrs
☐ 25+ yrs

5. How frequently did you modify or enhance the system, and how frequently did you do a major redesign of the system before its release to production?

	Modify/Enhance	**Major redesign**
6 months or less	☐	☐
6 to 12 months	☐	☐
1 to 2 years	☐	☐
2 to 3 years	☐	☐
3 to 5 years	☐	☐
5 to 7 years	☐	☐
7 years or more	☐	☐
Never	☐	☐

6. The amount of money initially committed to the system is/was (please give an estimate if you do not know exactly)? (check one)

☐ Less than $25,000
☐ $25,000-$50,000
☐ $50,000-$100,000
☐ $100,000-$250,000
☐ $250,000-$500,000
☐ $500,000-$1,000,000
☐ $1,000,000-$2,000,000
☐ $2,000,000-$5,000,000
☐ $5,000,000-$10,000,000
☐ $10,000,000-$25,000,000
☐ $25,000,000-$50,000,000
☐ $50,000,000-$100,000,000
☐ over $100,000,000

**If possible please list the name of the system you are referring to: **

____

____

____

Section 2. Business Unit Information

1. What is the industry group for the primary products/services of your business unit? (check all that apply)

☐ Transportation Equip
☐ Electrical/Electronics
☐ Precision Equipment
☐ Aerospace & Defense
☐ Steel
☐ Machinery
☐ Textiles
☐ Food
☐ Chemicals
☐ Other______________________________
☐ Non-ferrous/metal
☐ Oil, Rubber, Glass
☐ Pulp & Paper
☐ Service

2. What best characterizes your business organization? (check one)

☐ Government Contractor
☐ Commercial Supplier
☐ Retail Wholesaler
☐ Other____

3. Your functional area: (check one)

☐ Engineering
☐ Marketing
☐ Finance
☐ Purchasing
☐ Manufacturing
☐ Other _________________

4. In this survey, we use the term "business unit" to capture the organizational perspective from which you are answering the questions. Please tell us how we should interpret the business unit in your case. I am completing this survey from the perspective of: (check one)

☐ A Single Department/Function Only
☐ A Single Facility/Operation
☐ A Government Project or a Program
☐ Multiple Departments
☐ Multiple Facilities
☐ A Commercial Product line
☐ A Division/Group
☐ The Entire Company
☐ Other _______________________

5. How many people does your business unit employ? (check one)

☐ 250 or less
☐ 251-500
☐ 501-1000
☐ 1001-2000
☐ 2001-5000
☐ Over 5000

6. How important to your business unit are each of the following actions in meeting competitive threats. Please assign equal weight to two items only if you feel they are equally important to your business unit. (1 being not important to 5 being very important)

	Not Important		**Moderately**		**Very Important**
Beating competitors to the market place with new systems	**1**	**2**	**3**	**4**	**5**
Providing superior service/support to customers	**1**	**2**	**3**	**4**	**5**
Guaranteeing speedy delivery of systems	**1**	**2**	**3**	**4**	**5**
Providing more and better features than others	**1**	**2**	**3**	**4**	**5**
Providing more reliable, longer-lasting systems	**1**	**2**	**3**	**4**	**5**
Being cost leaders and providing the lowest cost systems	**1**	**2**	**3**	**4**	**5**
Being the performance leader	**1**	**2**	**3**	**4**	**5**
Being the sole supplier of a certain technology	**1**	**2**	**3**	**4**	**5**

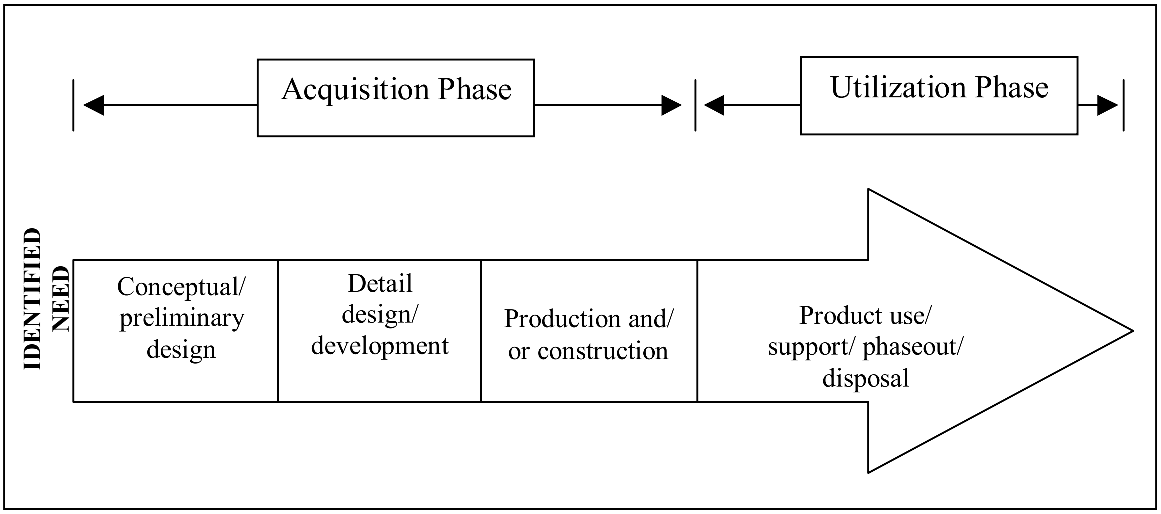
Other, please describe ____

____

____

SECTION 3. Life-Cycle Costing

The diagram below illustrates a system lifecycle. Activities progress from the identified need through conceptual/preliminary design, detail design and development, production and/or construction, and product utilization (Fabrycky and Blanchard, 1991). Please refer to this diagram when responding to the questions.



1. Looking at the diagram representing the system lifecycle, your business unit develops systematic and serious cost estimates for the systems at the following period:
(N/A=not applicable to your business unit)

	Yes	**No**	**N/A**
Prior to Conceptual/Preliminary Design	☐	☐	☐
During Conceptual/Preliminary Design	☐	☐	☐
During Detail/Design and Development	☐	☐	☐
During the Production/Construction Phase	☐	☐	☐

If not at a period in system lifecycle, please explain when cost estimates are made:

____

____

____

____

2. Cost estimates for new systems typically include the following elements:

(N/A=not applicable to your business unit)

	Yes	**No**	**N/A**
Research and Development Costs	☐	☐	☐
Production and Construction costs	☐	☐	☐
Marketing costs	☐	☐	☐
Distribution/Logistics costs	☐	☐	☐
Service/Support costs	☐	☐	☐
Disposal/Recycling costs	☐	☐	☐

> **"Life-cycle cost refers to all costs associated with the product or system in its defined life *…Life-cycle costing is employed in the evaluation of alternative system design configurations, alternative production schemes, alternative logistic support policies, and so on. The analysis constitutes a step-by-step approach employing life-cycle cost figures of merit as criteria to arrive at a cost-effective solution. The analysis process is iterative in nature and can be applied to any phase of the system of product life cycle" (*Fabrycky and Blanchard, 1991)**

3. Are you currently using Life-Cycle Costing (LCC) in your business unit? In answering this question please consider the following statement:

☐ I am not sure.
☐ The business unit does not use LCC
☐ The business unit recently started implementing LCC but has not fully implemented it.
☐ Life-cycle costing is well established in our business unit.
☐ The business unit uses LCC, or a costing principle with similar characteristics under a different name than LCC.

Name for LCC
____

4. If your business unit *does not* use LCC, reasons why are: (check all that apply)

☐ a general lack of familiarity with LCC
☐ faced with more pressing business problems that take priority
☐ LCC did not get top management support
☐ LCC is not relevant for our kind of business
☐ we already have good control of our costs and do not need LCC
☐ a general lack of motivation to use LCC
☐ people unwilling to change
☐ our customers do not want us to use LCC
☐ other, please describe:_________________________________
____

5. If your business unit has previously used *Life-Cycle Costing, but no longer uses Life-Cycle Costing*, the reasons for termination are: (check all that apply)

- ☐ a general lack of motivation to use LCC
- ☐ a general lack of familiarity with LCC
- ☐ faced with more pressing business problems
- ☐ did not get top management support
- ☐ LCC did not meet our expectations in its ability to manage costs
- ☐ The market did not require it
- ☐ Performance expectations were not met
- ☐ LCC required too much time
- ☐ people within organization were unwilling to adapt to the new costing procedure
- ☐ other, please describe:_________________________________

____

STOP HERE and GO TO SECTION 3 (page 9) IF YOU DO NOT USE LIFE-CYCLE COSTING

Questions 6→11 in section 2 are about life-cycle costing

With the system you have just described in mind, please answer the following questions:

6. The decision to adopt LCC was made by: (check one)

- ☐ A Single Department/Function
- ☐ A Project or a Program
- ☐ Multiple Facilities
- ☐ A Division/Group
- ☐ Other ______________________
- ☐ A Single Facility/Operation
- ☐ Multiple Departments
- ☐ A Product line
- ☐ The Entire Company

7. What is the depth of LCC implementation in your organization?

- ☐ Throughout the corporation
- ☐ Only at some business units
- ☐ Only at your business unit
- ☐ Other ____________________
- ☐ Within a group or division
- ☐ Only for some products
- ☐ Only for you product line

8. The Life-Cycle Costing system in your business unit:
(N/A=not applicable to your business unit)

	Yes	**No**	**N/A**
Mandates that all suppliers use life-cycle costing	☐	☐	☐
Requires only major suppliers to use lifecycle costing	☐	☐	☐
Requires trade studies to be completed for the majority of major design decisions	☐	☐	☐

9. Please comment on the successes/failures you have observed while using Life-Cycle Costing. Will you extend the use of life-cycle costing to other business units or systems? Why or why not?

____

____

____

____

____

____

____

Appendix B. Survey Amendment

LIFE-CYCLE COSTING SURVEY AMENDMENT

RESPONDANT INFORMATION

Name of person completing survey ______________________________________

1. How long has Life-Cycle Costing been used at your business unit? (Please mark in x in or beside the box)

- ☐ 0-6 months
- ☐ 6-12 months
- ☐ 1-2 yrs.
- ☐ 2-3 yrs.
- ☐ 3-4 yrs.
- ☐ 4-5 yrs.
- ☐ Over 5 yrs.
- ☐ Over 10 yrs.

2. If your business unit does trade studies for the system you described, please weight the importance of the following factors in the decision making (0=Unimportant/, 5=Extremely Important) Please <u>underline</u> your answers.

	Unimportant					Extremely Important
Initial Acquisition Cost	0	1	2	3	4	5
Long Term Life-Cycle Cost	0	1	2	3	4	5
Environmental Impact	0	1	2	3	4	5
Length of time Item Under Consideration Will be Operational	0	1	2	3	4	5
Relationship with Supplier	0	1	2	3	4	5
Component Reliability	0	1	2	3	4	5
Salvage Value	0	1	2	3	4	5

3. LCC may have caused the following changes in the system. Please rate the effect Life-Cycle Costing has had on the given factors stated below. The scale ranges from –5, extremely decreased to +5, extremely increased. Please underline your answers.

	Extremely Decreased					No Change					Extremely Increased
Cost of system before manufacturing	-5	-4	-3	-2	-1	0	1	2	3	4	5
Time required for system introduction	-5	-4	-3	-2	-1	0	1	2	3	4	5
System features and functions that customers value	-5	-4	-3	-2	-1	0	1	2	3	4	5
Customer expectations for system	-5	-4	-3	-2	-1	0	1	2	3	4	5
Cost of purchased materials	-5	-4	-3	-2	-1	0	1	2	3	4	5
Projected Manufacturing costs	-5	-4	-3	-2	-1	0	1	2	3	4	5
Projected Maintenance costs	-5	-4	-3	-2	-1	0	1	2	3	4	5
Projected Operating costs	-5	-4	-3	-2	-1	0	1	2	3	4	5
Number of design changes after production begins	-5	-4	-3	-2	-1	0	1	2	3	4	5
Overall system profitability	-5	-4	-3	-2	-1	0	1	2	3	4	5
Overall system performance	-5	-4	-3	-2	-1	0	1	2	3	4	5
The cost of owning the system throughout its lifecycle	-5	-4	-3	-2	-1	0	1	2	3	4	5
System Repair Time	-5	-4	-3	-2	-1	0	1	2	3	4	5
System Reliability	-5	-4	-3	-2	-1	0	1	2	3	4	5
Usable system life	-5	-4	-3	-2	-1	0	1	2	3	4	5

Other effects not listed above

____

Thank you for completing the survey!

Appendix C. Data

Section 1. System Information

1. For the purposes of this survey the "system" you are referring to is:

n	Percent	Answers
6	**85%**	A current system
1	**15%**	Other: a life extension
7	**100%**	**Totals**

2. How long did it take your business unit to create the system, from the development of the system concept to releasing of the system for production?

n	Percent	Answers
2	**28%**	5-6 years
2	**28%**	9-10 years
1	**14%**	10-15 years
1	**14%**	15-20 years
1	**14%**	25+ years
7	**100%**	**Totals**

3. How many people were involved in the development of this system?

n	Percent	Answers
4	**57%**	250 or less
2	**28%**	501-1000
1	**14%**	1001-2000
7	**100%**	**Totals**

4. How long is/was the system expected to be operational?

n	Percent	Answers
3	**42%**	25+ years
2	**28%**	20-25 years
1	**14%**	15-20 years
1	**14%**	10-15 years
7	**100%**	**Totals**

5. How frequently did you modify or enhance the system, and how frequently did you do a major redesign of the system before its release to production?

n	Percent	Answers for Modify/Enhance
3	42%	6 months or less
2	28%	3 to 5 years
1	14%	5 to 7 years
1	14%	2 to 3 years
7	100%	Totals

n	Percent	Answers for Major Redesign
3	42%	7 years or more
1	14%	3 to 5 years
1	14%	2 to 3 years
1	14%	Never
6	85%	Totals

6. The amount of money initially committed to the system is/was (please give an estimate if you do not know exactly)?

n	Percent	Answers
4	57%	over $100,000,000
2	28%	$25,000,000-$50,000,000
1	14%	$50,000,000-$100,000,000
7	100%	Totals

Section 2. Business Unit Information

1. What is the industry group for the primary products/services of your business unit?

n	Percent	Answers
7	100%	Aerospace & Defense
7	100%	Totals

2. What best characterizes your business organization?

n	Percent	Answers
4	57%	Government
3	42%	Government Contractor
7	100%	Totals

3. Your functional area:

n	Percent	Answers
4	57%	Engineering
3	42%	Program Management
7	100%	Totals

4. In this survey, we use the term "business unit" to capture the organizational perspective from which you are answering the questions. Please tell us how we should interpret the business unit in your case. I am completing this survey from the perspective of:

n	Percent	Answers
5	71%	A Government Project or a Program
1	14%	A Single Facility/Operation
1	14%	Other: (RDEC)
7	100%	Totals

5. How many people does your business unit employ?

n	Percent	Answers
3	42%	250 or less people
2	28%	Over 5000 people
1	14%	1001-2000 people
1	14%	2001-5000 people
6	85%	Totals

6. How important to your business unit are each of the following actions in meeting competitive threats. Please assign equal weight to two items only if you feel they are equally important to your business unit. (1 being not important to 5 being very important)

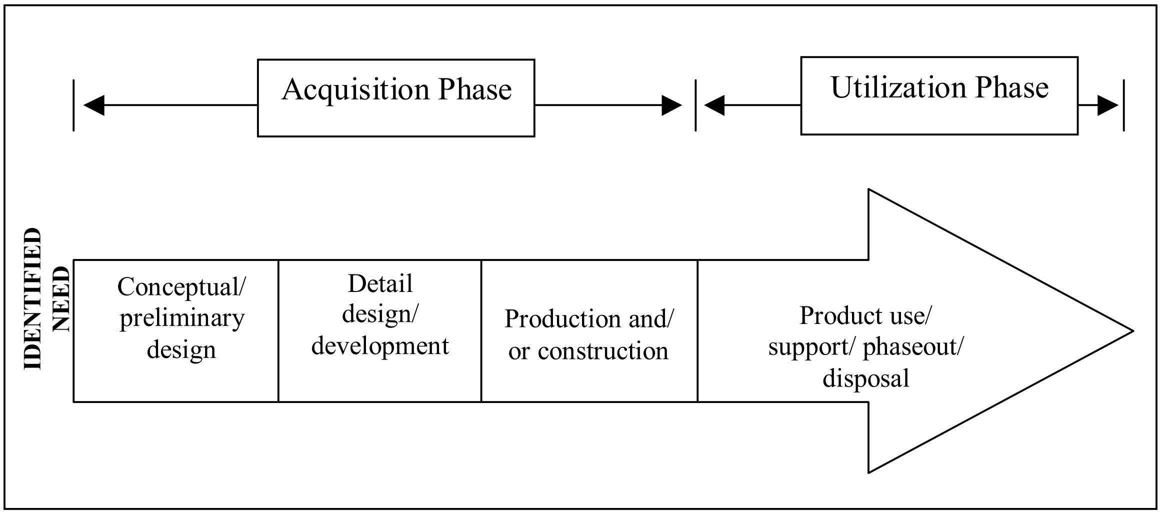
Statement	**1**	**2**	**3**	**4**	**5**	**Total**
Beating competitors to the market place with new systems						
n	3	1	0	2	1	7
Percent	42%	14%	0	28%	14%	100%
Mean= 2.57 Median=2 Mode=1 Standard Deviation=1.7						
Providing superior service/support to customers						
n	0	2	1	1	3	7
Percent	0	28%	14%	14%	42%	100%
Mean=3.71 Median=4 Mode=5 Standard Deviation=1.38						
Guaranteeing speedy delivery of systems						
n	0	0	2	4	1	7
Percent	0	0	28%	57%	14%	100%
Mean=3.86 Median=4 Mode=4 Standard Deviation=0.69						
Providing more and better features than others						
N	1	0	3	1	1	6
Percent	14%	0	42%	14%	14%	85%
Mean=3.17 Median=3 Mode=3 Standard Deviation=1.33						
Providing more reliable, longer-lasting systems						
N	1	0	0	2	4	7
Percent	14%	0	0	28%	57%	100%
Mean=4.14 Median=5 Mode=5 Standard Deviation=1.46						
Being cost leaders and providing the lowest cost systems						
n	0	1	0	5	1	7
Percent	0	14%	0	71%	14%	100%
Mean= 3.86 Median=4 Mode=4 Standard Deviation=0.90						
Statement	**1**	**2**	**3**	**4**	**5**	**Total**
Being the performance leader						
n	1	0	1	2	3	7
Percent	14%	0	14%	28%	42%	100%

Mean=3.86 Median=4 Mode=5 Standard Deviation=1.46						
Being the sole supplier of a certain technology						
n	2	1	0	3	0	6
Percent	28%	14%	0	42%	0	85%
Mean=2.67 Median=3 Mode=4 Standard Deviation=1.51						

Additional Comments: “Government, despite incentives to emulate business, is not business. Accordingly, the business metaphors are often not very accurate in relating government, especially Defense, situations. Since the DoD basically has three ‘labs’ developing missiles, one for each service, and the environmental and mission requirements are so different in each service, traditional ‘competition’ is almost completely absent. This is even more the case with helicopters where basic development is vested in one service with responsibility for assuring that the designs are adaptable to other service specifics. Overall, the arena of competition is budgetary in nature. That is, there is competition over which systems (programs) are funded.”

SECTION 3. Life-Cycle Costing

The diagram below illustrates a system lifecycle. Activities progress from the identified need through conceptual/preliminary design, detail design and development, production and/or construction, and product utilization (Fabrycky and Blanchard, 1991). Please refer to this diagram when responding to the questions.



1. Looking at the diagram representing the system lifecycle, your business unit develops systematic and serious cost estimates for the systems at the following period:
(N/A=not applicable to your business unit)

Statements	**Yes**	**No**	**N/A**	**Totals**
Prior to Conceptual/Preliminary Design	7	0	0	7
Percent	100%	0	0	100%
During Conceptual/Preliminary Design	7	0	0	7
Percent	100%	0	0	100%
During Detailed Design/Development	7	0	0	7
Percent	100%	0	0	100%
During the Production/Construction Phase	5	0	2	7
Percent	71%	0	29%	100%

2. Cost estimates for new systems typically include the following elements:
(N/A=not applicable to your business unit)

Statements	**Yes**	**No**	**N/A**	**Totals**
Research and Development Costs	7	0	0	7
Percent	100%	0	0	100%
Productions and Construction Costs	6	1	0	7
Percent	86%	14%	0	100%
Marketing Costs	4	1	2	7
Percent	57%	14%	29%	100%
Distribution/Logistics Costs	6	1	0	7
Percent	86%	14%	0	100%
Service/Support Costs	7	0	0	7
Percent	100%	0	0	100%
Disposal/Recycling Costs	4	2	1	7
Percent	57%	29%	14%	100%

3. Are you currently using Life-Cycle Costing (LCC) in your business unit? In answering this question please consider the following statement:

n	**Percent**	**Answers**
0	0	I am not sure
1	14%	The business unit does not use LCC
0	0	The business unit recently started implementing LCC but has not fully implemented it
6	86%	Life-cycle costing is well established in our business unit
0	0	The business unit uses LCC, or a costing principle with similar characteristics under a different name than LCC
6	100%	Totals

4. If your business unit does not use LCC, reasons why are:

n	Answers
1	LCC is not relevant for our kind of business
1	Total

Additional Comments: "We are not directly tied into the design phase. What we do does not drive design decisions. Our prime contractors used LCC trade studies to find the best selection at the best price."

5. If your business unit has previously used *Life-Cycle Costing, but no longer uses Life-Cycle Costing*, the reasons for termination are: (check all that apply)
(n=0)

6. The decision to adopt LCC was made by: (check one)

n	Percent	Answers
1	17%	A Government Project or Program
3	50%	The Entire Company
1	17%	Other: Entire Department of Defense
1	17%	Other: Department of Defense/US Army Direction
6	100%	Totals

7. What is the depth of LCC implementation in your organization?

N	Percent	Answers
3	50%	Throughout the corporation
1	17%	Within a group or division
1	17%	Other: Most Legal Programs
1	17%	Other: Throughout RDEC but form of cost estimates depends on nature of project/program IOW, meaning of lifecycle is not constant nor fixed
6	100%	Totals

8. The Life-Cycle Costing system in your business unit: (N/A=not applicable to your business unit)

Statements	Yes	No	N/A	Totals
Mandates that all Suppliers Use Life-Cycle Costing				
n	1	5	1	7
Percent	14%	72%	14%	100%
Requires Only Major Suppliers to Use Life-Cycle Costing				
n	2	4	1	7
Percent	29%	57%	14%	100%
Requires Trade Studies to be Completed for the Majority of Major Design Decisions				
n	6	0	0	0
Percent	100%	0	0	100%

Other comments: Life-cycle costing is more Expensive to Manage [than previous costing methods]

9. Please comment on the successes/failures you have observed while using Life-Cycle Costing. Will you extend the use of life-cycle costing to other business units or systems? Why or why not?

"It is often difficult to determine the logistics tail of a system during the early stages of development although we need to determine those costs as well as associated training needs."

"Yes [it is perceived as a success], LCC has become institutionalized within the DoD"

"Aspects of it that are labor intensive are perceived to be of little value. Success is not an issue. Cost estimation is a legal mandate"

"In this program (and most military systems) the operating and containment cost far outweighs the initial development and production. The ultimate success or failure will not be known for many years, but the LCC played a large role in the direction the program went."

"Finding Major costs are in support rather than design and initial build, it's important to focus on maintainability and obsolescence years. LCC will be extended more to other projects"

"Success: It is only with proper LCC that we are able to forecast our fiscal resource. Needs appropriated by the Congress. We are able to estimate the operational/support tail of the system after it is fielded..
Failure: We are not there with "good" cost estimating. This calls for cost readjustments and sometimes even asking for more resources than planned for.
Yes [LCC will be extended to other business units/systems]. It is only through LCC that a true picture of "things" can be understood. Without LCC management will not have an accurate picture of initiatives to make decisions on what initiatives should be funded."

Amendment to Survey:

1. How long has Life-Cycle Costing been used at your business unit?

n	Percent	Answers
		Less than 6 months
		6-12 months
		1-2 years
		2-3 years
		3-4 years
1	**20%**	4-5 years
1	**20%**	5-10 years
3	**6%**	Over 10 years
5		**Totals**

2. LCC may have caused the following changes in the system. If Life-Cycle Costing has significantly caused the given factor to decrease, you should underline/circle –5. However, if it has caused it to increase significantly you should underline/circle 5:

n=5, one of initial survey respondents could not be reached to fill out amendment to survey

Factor	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**N/A**	**Total**
Cost of System Before Manufacturing													
n				1		1	1		1	1			5
Percent				20%		20%	20%		20%	20%			100%
Time Required for System Introduction													
n				1		1	1	1		1			5
Percent				20%		20%	20%	20%		20%			100%
System Features and Functions that Customers Value													
n			1	1		1		1	1				5
Percent			20%	20%		20%		20%	20%				100%
Customer Expectations for System													
n			1			2		1	1				5
Percent			20%			40%		20%	20%				100%
Cost of Purchased Materials													
n				1		3		1					5
Percent				20%		60%		20%					100%
Projected Manufacturing Costs													
n				1		1		1		1		1	5
Percent				20%		20%		20%		20%		20%	100%

Factor	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**N/A**	**Total**
Projected Maintenance Costs													
n			1		1	1				2			5
Percent			20%		20%	20%				40%			100%
Projected Operating Costs													
n			1	1			1	1			1		5
Percent			20%	20%			20%	20%			20%		100%
Number of Design Changes After Production Begins													
n			2			1				2			5
Percent						20%							100%
Overall System Profitability													
n			1			2		1				1	5
Percent			20%					20%				20%	100%
Overall System Performance													
n		2				2		1					5
Percent								20%					100%
The Cost of Owning the System throughout its Life-Cycle													
n			1	1			1		1	1			5
Percent			20%	20%			20%		20%	20%			100%
System Repair Time													
n			2			1		2					5
Percent			40%			20%		40%					100%

Factor	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**N/A**	**Total**
System Reliability													
n			2					2	1				5
Percent			40%					40%	20%				100%
Useable System Life													
n			2					2	1				5
Percent			40%					40%	20%				100%

3. If your business unit does trade studies for the system you described, please weight the importance of the following factors in the decision making (0=Unimportant/, 5=Extremely Important)

Factor	**0**	**1**	**2**	**3**	**4**	**5**	**Totals**
Initial Acquisition Costs							
n		1		2	2		5
Percent		20%		40%	40%		100%
Long Term Life-Cycle Cost							
N		1			1	3	5
Percent		20%			20%	60%	100%
Environmental Impact							
n		2		1		2	5
Percent							100%
Length of Time Item Under Consideration will be Operational							
n		2	1		2		5
Percent		40%	20%		40%		100%
Relationship with Supplier							
n	2		1	2			5
Percent	40%		20%	40%			100%
Component Reliability							
n		1	1		2	1	5
Percent		20%	20%		40%	20%	100%
Salvage Value							
n	2	2	1				5
Percent	40%	40%	20%				100%

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