AFIT/GIR/LSQ/92D-6

RELIABILITY, MAINTAINABILITY, AND SUPPORTABILITY (RMS) EDUCATION IN ENGINEERING SCHOOLS

THESIS

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The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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THESIS

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Abstract

The purpose of this research is to show how engineering schools, as a whole, perceive the role of reliability, maintainability, and supportability in the engineering field. This includes the degree to which these concepts are included in their curricula, whether industry recruiters look for reliability, maintainability, and supportability training when they visit college campuses and to what degree college faculties are teaching reliability, maintainability, and supportability. This is done through research of existing literature and the analysis of data from a survey completed by engineering schools. General analyses are presented of the overall responses and detailed analysis of contrasts and similarities between the responses from private and public institutions are presented. Based upon the knowledge gained in conducting this research, conclusions on the state of RMS education in engineering institutions are forwarded.

RELIABILITY, MAINTAINABILITY, AND SUPPORTABILITY (RMS) EDUCATION IN ENGINEERING SCHOOLS

I. Introduction

Thesis Overview

The purpose of this research is to show how engineering schools, as a whole, perceive the role of reliability, maintainability, and supportability in the engineering field. This includes the degree to which these concepts are included in their curricula, whether industry recruiters look for reliability, maintainability, and supportability training when they visit college campuses and to what degree college faculties are teaching reliability, maintainability, and supportability. This is done through research of existing literature and the analysis of data from a survey completed by engineering schools. General analyses are presented of the overall responses and detailed analysis of contrasts and similarities between the responses from private and public institutions are presented (for the purposes of this paper, public and government are used interchangeably).

Chapter Overview

This chapter outlines the issues that relate to reliability, maintainability, and supportability (RMS) and their relationship to statistics and engineering design. This relationship is implied by the SAE G11 committee sponsored survey that queried engineering institutions on the courses they provided in statistics and engineering economics. The nature of the questions and the directions for completion of the survey indicate that these courses are an integral part of RMS education. The chapter then briefly touches on the conditions that are driving a re-evaluation of the importance of RMS and the role of RMS education in engineering schools. This chapter defines the scope of the study by detailing the research objective and developing hypotheses on the issues of RMS education. Assumptions required to conduct this study and limitations to research are also explained. The chapter concludes with an overview of the organization of the remainder of this thesis.

General Issue

During the forty five years since World War II, America has enjoyed being king of the hill. No other country could compete with our economic might and our technological superiority. Rapid economic and technological growth placed emphasis on the design of new products rather than the quality of the products. Universities could barely keep pace with the demand for engineers to design and develop these products. During this period of rapid expansion, quality, a critical element of engineering design was practically ignored. In the eyes of many consumers quality equates to the dependability of a product, the ability to repair it when broken, and the availability of repair parts. Quality can be translated to reliable, maintainable and supportable products. As other nations struggled to catch up to American industry, they found that they could use the element of quality, which many American products lacked, to carve a niche in the market place.

We are no longer a singular economic power. We have to compete with other nations of the world in order to sell what we produce. In order to compete in the international marketplace, the element of quality can no longer be ignored.

Another factor that has focused business and industry on the need for quality is the weakened economy. In this era of downsizing and budget reductions, businesses and government agencies are looking for ways to do more with less. Quality products designed with the features of reliability, maintainability and supportability are needed and desired.

This research paper touches upon the nature of the American economy, how RMS relates to it, and the perceptions of RMS' role in engineering schools. It also reviews the engineering curricula that supports RMS. A literature review of RMS and RMS education elucidates these issues. The analysis of a survey (see Appendix A), conducted by the Society of Automotive Engineering (SAE) and sent to all (approximately 250) of the accredited four-year engineering institutions (hereafter referred to as engineering institutions or schools) listed in the March 1989 issue of American Society of Engineering Educators, sheds considerable insight into this topic. Comparisons of private and government sponsored engineering institutions are made to further define the state of RMS and education.

Research Objective

The purpose of this research is to determine how engineering schools, as a whole, perceive the role of reliability, maintainability, and supportability in the engineering field and the degree to which these concepts are included in their curricula. In addition, this research will attempt to determine if funding, public or private, affects the school's perceptions or curricula.

Research Propositions and Hypotheses

This study addresses how engineering schools perceive the necessity of RMS in engineering, and their actions that support RMS. Hypotheses were broken into two groups to improve readability and to form logical groups of question types. There are 8 hypotheses (category A) that relate to the perception of RMS and 140 hypotheses (category B) that relate to the level of activity dedicated to RMS. These hypotheses were drawn directly from the SAE survey questions. For brevity, many of the hypotheses have been grouped in this chapter. A complete list of the 148 hypotheses is included in Chapter 4. The hypotheses listed are for engineering schools as a whole. Similarities and differences between privately funded and government funded institutions will also be analyzed and related to these hypotheses.

Category A Hypotheses. Engineering schools' perceptions of the necessity of RMS in engineering. The respondents feel that:

Hypothesis 1. RMS should be included in the design process when a system or component is being designed.

Hypothesis 2. When RMS is designed into a product, it adds value to that product.

Hypothesis 3. RMS should be included in a design engineer's education.

Hypothesis 4. Faculty should include RMS in their research and professional activities.

Hypothesis 5. Students should include RMS in their research.

Hypothesis 6. RMS parameters should be part of the accrediting process for engineering degrees.

Hypothesis 7. Recruiters are looking for RMS educated students.

Hypothesis 8. Recruiters feel that RMS training contributes to a student's education.

Category B Hypotheses. Engineering schools' participation in RMS education. Respondents indicate that:

Hypothesis 9. RMS is included in the design curriculum.

Hypothesis 10 to 29. Statistics courses are required/electives in aerospace, electrical, industrial, mechanical or other undergraduate/graduate engineering curricula.

Hypothesis 30 to 49. There are plans to include a required/elective statistics course in aerospace, electrical, industrial, mechanical or other undergraduate/graduate engineering curricula within the next five years.

Hypothesis 50 to 69. Statistics is a portion of required/elective aerospace, electrical, industrial, mechanical or other engineering design undergraduate/graduate courses.

Hypothesis 70 to 89. Engineering economics is required/elective in aerospace, electrical, industrial, mechanical or other undergraduate/graduate engineering curricula.

Hypotheses 90 to 109. There are plans to include engineering economics as a requirement/elective in aerospace, electrical, industrial, mechanical or other undergraduate/graduate engineering curricula.

Hypotheses 110 to 115. Undergraduate/graduate engineering economics courses include aspects of reliability, maintainability, or supportability that pertain to life cycle engineering.

Hypotheses 116 to 121. Plans for the next five years include formal credit courses in reliability, maintainability or supportability.

Hypothesis 122 to 131. Plans for the next five years include incorporating RMS in other undergraduate/graduate engineering design courses (both required and elective) within the aerospace, electrical, industrial, mechanical or other engineering curricula.

Hypothesis 132. Faculty participates in RMS research or scholarly RMS-related activities.

Hypothesis 133. Student's participate in RMS research or scholarly RMS-related activities.

Hypothesis 134 to 139. An undergraduate/graduate degree is offered in reliability, maintainability, or supportability.

Hypothesis 140 to 145. Plans for the next five years include offering a degree in reliability, maintainability, or supportability.

Hypothesis 146. Faculty and students develop or participate in RMS short courses.

Hypothesis 147. More than 50% of the engineering faculty with RMS education are capable of teaching RMS.

Hypothesis 148. More than 50% of previous graduates work within the general area of RMS.

Scope

This research is based upon a survey that was conducted in 1989. Much of the literature that was reviewed is more current. The conclusions drawn from the survey relate the status and projections of RMS education in 1989 while the literature will illustrate current trends. Since the responses to this survey were not previously analyzed, this paper contributes to the general body of knowledge and makes available an important database on this topic.

It must be stipulated that where current literature and the information gained from this survey differ, the literature may be more reflective of the current state of events. Trends and attitudes of all respondents are categorized as a whole. The respondents can be separated into over 27 demographic categories, as a result detailed comparisons of these demographics could result in a lifetime of research. One demographic breakdown, whether a school is private or publicly funded (government), was selected for analysis to illustrate how relevant data can be extracted from the completed SAE survey. Since the population of engineering schools were asked to respond to the survey, the results should reflect the nature of RMS and formal education in the selected group of schools.

Overall, the response rate was approximately 20% of the population.

Assumptions

The literature review indicates that the current actions and attitudes of engineering institutions in regard to RMS are similar to those in 1989 when this survey was conducted. It is assumed that the results of this survey are still applicable.

The response rate of 20.4% of the population is not as high as we would like; however, it is a sufficient base from which to draw generalities about the hypotheses. Although we have a record of the population that this survey was sent to, we do not have any information on the demographics of the non-respondents. As a result, it must be assumed that the 20.4% of the population that did respond are representative of the entire population.

Limitations

Bias can effect conclusions developed in this research. Although efforts are made to control bias, the following are the sources from which they can occur:

(1) The survey was developed by the Society of Automotive Engineering (SAE), a group dedicated to improving the quality of products through the use of RMS. They have their own opinions of the necessity of RMS education. The questions appear to be very objective, but there is the possibility that they are unintentionally

worded to extract responses that agree with the attitude of the developer of the survey.

(2) A bias on the part on the researchers exists. There is a bias on the part of the researchers to see that the survey results agree with their opinions on RMS and the literature that they have reviewed. Results that differ from those anticipated cause the researchers to scrutinize the varying conclusions more thoroughly than conclusions that agree with their pre-conceived notions. A reasonable attempt has been made to reduce or eliminate this bias by ensuring that equal consideration was given to a conclusion whether it met the researcher's expectations or not.

Thesis Organization

This chapter presents an overview of the thesis and research objectives. Chapter 2 is a literature review summarizing the literature that has been written on the topics of quality, reliability, maintainability, and supportability and their relationship to engineering education. It provides a brief historical perspective of these issues to assist in understanding the concepts presented throughout the remainder of this paper. Chapter 3 provides the methodology of our study. This is the description of how the survey was formulated and distributed and a detailed analysis of how it relates to the stated hypotheses. Chapter 4 is an analysis of the experimental measurement. It discusses the analysis of the survey, and the conclusions to our hypotheses. Chapter 5 summarizes the research and provides conclusions and future recommendations.

II. Literature Review

Introduction

This chapter examines the literature pertaining to reliability, maintainability, and supportability. The first section will provide definitions for each of these terms. This is followed with a review of some of the historical events that are significant to the understanding of RMS. This chapter concludes with a review of current literature that is illustrative of the present status of RMS and the state of RMS education in engineering schools.

Definitions

There are a variety of definitions that are used in conjunction with common RMS terms. These vary depending on the activities of the organization. Although the Society of Automotive Engineering (SAE) has compiled a database of over 1,100 unique definitions for many of these terms, they do not all apply to our context (Breneman and Stracener, 1991:137). The following explanation of key terms defines how they are used in this document.

Reliability - The "probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions" (Blanchard, 1986:12). Measures of reliability include operating time, failure rate and mean time between failure (MTBF) (Blanchard, 1986:28).

Maintainability - The ability to keep an item in, or return it to, a specified condition when maintenance is done by trained individuals using designated procedures and resources (Department of Defense, 1990:XV-6). "Like reliability, it is an inherent characteristic of system or product design" (Blanchard, 1986:15). Measures of maintainability include mean time between maintenance (MTBM), mean time between replacement (MTBR), maintenance costs, elapsed times, and personnel labor-hour rates (Blanchard, 1986:32).

Supportability - The capability to keep an item functioning. "Measures of supportability are reliability, maintainability, availability, durability, maintenance manpower, performance of maintenance training aids, and performance of test equipment" (Curtis, 1984:9).

Life Cycle Costs (LCC) - All of the costs of a system over its full expected life. This includes research and development, investment, operating, and final disposal expenses. (Gill, 1990:1)

Total Quality Management (TQM) - The management of all resources with the objective of achieving continuous improvement in quality. "The successful TQM operation is characterized by an organization of quality trained and motivated employees, working in an environment where managers encourage creativity, initiative, and trust" (Department of Defense, 1988:1).

Background

America's Historical Role in Technology. After World War II, the United States took a leadership role in the development and design of new products. As the nations of Europe and Asia set out to rebuild their economies, the US was the world's main economic power and technological leader. Through the years this lead has diminished.

An article in the Communications of the Association for Computing Machinery capsulized several articles from other journals and magazines that looked at America's changing technological superiority. It states that "before World War II the American market share was overall about 25 percent worldwide; after the war, when many economies were in shambles, it rose to 40 percent; now, with American ideas being adopted and adapted throughout the world, it has dropped to pre-war levels." They concluded: "America is losing share, in one market after another, to foreigners who are sometimes ruthless" (Denning, 1990:15-16).

When discussing loses of market share to foreign competitors, the automobile industry immediately comes to mind. It serves as a prime example of how competitors have encroached upon traditional US market shares. Ford, GM, and Chrysler have all lost a considerable part of their markets to Japanese companies. This is "partly because of the perceived lower reliability" of the US firm's product (Bowles, 1992:134).

Other industries have also been effected. The US Department of Commerce, Office of Technology Administration, has a report that indicates the US is losing its lead in several critical technologies. One such technology is electronics, which is becoming dominated by Japanese and European firms. According to the report, the electronics industry will be worth $350 billion worldwide by the year 2000, of which the US is the single largest segment. However, US market share has dropped from 95% to 5%. This loss of market share can be attributed to Japan's huge investment into research and development (Report Finds...,1990:21). "More reliable, maintainable and supportable products are required in order to enhance producer competitiveness and increase customer satisfaction to remain competitive"(Breneman and Stracener, 1991:137). In a paper prepared for the 1992 Annual Reliability and Maintainability Symposium Klinger, Saraidaridis, and Vanderbei relate that:

> In the past ten years, customer expectations have been increasing in response to evolving new technologies. Customers are becoming more sophisticated and knowledgeable than ever before. As part of this evolution, they are demanding from their suppliers: products with higher quality and reliability, designed and manufactured faster and with more features, low initial cost, improved customer support, and most importantly, products that are easy and inexpensive to maintain. (Klinger and others, 1992:86)

Recognition of these rising expectations is necessary to maintain economic growth. Because it has not responded to changes, the US has abandoned some market segments to foreign competitors.

One of the reasons given for this negligence in applying RMS principles include engineers who are solely focused on performance. Many are only concerned with getting products operational and they spend no time contemplating potential system failures. Often times, the performance parameters are not clearly prioritized or fully explained to the designers. Another potential explanation as to why many US products lack the distinction of quality is that design engineers may not be familiar with the ultimate use of the products and therefore may not be aware of how much these systems can be degraded before they are unusable (Goldstein and others, 1989:ES-4). The US must recapture a competitive edge in the world's technological leadership. The harsh realities of the international market will not allow them to pass off products that are not of the highest quality and most current technology.

<u>Awareness that Changes Must Be Made.</u> The revelation that America must rethink its design and development of products to include the element of quality has resulted in many institutional changes. Government agencies and private enterprise agree that our focus on producing must now include RMS. If companies are to survive, "product quality must become more important" (Brennan and Stracener, 1992:44). The Air Force is also re-examining the criteria that it uses to judge the value of its systems.

> Air Force management realized that the emphasis on achieving systems performance at the expense of reliability, maintainability, and availability had brought about system designs which resulted in low systems availability, high maintenance costs, and an unmanageable logistic support tail. (Kleinhofer and others 1991:3)

Many trade organizations have set out to correct some of the errors that have been made in the past. The manufacturers of computer chips have formed a group called the Council for Continuous Improvement. "The organization is set up to build on the real-world experience of each member company, and has gathered their most successful quality improvement techniques." This group seeks to stop the decline of the US as the world's technology leader. They feel that they have a significant effect on international competition in the area of quality (Woods, 1990:1). Another group, the Society for Automotive Engineering (SAE), is very active in RMS issues and has established a G-11 committee which conducts activities to promote reliability and maintainability.

> Significant accomplishments to date include:
> * RMS survey of industry, government and academia
> * The 1st and 2nd Annual SAE International Workshops - April of 1989, 1990, 1991, and 1992.
> * Publication of the SAE RMS Guidebook, First Edition, April 1990.
> * Initiation of the SAE RMS Newsletter in April 1990.
> * Publication of the Aerospace Industry Status Report on Computerization of RMS in Design (AIR 4276).
> * SAE Aerospace Resource Document on Recommended RMS Terms and Their Definitions (ARD 50010).

* SAE Aerospace Resource Document on Liquid Rocket Engine Reliability Certification (ARD 50009).
* SAE Aerospace Resource Document entitled Solid Rocket Reliability Guidebook, Volume 1 (ARD 50013).

Current active projects of the SAE G-11 Committee include:

* SAE RMS Guidebook... 2nd edition April 1991
* 3rd annual RMS workshop, held in May 1991
* Report on RMS Education & Training in the United States
* Directory of RMS Professionals
* Automation of the Failure Modes and Effects Criticality Analysis in a CALS/CE environment
* RMS Technology Workshop
* RMS Analysis Tools and Methodology Review
* RMS Technology Development and Insertion Report
* RMS Technology Assessment and Plans Annual Report. (Breneman and Stracener, 1991:138)

The survey that this thesis analyzes is also a product of the SAE.

The TQM and RMS Relationship. With the need for quality established, American industry and government have set out to find ways to implement the necessary changes. The concepts of RMS have been around for many years; however, the application of these principles has been sporadic. The introduction of TQM into American companies was viewed as a new concept; in reality it espouses many of the same principles that RMS proponents do. There is an on-going battle between the "TQM camp" and the "RMS camp" as to which discipline is incorporated under the other (Williams, 1992:interview). Both TQM and RMS are concerned with consumer acceptability and satisfaction, as well as product improvement. Due to these similarities, we consider the terms synonymous for the purposes of this paper. Total Quality Management (TQM) became the mechanism that many of these organizations are using to instigate necessary changes.

Much of corporate America and the US government have embraced the concepts of TQM. They see that "TQM philosophy, techniques, and tools are proven vehicles which result in higher quality and reliability at lower costs to the customer" (Johnson and Yates, 1991:576). Klinger, Saraidaridis, and Vanderbei relate the importance of TQM and reliability management.

> Customers and the competitive marketplace are driving the needs for Total Quality Management (TQM) and Reliability Program Management. Customers are demanding dependable service and highly reliable products. Today, the customer selects the product and service in a competitive marketplace and decides what product and service quality and reliability the supplier must provide, when it must be available, and how much it costs. Increasingly more suppliers are using reliability program management to help them meet stringent customer requirements. (Klinger and others, 1992:85)

RMS - It's Value and Application. The old concept of reliability has changed. In the past, the early design process placed little emphasis on RMS. As a result, a large amount of effort was required to redesign the product to include measures of reliability, maintainability and supportability. Some government contractors were hesitant to design too much R&M into their products. Reliable, maintainable equipment ultimately meant less sales of new equipment and spare parts (Cochoy, 1985:7-10).

Aware of this reluctancy to incorporate RMS, the Air Force is seeking ways to favor companies that actively support these principles. When Gen Hansen was the AFLC Commander, he suggested that we emphasize "doing business with those companies which have the best R&M track records, making R&M the key to corporate success with the contractors' market share proportional to the R&M of their products" (Hansen, 1988:5-6). The importance of RMS is no longer going unnoticed. In December of 1985, the Air Force initiated its R&M 2000 program. According to Major General Jimmie Adams, former Deputy Chief of Staff, Requirements Headquarters Tactical Air Command, the "Air Force R&M 2000 Action Plan was developed to provide general policy and guidance to institutionalize R&M in the way we do business - now and in the future" (Department of the Air Force, 1986:i). As a part of their effort to increase value engineering, the Federal Acquisition Regulation (FAR) now requires that major systems production contracts include a Value Engineering Program Requirement (VEPR) clause (unless the contractor has a proven record of reliability or the contract was awarded competitively). This clause encourages the use of value engineering, and often provides incentives to the contractor for building the concepts of RMS into their systems (Federal Acquisition Regulation, 1989:48.101(b)-48:102(d)).

Changes in the design process are necessary because historical evidence shows that by the time a system is released to production, most of its life cycle costs are "locked in". After this point, additional design decisions will sub-optimize the costs (Carrubba, 1992:101). Some organizations feel that including RMS early in the design process is too costly; however, "the benefit of an aggressive R&M program significantly outweighs the cost" (Hartman and Whitt, 1991:162). Ronald C. Lisk, who works for NASA, states that:

> The days when the scope of the reliability effort could be restricted to a critique of a design after key design decisions have been made, or limiting reliability assurance activities to Failure Modes and Effects Analysis and probabilistic analysis to assess the risk of flying with a given design, are over. The Reliability Assurance discipline must expand its horizons to include an independent set of eyes that will examine key facets of a sound engineering system process. This set of eyes should review environmental requirements definitions, engineering analysis results, test planning, interface control documentation, and more. Further, this independent set of eyes must focus attention on design details with technical credibility and in a timely and technically credible manner to identify and support redesign efforts to fix problems early. (Lisk, 1992:8)

In his book "Better Designs in Half the Time", Bob King uses the illustration in Figure 1 to describe the old concept of design compared with the approach that incorporates early planning for RMS.

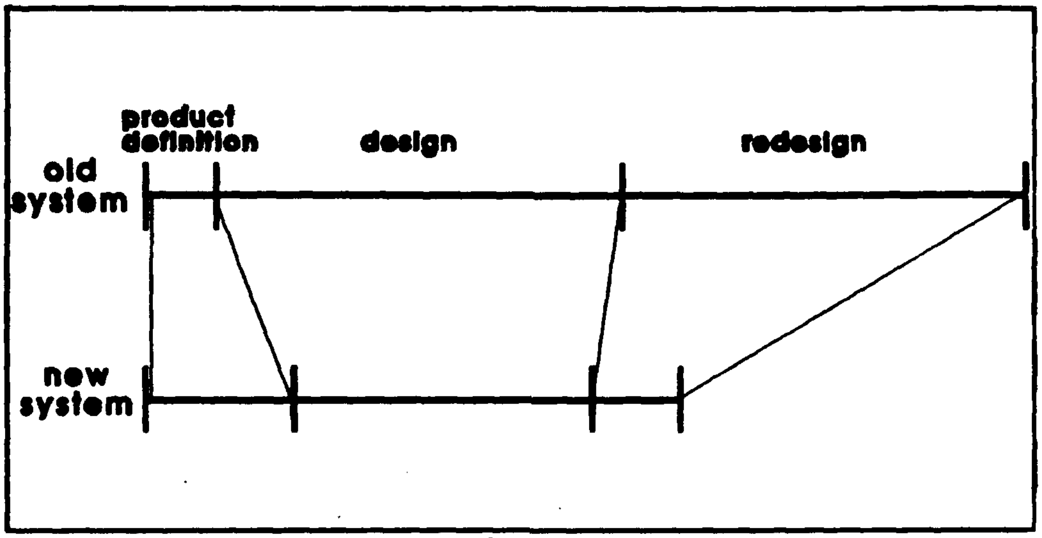

Figure 1. Comparison of Old and New Design Systems
(King, 1989:1-2)

It can be seen that by increasing the time to define a product and incorporating the principles of RMS, the time during the design phase of the project is reduced slightly and the redesign phase is practically eliminated. This results in a reduction of time for the overall design of a product. As illustrated, RMS must be considered early.

In the past Johnson and Yates found that:

> By the time most of the traditional reliability tasks are complete enough to provide beneficial feedback to the designer, there is very little opportunity to improve product reliability. Many of these required tasks are reactionary in nature, in that they represent a defect detection approach rather than a defect prevention approach to reliability and quality. (Johnson and Yates, 1991:571)

This "reactionary" approach shows up in the time it takes to redesign a product. RMS must be considered early in the process. By the end of a systems concept definition, 70% of its life cycle costs (LCC) are committed. Changes made after this point to enhance RMS features have much less impact. Figure 2 is a graphic illustration of the LCC's committed at various stages of a system's design (Brennan and Stracener, 1992:45).

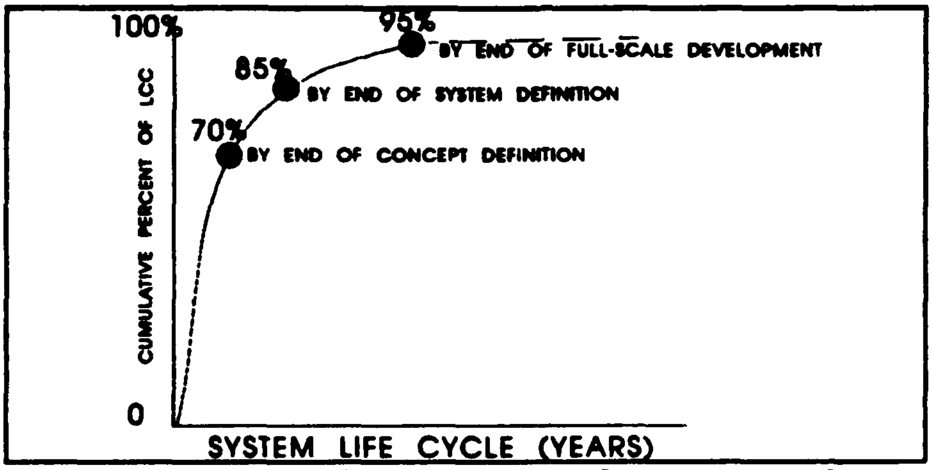

Figure 2. Cumulative Percent of LCC Committed Versus System Life Cycle (Brennan and Stracener, 1992:45)

To achieve the level of quality that we need in today's products, the elements of RMS must be considered early in the design process. "It is imperative that R&M issues be addressed early and traded equally with performance requirements" (Walters, 1992:210). There is no substitute for RMS. Early consideration of RMS is essential.

> It is estimated that as much as 70% of an aircraft program's LCC has been rendered unchangeable by the end of the preliminary design. Consequently, in the current engineering system, the downstream detail design and support requirements analysis groups can influence only the minority of the LCC. The main drawback has been the lack of effective early design analysis aids to evaluate design for

> the RM&S characteristics that decide life cycle and support costs. (Bordelon, 1991:202)

Goldstein, Owen, and Richter reinforce this conclusion. They say that there are "problems in the design process that hinder the delivery of supportable equipment at the lowest cost. The solution being sought is the integration of supportability and producability considerations in the early design stages" (Goldstein and others, 1989:ES-2). The cliche "an ounce of prevention is worth a pound of cure" rings true when it comes to including RMS considerations in the design process. John Hartman and James Whitt, who work for the US Army Strategic Defense Command, say that they "have observed on many occasions R&M problems uncovered late in a program. Correction of these problems resulted in major cost impacts. Timely identification of the problems could have led to much less costly solutions" (Hartman and Whitt, 1991:164). "Since product RMS characteristics are system effectiveness and LCC drivers, it is essential that they become an integral part of the product design and development process" (Brennan and Stracener, 1992:51). The days of limited reliability analysis are over. It is now necessary to have specialists that understand the engineering process for developing a sound, reliable product (Lisk, 1992:7). To compete in the marketplace, our engineering graduates must receive RMS training (Hadjilogiou and others, 1990:90).

The Status of Education in RMS. Having established the necessity for RMS, the focus now becomes discovering if we are educating our engineering designers and developers to incorporate these principles in their work. John Bowles from the University of South Carolina lists the basics that he feels important for every undergraduate engineer to acquire. These include:

> * a basic knowledge of probability and familiarity with its applications to 1) reliability calculations for simple series and parallel redundant systems; 2) statistical methods in process control; and 3) probabilistic design techniques;
>
> * an awareness of the need for robust design techniques to handle both product and process variation; and
>
> * an appreciation of the need to identify causes of failure and use this knowledge to continuously improve designs. (Bowles, 1992:138)

Some schools are teaching these basics, but many are not. "In their basic engineering education, few engineers are taught to design for reliability, trained in the techniques for doing it effectively, or even convinced of its importance and cost effectiveness in the design of a product" (Bowles, 1992:134). The reality is that "a design engineer, unless trained in the reliability, maintainability, and supportability (RM&S) discipline, has difficulty relating to the maintenance statistics" (Goldstein and others, 1989:ES-5). Despite the realization that R&M needs to be considered in the initial design, often times it is not being done. This is because the designers "were never taught the principles of R&M in their respective educational courses. For the future, designers need to be educated regarding R&M being mandatory design parameters, and their education must include analysis and tools for the future designers to be capable of including R&M in their designs" (Williams, 1992:131).

Workshops seminars and symposiums on RMS are a response to the need for increasing education but they are not enough. Initial RMS training should occur in engineering schools; but according to RMS proponents, their response to providing this curricula has been very slow (Breneman and Stracener, 1991:137). In May of 1990, the US Air Force conducted a workshop entitled "Prospects For Integrating Reliability and Maintainability Into Undergraduate Engineering Curricula". Some of the comments made at that meeting reflect the need for academia to stress the concepts of RMS. General William Collins, Special Assistant for R&M, USAF/LE-RD, stated that "In the future, we must train new engineers coming into the work force to consider R&M, quality, supportability, and operability during equipment design and manufacturing. Academia must recognize our needs and help us solve this educational problem over time; not tomorrow, but certainly in the near term". Colonel James Harrington, Deputy Director for R&M, USAF/LE-RD, reinforces the necessity for engineering education to include the concepts of RMS. He says that these institutions "are a key part of this building block concept as they educate the engineers with the tools which form the basis for our building blocks. They must rise to the challenge in evolving their curricula to meet industry and government needs" (Loose and Shapiro, 1990:3-4).

There are some impediments to teaching RMS in engineering schools. It is up to the academic institutions to integrate the principles of reliability into engineering education. This "must be done by the faculty -- by each faculty member in each individual course (Bowles, 1992:138-139). Many of the faculty at the engineering schools have not been trained in the concepts of RMS, and they have little practical knowledge of industrial requirements. Their energies go towards publishing, supporting graduate students, and teaching. The priority is not in learning new concepts to teach their students (Loose, Shapiro, 1990:11). "If the educators have never been exposed to R&M, then it is highly unlikely that they will in turn introduce subject matter that they have not studied on their own" (Williams, 1992:132).

There are a handful of institutions that have responded to the need to stress RMS to their students. Florida Institute of Technology (FIT), Virginia Polytechnic Institute (VPI), University of Maryland (UM), University of Iowa, University of South Carolina, Air Force Institute of Technology (AFIT), and the United States Air Force Academy (USAFA) all have incorporated RMS in their curricula. These schools have integrated RMS in a variety of ways. They have integrated RMS into their existing courses, offered courses in RMS, and one school, AFIT, added a special post degree program that addresses reliability engineering. They are encouraging students and faculty to include RMS in their research (Loose and Shapiro, 1990:4-11).

In order to encourage schools to add more RMS to their curricula, several steps must take place. "Unfortunately, the desires of senior technical managers rarely get translated to the recruiters who go to college campuses to recruit engineers" (Williams, 1992:133). Industry must make it known that RMS training is important, this needs to be conveyed through the recruiters they send to the campuses. "If the recruiters do not ask for R&M, then many educators do not think industry is interested, and there is no overwhelming pressure to change" (Williams, 1992:133). The Accreditation Board for Engineering and Technology (ABET) could require some RMS-related curricula. This would force institutions to include these concepts or lose their accreditation. And finally, perhaps most importantly, industry and government must provide financial incentives by funding RMS research at the engineering schools (Loose and Shapiro, 1990:13).

Conclusion

The issues discussed are an integral part of the Air Force's future. Air Force drawdowns of personnel and reduced budgets heighten the need to do more with less.

Incorporating the principles of RMS work toward this goal. Systems designed by or used by the Air Force will need to have these characteristics. Corporate America is also aware that the quality of the products they produce or use can no longer be an issue that is ignored. The necessity of RMS and the need to include it's principles early in the design process has been illustrated. The literature shows that the life cycle costs of a product can be dramatically reduced through the incorporation of RMS principles.

Although the necessity of RMS in engineering seems apparent to academicians, few institutions have changed their curricula to account for this need. There are various reasons for engineering institutions' lack of RMS education. These institutions have been able to market their students without this training due to the general lack of corporate recruiting in the RMS area, as well as the overall dearth of engineers in today's marketplace accompanied by the propensity to hire engineers whether they have RMS training or not. As a result, academic institutions have not felt it necessary to change their curricula. The Air Force and corporate America need to encourage the engineering institutions to make RMS issues a more active part of their programs.

III. Methodology

Chapter Overview

This chapter describes the methodology used to meet the research objective. It discusses how the survey instrument was selected, its intended purpose, and the population it was sent to. The strengths and limitations of the survey instrument are delineated. The chapter then goes on to describe the analytical tools used to interpret the results of the survey and the scope of the interpretation.

Survey Development

This survey was developed in response to the SAE's need to gather information as to the state of RMS-related education in today's higher educational institutions. Dr. Ben Williams of the Air Force Institute of Technology Center of Excellence for Reliability/Maintainability/Quality, and member of the SAE G11 committee, developed the survey in early 1989. At this time little was known about the attitudes, perceptions, or curricula of engineering schools with regard to RMS. The survey was sent to obtain some feedback from engineering institutions on the subject of RMS. It also served as a mechanism to let the deans of these schools know that there was interest from the business and government community in how the schools implemented RMS instruction. Questions were designed to gather information on RMS-related courses, the inclusion of these courses in future plans, and the number of students receiving RMS-related education. Additional questions addressed faculty/student participation in RMS-related activities or research, incentives used to promote said activities/research, recruiters interest in RMS education, and the depth of faculty able to instruct in the RMS area. The questions were developed to focus on issues relevant to the SAE and at the time, no consideration was given to how the data would be analyzed on completion of the survey.

Survey Justification

The data collection technique chosen for this research was to use a previously completed survey. This method was chosen because this was the only collective data of this nature and it had not previously been analyzed. Sending out a new survey was considered, but the logical first step in exploring this issue was to fully analyze the data that was already available. By establishing a baseline with the results of this analysis, future research can determine if the nature of RMS perceptions and curricula have changed over time. A mail survey is the optimal research tool to use in gathering this type of detailed, information. The respondents have the opportunity to research the answers to many of the questions. Telephone surveys or personal interviews would not allow the respondents ample time or resources to adequately answer many of the questions. As a whole, the survey was designed to gather information regarding the state of RMS education in the academic community. Specifically, survey questions were designed to garner information in the following areas:

(1) university course offerings in RMS areas,

(2) the emphasis companies place on RMS when recruiting at the surveyed institutions,

(3) to determine if these institutions had the capability to teach courses in RMS,

(4) what incentives universities offer faculty and student to include RMS in research and study.

The survey instrument is ideal for accumulating the data that relates to these issues.

Population Description

The population for this survey was four-year engineering institutions listed in the March 1989 publication of the Society of American Engineering Educators. The types of institutions included liberal arts, multi-disciplined, and engineering and sciences colleges and universities. The survey, and cumulative data received from all respondents, is included in Appendix A.

There were over 25 demographic categories that could be determined from the survey. These included size, location, funding, age, and type. Each of these demographic distinctions could be analyzed singularly, or their could be a great number of combinations used to determine how they interplay with the perceptions and curricula in relation to RMS. For example, an attempt could be made to try to determine if statistics courses were required in greater than 50% of the undergraduate aerospace private institutions 26 to 100 years old that are in Kansas and had 51 to 200 students. How does this result compare with the undergraduate aerospace private institutions in Texas that are 26 to 100 years old with 51 to 200 students? The importance of the demographic distinctions is dependent upon the purpose of those analyzing the data. For the purpose of this research, we felt that an analysis of how institutions were funded would be interesting and would be indicative of how the data could be analyzed.

Of these initial surveys, 52 responses were received, one of which was discarded because it was incomplete. The 51 responses that we include in our analysis is approximately 20% of the total population.

Difficulties with Survey Instrument

Because this survey was not developed by the researchers with their statistical analysis in mind, it often was difficult to apply the responses to hypotheses that they developed. As a result, some assumptions had to be made in order to conduct the analysis. If these assumptions are invalid, the resulting conclusions to hypotheses may also be invalid. Some of the difficulties that the researchers encountered with the survey include:

(1) Question 6 asks if the institution is primarily liberal arts, engineering and science, or multi-disciplined. These terms were not defined and some confusion could exist. Is an institution that has an engineering school as well as other schools multidisciplined or engineering and science?

(2) Although RMS is defined, the relationship of statistics, engineering economics, and life cycle engineering to RMS is not discussed. This makes it difficult to interpret the intent of questions on these topics.

(3) Several questions ask the respondents to answer yes, no, or NA to undergraduate/graduate course offerings in aerospace, electrical, industrial, mechanical, and other engineering. The survey never directly asks which of these degrees the institution offers. This was one of the assumptions the researchers had to make in order to analyze the data. It is possible that a university offered a certain degree but did not answer the questions in a way that would allow the researchers to determine that the degree was offered. It would have been easier on the respondents if the questions were grouped according to these specific degrees and they didn't have to wade through

the rows and columns of answers to degrees they didn't offer.

(4) The groups of questions relating to statistics and engineering economics are similar, but since identical phrasing and vocabulary is not used, it is difficult to draw a direct corollary between the responses.

(5) No questions were asked that allowed a respondent to tell the researchers how RMS was included in their curriculum except for those courses that were defined by the survey,

Because the survey was not developed by the researchers with their specific research in mind it was sometimes difficult to analyze the responses. These problems caused the researchers to occasionally draw conclusions about question correlation based on an intuitive grasp of the survey question rather than on an entirely factual basis.

Data Analysis

As most of the questions asked are "yes"/"no" type questions, the type of statistics used to analyze the data was simple percentage of "yes" and "no" answers compared across questions. This method seemed the most descriptive way to clearly present the data collected. It is also general enough that some value can be placed on the analysis despite the limitations described above. A number of conventions were used when analyzing the data:

(1) Only "yes" and "no" answers were considered,

(2) Null responses and "not applicable" responses were usually filtered out by the assumptions made to gather only data from institutions that offered the degrees. If they were not filtered in this manner, the responses were considered as "no's".

(3) Any question with less than five responses was not analyzed as this was considered too small a group to draw conclusions from. Any one response caused a large change in statistics for that question and was deemed to not be indicative of the response group as a whole.

(4) Significant difference was set at 20% difference between responses across the demographic breakdown of private versus government institutions. This number was chosen arbitrarily to account for the small response group while at the same time being large enough to show a disparity between the two groups.

Summary

Two research methods were employed to resolve the research objective. Descriptive research was used to determine the nature and value of RMS. A mail survey was used to evaluate the attitudes and actions of engineering institutions with regard to RMS. These two techniques when used together provide further insight into the issue of reliability, maintainability, and supportability and their relationship to engineering schools.

IV. Findings and Analysis

Overview

The basis of this chapter is the findings and analysis of the survey instrument used to gather RMS information. General information about how the hypotheses are addressed is discussed in the first section. An analysis of each hypothesis is then discussed. Finally, tables and some of their implications are presented which show the relationship between a number of the hypotheses.

General Information

Hypotheses 1,2,3 and 9 include confidence estimates for the responses received. These questions were chosen due to the high response rate and are used to illustrate how confidence factors can be devepoled for each question.

All of the hypotheses are addressed in two other ways. The first is to look at the cumulative responses of the respondents. This addresses the general attitudes of the respondents as a whole. The hypotheses are then analyzed by reviewing the differences between the responses of the private and public schools. Many of the hypotheses were analyzed using a reduced pool of respondents representing those schools which actually offered the various degrees. All "yes" responses were totaled and the remaining pool was assumed to be "no" responses. The hypotheses referencing events that may occur in the future were analyzed using the entire pool of respondents.

Because of the small sample size of private schools (10), and the even smaller sample of private schools that offered specific degrees, we eliminated comparisons of private and public schools where the pool of private school respondents was less than five. In essence, comparisons of private and public schools were not conducted on aerospace and industrial engineering degrees (except where noted).

The hypotheses that discussed whether a portion of elective courses included statistics was not analyzed by comparing values of public and private schools. The question was too general to draw any reasonable inferences from. All hypothesis are addressed as a response of the sum of all respondents under the category of "General Analysis". Public school versus private school comparisons are made under the category of "Comparative Analysis". The comparative analysis takes 3 forms. If an analysis was not conducted, it is so stated. If there was less than a 20% difference between public and private schools, the statement "No significant differences between private and public schools" is printed. If there is a 20% or greater difference between the public and private school respondents, a comparison of the values is stated.

Findings and Analysis

Hypothesis 1. RMS should be included in the design process when a system or component is being designed.

General and comparative analysis: All respondents answered yes, indicating that RMS should be included in the design process. With a confidence level of 99%, 98.89% of the population would respond in a like manner.

Hypothesis 2. When RMS is designed into a product, it adds value to that product.

General and comparative analysis: All respondents answered yes, indicating RMS does add value. With a confidence level of 99%, 98.89% of the population would respond in a like manner.

Hypothesis 3. RMS should be included in a design engineer's education. With a confidence level of 99%, 98.9% of the population would respond in a like manner.

General and comparative analysis: 50 respondents answered yes, 1 respondent answered no. RMS should be included in a design engineer's education.

Hypothesis 4. Faculty should include RMS in their research and professional activities.

General Analysis: 43 answered yes, 3 answered no. RMS should be included in faculty research and professional activities.

Comparative Analysis: 77.8% of private schools answered yes, compared to 97.3% of public schools.

Hypothesis 5. Students should include RMS in their research and professional activities.

General Analysis: 42 respondents answered yes, 3 answered no. Students should include RMS in their research and professional activities.

Comparative Analysis: 77.8% of the private schools answered that students should include RMS in research and professional activities, compared to 97.1% of the public schools.

Hypothesis 6. RMS parameters should be part of the accrediting process for engineering degrees.

General Analysis: 22 respondents answered yes, 27 respondents answered no. Most schools feel RMS parameters should not be part of the accrediting process for engineering degrees.

Comparative Analysis: No significant difference between private and public schools.

Hypothesis 7. Recruiters are looking for RMS educated students.

General Analysis: 16 respondents answered recruiters never look for RMS educated students, 19 answered infrequently, 7 answered sometimes, and 2 answered frequently. Most recruiters are not looking for RMS educated students.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 8. Recruiters feel that RMS training contributes to a student's education.

General Analysis: 22 respondents answered yes, 16 answered no. Most recruiters think RMS training contributes to a student's education.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 9. RMS is included in the design curriculum. With a confidence level of 99%, 98.95% of the population would respond in a like manner.

General Analysis: 46 respondents answered yes, 5 respondents answered no. In the respondent's opinion, RMS is included in their design curricula.

Comparative Analysis: No significant differences between private and public schools.

NOTE: In order to evaluate hypotheses 10 through 29 we must determine the number of schools who offer the curricula that is referenced in each of the questions. In this way we can better evaluate comparisons between private and public schools. Since the survey did not directly ask if the respondents offered engineering degree's in the areas of aerospace, electrical, industrial, mechanical, or other, this determination had to be made through an analysis of their responses to other questions. If a respondent indicated that he did offer an elective or required course in a degree program, yes to survey questions 15-34, or that he did not offer an elective or required course in a degree program, no to survey questions 15-34, it is assumed that he does offer the degree. No response or an N/A would indicate that no degree was offered in this field. On the following page you will find a table summarizing the results:

TABLE 1

SUMMARY OF ENGINEERING DEGREES OFFERED BY RESPONDENTS

ENGINEERING DEGREES OFFERED BY RESPONDENTS

DEGREE PROGRAM	PRIVATE SCHOOLS		GOVERNMENT SCHOOLS		COMBINED TOTAL	
UNDERGRAD AEROSPACE	2 OF 10	20.0%	18 OF 41	43.9%	20 OF 51	39.2%
GRAD AEROSPACE	1 OF 10	10.0%	13 OF 41	31.7%	14 OF 51	27.5%
UNDERGRAD ELECTRICAL	7 OF 10	70.0%	33 OF 41	80.5%	40 OF 51	78.4%
GRAD ELECTRICAL	6 OF 10	60.0%	23 OF 41	56.1%	29 OF 51	56.9%
UNDERGRAD INDUSTRIAL	3 OF 10	30.0%	27 OF 41	65.9%	30 OF 51	58.8%
GRAD INDUSTRIAL	2 OF 10	20.0%	22 OF 41	53.7%	24 OF 51	47.1%
UNDERGRAD MECHANICAL	9 OF 10	90.0%	37 OF 41	90.2%	46 OF 51	90.2%
GRAD MECHANICAL	7 OF 10	70.0%	27 OF 41	65.9%	34 OF 51	66.7%
UNDERGRAD OTHER	6 OF 10	60.0%	26 OF 41	63.4%	32 OF 51	62.7%
GRAD OTHER	5 OF 10	50.0%	18 OF 41	43.9%	23 OF 51	45.1%

The comparative analysis takes 3 forms. If an analysis was not conducted, it is so stated. If there was less than a 20% difference between public and private schools, the statement "No significant differences between private and public schools" is printed. If there is a 20% or greater difference between the public and private school respondents, a comparison of the values is stated.

<u>Hypothesis 10.</u> Statistics courses are required in the aerospace undergraduate engineering curriculum.

General Analysis: 5 respondents answered yes, 15 answered no. Most schools do not require undergraduate aerospace engineers to take a statistics course.

Comparative Analysis: Not conducted.

<u>Hypothesis 11.</u> Statistics courses are an elective in the aerospace undergraduate engineering curriculum.

General Analysis: 10 respondents answered yes, 10 answered no. Half of the schools offer a statistics elective to undergraduate aerospace engineers.

Comparative Analysis: Not conducted.

<u>Hypothesis 12.</u> Statistics courses are required in the aerospace graduate engineering curriculum.

General Analysis: 2 respondents answered yes, 12 answered no. Most schools do not require graduate aerospace engineers to take a statistics course.

Comparative Analysis: Not conducted.

<u>Hypothesis 13.</u> Statistics courses are an elective in the aerospace graduate engineering curriculum.

General Analysis: 10 respondents answered yes, 4 answered no. Most schools offer a statistics elective to graduate aerospace engineers.

Comparative Analysis: Not conducted.

Hypothesis 14. Statistics courses are required in the electrical undergraduate engineering curriculum.

General Analysis: 14 respondents answered yes, 26 answered no. Most schools do not require undergraduate electrical engineers to take a statistics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 15. Statistics courses are an elective in the electrical undergraduate engineering curriculum.

General Analysis: 17 respondents answered yes, 23 answered no. Most schools do not offer a statistics elective to undergraduate electrical engineers.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 16. Statistics courses are required in the electrical graduate engineering curriculum.

General Analysis: 3 respondents answered yes, 26 answered no. Most schools do not require graduate electrical engineers to take a statistics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 17. Statistics courses are an elective in the electrical graduate engineering curriculum.

General Analysis: 20 respondents answered yes, 9 answered no. Most schools offer a statistics elective to graduate electrical engineers.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 18. Statistics courses are required in the industrial undergraduate engineering curriculum.

General Analysis: 26 respondents answered yes, 4 answered no. Most schools require undergraduate industrial engineers to take a statistics course.

Comparative Analysis: Not conducted.

Hypothesis 19. Statistics courses are an elective in the industrial undergraduate engineering curriculum.

General Analysis: 7 respondents answered yes, 23 answered no. Most schools do not offer a statistics elective to undergraduate industrial engineers.

Comparative Analysis: Not conducted.

Hypothesis 20. Statistics courses are required in the industrial graduate engineering curriculum.

General Analysis: 16 respondents answered yes, 8 answered no. Most schools require graduate industrial engineers to take a statistics course.

Comparative Analysis: Not conducted.

Hypothesis 21. Statistics courses are an elective in the industrial graduate engineering curriculum.

General Analysis: 9 respondents answered yes, 15 answered no. Most schools do not offer a statistics elective to graduate industrial engineers.

Comparative Analysis: Not conducted.

Hypothesis 22. Statistics courses are required in the mechanical undergraduate engineering curriculum.

General Analysis: 18 respondents answered yes, 28 answered no. Most schools do not require undergraduate mechanical engineers to take a statistics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 23. Statistics courses are an elective in the mechanical undergraduate engineering curriculum.

General Analysis: 22 respondents answered yes, 24 answered no. Most schools do not offer a statistics elective to undergraduate mechanical engineers.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 24. Statistics courses are required in the mechanical graduate engineering curriculum.

General Analysis: 4 respondents answered yes, 30 answered no. Most schools do not require graduate mechanical engineers to take a statistics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 25. Statistics courses are an elective in the mechanical graduate engineering curriculum.

General Analysis: 25 respondents answered yes, 9 answered no. Most schools offer a statistics elective to graduate mechanical engineers.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 26. Statistics courses are required in other undergraduate engineering curriculum.

General Analysis: 18 respondents answered yes, 14 answered no. Most schools require other undergraduate engineers to take a statistics course.

Comparative Analysis: While only 33% of the private schools required that other undergraduate engineering students take statistics, 62% of the public schools required it.

Hypothesis 27. Statistics courses are an elective in other undergraduate engineering curriculum.

General Analysis: 12 respondents answered yes, 20 answered no. Most schools do not offer a statistics elective to other undergraduate engineers.

Comparative Analysis: While 67% of the private schools offered statistics as an elective to their other undergraduate engineering students, only 31% of the public schools offered it as an elective.

Hypothesis 28. Statistics courses are required in other graduate engineering curriculum.

General Analysis: 5 respondents answered yes, 18 answered no. Most schools do not require other graduate engineers to take a statistics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 29. Statistics courses are an elective in other graduate engineering curriculum.

General Analysis: 17 respondents answered yes, 6 answered no. Most schools offer a statistics elective to other graduate engineers.

Comparative Analysis: While 100% of the private schools offered statistics as an elective to their other undergraduate engineering students, only 67% of the public schools offered it as an elective.

NOTE: Unlike hypotheses 10-29 and 50-89 which determine the present course offerings of engineering institutions, hypotheses 30-49 try to assess the future of institution's course offerings. Because an institution may plan on developing a degree program where they do not have one now, we could not limit the respondent pool to those who only currently offer the degree. As a result, the general analysis of the questions reflect the number of "yes" responses and "no" responses from the entire respondent base. The comparative analysis looks at the institutions who do not presently offer a particular course in a degree program and then looks to see if those same institutions are forecasting offering it in the future. If the percentage of the responses were within 20% of the general analysis and the differences between private and public schools were within 20% of each other then under the category of "Comparative Analysis", the statement "No significant difference between private and public schools" is printed. If any of these conditions does not exist, an explanation of the difference is discussed.

Hypothesis 30. There are plans to include a required statistics course in undergraduate aerospace engineering curricula.

General Analysis: 5 respondents answered yes, 9 respondents answered no. Most schools will not add statistics as a required course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 31. There are plans to include an elective statistics course in undergraduate aerospace engineering curricula.

General Analysis: 8 respondents answered yes, 5 answered no. Most schools will add statistics as an elective.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 32. There are plans to include a required statistics course in graduate aerospace engineering curricula.

General Analysis: 6 respondents answered yes, 9 answered no. Most schools will not add statistics as a required course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 33. There are plans to include an elective statistics course in graduate aerospace engineering curricula.

General Analysis: 8 respondents answered yes, 5 answered no. Most schools will add statistics as an elective.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 34. There are plans to include a required statistics course in undergraduate electrical engineering curricula.

General Analysis: 3 respondents answered yes, 16 answered no. Most schools will not add statistics as a required course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 35. There are plans to include an elective statistics course in undergraduate electrical engineering curricula.

General Analysis: 10 respondents answered yes, 12 answered no. Most schools will not add statistics as an elective.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 36. There are plans to include a required statistics course in graduate electrical engineering curricula.

General Analysis: 7 respondents answered yes, 17 answered no. Most schools will not add statistics as a required course.

Comparative Analysis: Given that the school does not offer the course now, no private schools answered they were going to offer statistics, while only 14.3% of public schools answered they would. Schools not offering statistics as a required course will not offer it in the future.

Hypothesis 37. There are plans to include an elective statistics course in graduate electrical engineering curricula.

General Analysis: 12 respondents answered yes, 11 answered no. Most schools will add statistics as an elective.

Comparative Analysis: Given the school does not offer the course now, no private schools will add an elective statistics course, while only 25% of public schools answered they would. Statistics as an elective will not be added to the curriculum in schools who do not already offer the course.

Hypothesis 38. There are plans to include a required statistics course in undergraduate industrial engineering curricula.

General Analysis: 15 respondents answered yes, only 3 answered no. Most schools will add a required statistics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 39. There are plans to include an elective statistics course in undergraduate industrial engineering curricula.

General Analysis: 4 respondents answered yes and 4 respondents answered no. It is equally likely that schools will add statistics as an elective as not.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 40. There are plans to include a required statistics course in graduate industrial engineering curricula.

General Analysis: 12 respondents answered yes, 6 answered no. Most schools will add statistics as a required course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 41. There are plans to include an elective statistics course in graduate industrial engineering curricula.

General Analysis: 6 respondents answered yes, 4 answered no. Most schools will add statistics as an elective.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 42. There are plans to include a required statistics course in undergraduate mechanical engineering curricula.

General Analysis: 10 respondents answered yes, 14 answered no. Most schools will not offer statistics as a required course.

Comparative Analysis: Given the school does not offer the course now, 40% of private schools answered they would offer the course in the future, while only 7.14% of public schools answered they would offer the course. Private schools are more likely to offer the course than public schools.

Hypothesis 43. There are plans to include an elective statistics course in undergraduate mechanical engineering curricula.

General Analysis: 12 respondents answered yes, 14 answered no. Most schools will not add statistics as an elective in the future.

Comparative Analysis: Given that the school does not offer the course now, 100% of private schools will offer the course in the future, compared to only 28.6% of public schools. Private schools are more likely to offer the course in the future than public schools.

Hypothesis 44. There are plans to include a required statistics course in graduate mechanical engineering curricula.

General Analysis: 10 respondents answered yes, 17 answered no. Most schools will not require statistics in graduate mechanical engineering curricula.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 45. There are plans to include an elective statistics course in graduate mechanical engineering curricula.

General Analysis: 13 respondents answered yes, 12 respondents answered no. Most schools will add statistics as an elective in the future.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 46. There are plans to include a required statistics course in undergraduate other engineering curricula.

General Analysis: 12 respondents answered yes, 9 answered no. Most schools will not offer statistics as a required course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 47. There are plans to include an elective statistics course in undergraduate other engineering curricula.

General Analysis: 5 respondents answered yes, 11 answered no. Most schools will not offer statistics as an elective course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 48. There are plans to include a required statistics course in graduate other engineering curricula.

General Analysis: 7 respondents answered yes, 12 answered no. Most schools will not offer statistics as a required course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 49. There are plans to include an elective statistics course in graduate other engineering curricula.

General Analysis: 7 respondents answered yes, 10 answered no. Most schools will not offer statistics as an elective.

Comparative Analysis: No significant differences between private and public schools.

NOTE: In order to evaluate hypotheses 50 through 89 we must determine the number of schools who offer the curricula that is referenced in each of the questions. In this way we can better evaluate comparisons between private and public schools. Since the survey did not directly ask if the respondents offered engineering degree's in the areas of aerospace, electrical, industrial, mechanical, or other, this determination had to be made through an analysis of their responses to other questions. If a respondent indicated that he did offer an elective or required course in a degree program, yes to survey questions 15-34, or that he did not offer an elective or required course in a degree program, no to survey questions 15-34, it is assumed that he does offer the degree. No response or an N/A would indicate that no degree was offered in this field. The comparative analysis takes 3 forms. If an analysis was not conducted, it is so stated. If there was less than a 20% difference between public and private schools, the statement "No significant differences between private and public schools" is printed. If there is a 20% or greater difference between the public and private school respondents, a comparison of the values is stated.

Hypothesis 50. Statistics is a portion of required aerospace engineering design undergraduate courses.

General Analysis: 10 respondents answered yes, 10 answered no. Half of the schools include statistics as part of their required undergraduate aerospace engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 51. Statistics is a portion of elective aerospace engineering design undergraduate courses.

General Analysis: 8 respondents answered yes, 12 answered no. Most schools do not include statistics as part of their elective undergraduate aerospace engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 52. Statistics is a portion of required aerospace engineering design graduate courses.

General Analysis: 8 respondents answered yes, 6 answered no. Most schools include statistics as part of their required graduate aerospace engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 53. Statistics is a portion of elective aerospace engineering design graduate courses.

General Analysis: 8 respondents answered yes, 6 answered no. Most schools include statistics as part of their elective graduate aerospace engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 54. Statistics is a portion of required electrical engineering design undergraduate courses.

General Analysis: 23 respondents answered yes, 17 answered no. Most schools include statistics as part of their required undergraduate electrical engineering design courses.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 55. Statistics is a portion of elective electrical engineering design undergraduate courses.

General Analysis: 13 respondents answered yes, 27 answered no. Most schools do not include statistics as part of their elective undergraduate electrical engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 56. Statistics is a portion of required electrical engineering design graduate courses.

General Analysis: 13 respondents answered yes, 12 answered no. Most schools include statistics as part of their required graduate electrical engineering design courses.

Comparative Analysis: While only 17% of the private schools included statistics as a portion of their required graduate electrical engineering design courses, 52% of the public schools included it.

Hypothesis 57. Statistics is a portion of elective electrical engineering design graduate courses.

General Analysis: 17 respondents answered yes, 12 answered no. Most schools include statistics as part of their elective graduate electrical engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 58. Statistics is a portion of required industrial engineering design undergraduate courses.

General Analysis: 24 respondents answered yes, 6 answered no. Most schools include statistics as part of their required undergraduate industrial engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 59. Statistics is a portion of elective industrial engineering design undergraduate courses.

General Analysis: 6 respondents answered yes, 24 answered no. Most do not schools include statistics as part of their elective undergraduate industrial engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 60. Statistics is a portion of required industrial engineering design graduate courses.

General Analysis: 18 respondents answered yes, 6 answered no. Most schools include statistics as part of their required graduate industrial engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 61. Statistics is a portion of elective industrial engineering design graduate courses.

General Analysis: 7 respondents answered yes, 17 answered no. Most schools do not include statistics as part of their elective graduate industrial engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 62. Statistics is a portion of required mechanical engineering design undergraduate courses.

General Analysis: 25 respondents answered yes, 21 answered no. Most schools include statistics as part of their required undergraduate mechanical engineering design courses.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 63. Statistics is a portion of elective mechanical engineering design undergraduate courses.

General Analysis: 15 respondents answered yes, 31 answered no. Most schools do not include statistics as part of their elective undergraduate mechanical engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 64. Statistics is a portion of required mechanical engineering design graduate courses.

General Analysis: 15 respondents answered yes, 19 answered no. Most schools do not include statistics as part of their required graduate mechanical engineering design courses.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 65. Statistics is a portion of elective mechanical engineering design graduate courses.

General Analysis: 19 respondents answered yes, 15 answered no. Most schools include statistics as part of their elective graduate mechanical engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 66. Statistics is a portion of required other engineering design undergraduate courses.

General Analysis: 18 respondents answered yes, 14 answered no. Most schools include statistics as part of their required undergraduate other engineering design courses.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 67. Statistics is a portion of elective other engineering design undergraduate courses.

General Analysis: 10 respondents answered yes, 22 answered no. Most schools do not include statistics as part of their elective undergraduate other engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 68. Statistics is a portion of required other engineering design graduate courses.

General Analysis: 13 respondents answered yes, 10 answered no. Most schools include statistics as part of their required graduate other engineering design courses.

Comparative Analysis: While only 20% of the private schools included statistics as a portion of their required graduate other engineering design courses, 67% of the public schools included it.

Hypothesis 69. Statistics is a portion of elective other engineering design graduate courses.

General Analysis: 12 respondents answered yes, 11 answered no. Most schools include statistics as part of their elective graduate other engineering design courses.

Comparative Analysis: Not conducted.

Hypothesis 70. Engineering economics is required in the aerospace undergraduate engineering curriculum.

General Analysis: 10 respondents answered yes, 10 answered no. Half of the schools require undergraduate aerospace engineers to take an engineering economics course.

Comparative Analysis: Not conducted.

Hypothesis 71. Engineering economics is an elective in the aerospace undergraduate engineering curriculum.

General Analysis: 10 respondents answered yes, 10 answered no. Half of the schools offer engineering economics as an elective for their undergraduate aerospace engineering degrees.

Comparative Analysis: Not conducted.

Hypothesis 72. Engineering economics is required in the aerospace graduate engineering curriculum.

General Analysis: 1 respondent answered yes, 13 answered no. Most schools do not require graduate aerospace engineers to take an engineering economics course.

Comparative Analysis: Not conducted.

Hypothesis 73. Engineering economics is an elective in the aerospace graduate engineering curriculum.

General Analysis: 10 respondents answered yes, 4 answered no. Most schools offer engineering economics as an elective for their graduate aerospace engineering degrees.

Comparative Analysis: Not conducted.

Hypothesis 74. Engineering economics is required in the electrical undergraduate engineering curriculum.

General Analysis: 20 respondents answered yes, 20 answered no. Half of the schools require undergraduate electrical engineers to take an engineering economics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 75. Engineering economics is an elective in the electrical undergraduate engineering curriculum.

General Analysis: 20 respondents answered yes, 20 answered no. Half of the schools offer engineering economics as an elective for their undergraduate electrical engineering degrees.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 76. Engineering economics is required in the electrical graduate engineering curriculum.

General Analysis: 3 respondents answered yes, 26 answered no. Most schools do not require graduate electrical engineers to take an engineering economics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 77. Engineering economics is an elective in the electrical graduate engineering curriculum.

General Analysis: 15 respondents answered yes, 8 answered no. Most schools offer engineering economics as an elective for their graduate electrical engineering degrees.

Comparative Analysis: While only 33% of the private schools offered engineering economics as an elective for their electrical graduate degree, 57% of the public schools offered it.

Hypothesis 78. Engineering economics is required in the industrial undergraduate engineering curriculum.

General Analysis: 27 respondents answered yes, 3 answered no. Most schools require undergraduate industrial engineers to take an engineering economics course.

Comparative Analysis: Not conducted.

Hypothesis 79. Engineering economics is an elective in the industrial undergraduate engineering curriculum.

General Analysis: 5 respondents answered yes, 25 answered no. Most schools do not offer engineering economics as an elective for their undergraduate industrial engineering degrees.

Comparative Analysis: Not conducted.

Hypothesis 80. Engineering economics is required in the industrial graduate engineering curriculum.

General Analysis: 8 respondents answered yes, 16 answered no. Most schools do not require graduate industrial engineers to take an engineering economics course.

Comparative Analysis: Not conducted.

Hypothesis 81. Engineering economics is an elective in the industrial graduate engineering curriculum.

General Analysis: 12 respondents answered yes, 12 answered no. Half of the schools offer engineering economics as an elective for their graduate industrial engineering degrees.

Comparative Analysis: Not conducted.

Hypothesis 82. Engineering economics is required in the mechanical undergraduate engineering curriculum.

General Analysis: 27 respondents answered yes, 19 answered no. Most schools require undergraduate mechanical engineers to take an engineering economics course.

Comparative Analysis: While only 22% of the private schools required engineering economics for their mechanical undergraduate degree, 68% of the public schools required it. Public schools are more likely to require engineering economics in their undergraduate mechanical engineering degrees.

Hypothesis 83. Engineering economics is an elective in the mechanical undergraduate engineering curriculum.

General Analysis: 18 respondents answered yes, 28 answered no. Most schools do not offer engineering economics as an elective for their undergraduate mechanical engineering degrees.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 84. Engineering economics is required in the mechanical graduate engineering curriculum.

General Analysis: 3 respondents answered yes, 31 answered no. Most schools do not require graduate mechanical engineers to take an engineering economics course.

Comparative Analysis: While none of the private schools required engineering economics for their mechanical graduate degree, 30% of the public schools required it.

Hypothesis 85. Engineering economics is an elective in the mechanical graduate engineering curriculum.

General Analysis: 18 respondents answered yes, 16 answered no. Most schools offer engineering economics as an elective for their graduate mechanical engineering degrees.

Comparative Analysis: While only 14% of the private schools offered engineering economics as an elective for their mechanical graduate degree, 41% of the public schools offered it.

Hypothesis 86. Engineering economics is required in the other undergraduate engineering curriculum.

General Analysis: 19 respondents answered yes, 13 answered no. Most schools require undergraduate other engineers to take an engineering economics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 87. Engineering economics is an elective in the other undergraduate engineering curriculum.

General Analysis: 11 respondents answered yes, 21 answered no. Most schools do not offer engineering economics as an elective for their undergraduate other engineering degrees.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 88. Engineering economics is required in the other graduate engineering curriculum.

General Analysis: 4 respondents answered yes, 19 answered no. Most schools do not require graduate other engineers to take an engineering economics course.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 89. Engineering economics is an elective in the other graduate engineering curriculum.

General Analysis: 10 respondents answered yes, 13 answered no. Most schools offer engineering economics as an elective for their graduate other engineering degrees.

Comparative Analysis: While only 40% of the private schools offered engineering economics as an elective for their other graduate degree, 89% of the public schools offered it.

NOTE: Unlike hypotheses 10-29 and 50-89 which determine the present course offerings of engineering institutions, hypotheses 90-109 try to assess the future of institution's course offerings. Because an institution may plan on developing a degree program where they do not have one now, we could not limit the respondent pool to those who only currently offer the degree. As a result, the general analysis of the questions reflect the number of "yes" responses and "no" responses from the entire respondent base. The comparative analysis looks at the institutions who do not presently offer a particular course in a degree program and then looks to see if those same institutions are forecasting offering it in the future. If the percentage of the responses were within 20% of the general analysis and the differences between private and public schools were within 20% of each other then under the category of "Comparative Analysis", the statement "No significant difference between private and public schools" is printed. If any of these conditions does not exist, an explanation of the difference is discussed.

<u>Hypothesis 90.</u> There are plans to include engineering economics as a requirement in aerospace undergraduate engineering curricula.

General Analysis: 5 respondents answered yes, 10 answered no. Most schools will not add engineering economic as a required course.

Comparative Analysis: Given that the school does not offer the course now, none of the private or public schools said they would add the course.

<u>Hypothesis 91.</u> There are plans to include engineering economics as an elective in aerospace undergraduate engineering curricula.

General Analysis: 10 respondents answered yes, 2 answered no. Most schools will add engineering economics as an elective.

Comparative Analysis: Given that the school does not offer the course now, none of the private or public schools said they would add the course.

Hypothesis 92. There are plans to include engineering economics as a requirement in aerospace graduate engineering curricula.

General Analysis: 3 respondents answered yes, 9 answered no. Most schools will not add engineering economics as a required course in their graduate aerospace engineering curricula.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while 28.6% of public schools will add the course. Public schools are more likely to add the course than private schools..

Hypothesis 93. There are plans to include engineering economics as an elective in aerospace graduate engineering curricula.

General Analysis: 11 respondents answered yes, 3 answered no. Most schools will add the course in the future.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while one of two public schools will add the course.

Hypothesis 94. There are plans to include engineering economics as a requirement in electrical undergraduate engineering curricula.

General Analysis: While 11 respondents answered yes, 17 answered no. Most schools will not add engineering economic as a required course.

Comparative Analysis: Given that the school does not offer the course now, none of the private or public schools said they would add the course.

<u>Hypothesis 95.</u> There are plans to include engineering economics as an elective in electrical undergraduate engineering curricula.

General Analysis: 16 respondents answered yes, 5 answered no. Most schools will add engineering economics as an elective.

Comparative Analysis: Given that the school does not offer the course presently, none of the private or public schools said they would add the course.

<u>Hypothesis 96.</u> There are plans to include engineering economics as a requirement in electrical graduate engineering curricula.

General Analysis: 4 respondents answered yes, 16 answered no. Most schools will not add engineering economics as a required course.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while only one out of fifteen public schools said they would add the course. Schools will more than likely not add the course.

Hypothesis 97. There are plans to include engineering economics as an elective in electrical graduate engineering curricula.

General Analysis: 13 respondents answered yes, 9 answered no. Most schools will add the course in the future.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while only one out of five public schools will add the course. Schools will most likely not add the course.

Hypothesis 98. There are plans to include engineering economics as a requirement in industrial undergraduate engineering curricula.

General Analysis: 17 respondents answered yes, 3 answered no. Most schools will add the course.

Comparative Analysis: Given that the schools do not offer the course now, none of the private or public schools said they would add the course.

Hypothesis 99. There are plans to include engineering economics as an elective in industrial undergraduate engineering curricula.

General Analysis: 5 respondents answered yes, 4 answered no. Most schools will add engineering economics in the future.

Comparative Analysis: Given that the schools do not offer the course now, none of the private or public schools will add the course.

Hypothesis 100. There are plans to include engineering economics as a requirement in industrial graduate engineering curricula.

General Analysis: 8 respondents answered yes, 8 respondents answered no. It is equally likely that a school will add the course as not.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while only two out of seven public schools will add the course.

Hypothesis 101. There are plans to include engineering economics as an elective in industrial graduate engineering curricula.

General Analysis: 9 respondents answered yes, 3 answered no. Most schools will add the course.

Comparative Analysis: Given that the school does not offer the course now, no private or public school will add the course.

Hypothesis 102. There are plans to include engineering economics as a requirement in mechanical undergraduate engineering curricula.

General Analysis: 14 respondents answered yes, 14 respondents answered no. It is equally likely that a school will add the course as not.

Comparative Analysis: Given that the school does not offer the course now, no private or public schools will add the course.

Hypothesis 103. There are plans to include engineering economics as an elective in mechanical undergraduate engineering curricula.

General Analysis: 12 respondents answered yes, 11 answered no. Most schools will add the course in the future.

Comparative Analysis: Given that the school does not offer the course now, no private or public schools will offer the course in the future.

Hypothesis 104. There are plans to include engineering economics as a requirement in mechanical graduate engineering curricula.

General Analysis: 4 respondents answered yes, 17 answered no. Most schools will not add the course in the future.

Comparative Analysis: Given that the schools does not offer the course now, no private school will add the course, while only one out of sixteen public schools will add the course.

Hypothesis 105. There are plans to include engineering economics as an elective in mechanical graduate engineering curricula.

General Analysis: 14 respondents answered yes, 11 answered no. Most schools will add the course in the future.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while only one out of six public schools will add the course.

Hypothesis 106. There are plans to include engineering economics as a requirement in other undergraduate engineering curricula.

General Analysis: 12 respondents answered yes, 10 answered no. Most schools will add the course.

Comparative Analysis: Given that the school does not offer the course now, no private or public schools said they would add the course.

Hypothesis 107. There are plans to include engineering economics as an elective in other undergraduate engineering curricula.

General Analysis: 10 respondents answered yes, 7 answered no. Most schools will add the course.

Comparative Analysis: Given that the school does not offer the course now, no private or public schools will add the course in the future.

Hypothesis 108. There are plans to include engineering economics as a requirement in other graduate engineering curricula.

General Analysis: 4 respondents answered yes, 13 answered no. Most schools will not add the course in the future.

Comparative Analysis: Given that the school does not offer the course now, no private schools will add the course, while only one out of eleven public schools will add the course.

Hypothesis 109. There are plans to include engineering economics as an elective in other graduate engineering curricula.

General Analysis: 12 respondents answered yes, 8 answered no. Most schools will add the course in the future.

Comparative Analysis: Given that the school does not offer the course now, no private or public schools will add the course in the future.

Hypothesis 110. Undergraduate engineering economics courses include aspects of reliability that pertain to life cycle engineering.

General Analysis: 12 respondents answered yes, 31 answered no. Most schools do not include reliability in engineering economics.

Comparative Analysis: Private schools included reliability 11.1% of the time, while public schools included it 33.3% of time. Public schools are more likely to include reliability.

Hypothesis 111. Graduate engineering economics courses include aspects of reliability that pertain to life cycle engineering.

General Analysis: 12 respondents answered yes, 18 answered no. Schools more than likely do not include reliability.

Comparative Analysis: No significant difference between private and public schools.

Hypothesis 112. Undergraduate engineering economics courses include aspects of maintainability that pertain to life cycle engineering.

General Analysis: 14 respondents answered yes, 29 answered no. Most schools do not include maintainability.

Comparative Analysis: Private schools include maintainability 11.1% of the time, while public schools include it 39.4% of time. Public schools are more likely to include maintainability.

Hypothesis 113. Graduate engineering economics courses include aspects of maintainability that pertain to life cycle engineering.

General Analysis: 10 respondents answered yes, 19 answered no. Most schools do not include maintainability.

Comparative Analysis: No private schools included maintainability, while 32.3% of the public schools included it. Public schools are much more likely to include maintainability.

Hypothesis 114. Undergraduate engineering economics courses include aspects of supportability that pertain to life cycle engineering.

General Analysis: 13 respondents answered yes, 31 answered no. Most schools do not include supportability.

Comparative Analysis: 11.1% of the private schools included supportability, while 38.7% of the public schools included it. Public schools are more likely to include supportability.

Hypothesis 115. Graduate engineering economics courses include aspects of supportability that pertain to life cycle engineering.

General Analysis: 11 respondents answered yes, 19 answered no. Most schools do not include supportability.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 116. Plans for the next five years include formal credit courses in undergraduate reliability.

General Analysis: 12 respondents answered yes, 24 answered no. Most schools will not offer courses in reliability.

Comparative Analysis: Only 10% of private schools will offer these courses, while 26.8% of public schools will offer these courses.

Hypothesis 117. Plans for the next five years include formal credit courses in graduate reliability.

General Analysis: 17 respondents answered yes, 15 answered no. Most schools will add courses in graduate reliability.

Comparative Analysis: 20% of private schools will offer these courses, while 36.6% of public schools will offer these courses.

Hypothesis 118. Plans for the next five years include formal credit courses in undergraduate maintainability.

General Analysis: 7 respondents answered yes, 28 answered no. Most schools will not offer courses in maintainability.

Comparative Analysis: 20% of private schools will offer these courses, while 12.2% of public schools will offer these courses.

Hypothesis 119. Plans for the next five years include formal credit courses in graduate maintainability.

General Analysis: 9 respondents answered yes, 21 answered no. Most schools will not offer courses in maintainability.

Comparative Analysis: 10% of private schools will offer these courses, while 19.5% of public will offer these courses.

Hypothesis 120. Plans for the next five years include formal credit courses in undergraduate supportability.

General Analysis: 7 respondents answered yes, 28 answered no. Most schools will not offer courses in supportability.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 121. Plans for the next five years include formal credit courses in graduate supportability.

General Analysis: 10 respondents answered yes, 21 answered no. Most schools will not offer courses in supportability.

Comparative Analysis: 10% of private schools will offer these courses, while 22% of public schools will offer these courses.

Hypothesis 122. Plans for the next five years include incorporating RMS in other undergraduate design courses in aerospace engineering curricula.

General Analysis: 7 respondents answered yes, 12 answered no. Most schools will not incorporate RMS into other undergraduate aerospace design courses.

Comparative Analysis: None of the private schools incorporate RMS, while 43.8% of public schools will incorporate RMS. Public schools are much more likely to incorporate RMS.

Hypothesis 123. Plans for the next five years include incorporating RMS in other graduate design courses in aerospace engineering curricula.

General Analysis: 6 respondents answered yes, 9 answered no. Most schools will not incorporate RMS into other graduate aerospace design courses.

Comparative Analysis: None of the private schools will incorporate RMS while 46.2% of public schools will incorporate RMS. Public schools are much more likely to incorporate RMS.

Hypothesis 124. Plans for the next five years include incorporating RMS in other undergraduate design courses in electrical engineering curricula.

General Analysis: 13 respondents answered yes, 20 respondents answered no. Most schools will not incorporate RMS into other undergraduate electrical design courses.

Comparative Analysis: 16.6% of private schools will incorporate RMS, while 42.3% of public schools will incorporate RMS. Public schools are more likely to incorporate RMS.

Hypothesis 125. Plans for the next five years include incorporating RMS in other graduate design courses in electrical engineering curricula.

General Analysis: 8 respondents answered yes, 15 answered no. Most schools will not incorporate RMS into other graduate electrical design courses.

Comparative Analysis: None of the private schools will incorporate RMS, while 44.4% of public schools will incorporate RMS. Public schools are much more likely to incorporate RMS.

Hypothesis 126. Plans for the next five years include incorporating RMS in other undergraduate design courses in industrial engineering curricula.

General Analysis: 9 respondents answered yes, 11 answered no. Most schools will not incorporate RMS into other undergraduate industrial design courses within the next five years.

Comparative Analysis: None of the private schools will incorporate RMS, while 50% of the public schools will incorporate RMS. Public schools are much more likely to incorporate RMS into other undergraduate industrial design courses within five years.

Hypothesis 127. Plans for the next five years include incorporating RMS in other graduate design courses in industrial engineering curricula.

General Analysis: 7 respondents answered yes, 6 answered no. Most schools will incorporate RMS into other graduate industrial design courses.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 128. Plans for the next five years include incorporating RMS in other undergraduate design courses in mechanical engineering curricula.

General Analysis: 13 respondents answered yes, 24 answered no. Most schools will not incorporate RMS into other undergraduate mechanical design courses.

Comparative Analysis: No significant differences between private and public schools.

Hypothesis 129. Plans for the next five years include incorporating RMS in other graduate design courses in mechanical curricula.

General Analysis: 8 respondents answered yes, 17 answered no. Most schools will not incorporate RMS into other graduate mechanical courses.

Comparative Analysis: No significant difference between private and public schools.

Hypothesis 130. Plans for the next five years include incorporating RMS in other undergraduate design courses in other engineering curricula.

General Analysis: 11 respondents answered yes, 14 answered no. Most schools will not incorporate RMS into other undergraduate design courses.

Comparative Analysis: No significant difference between private and public schools.

Hypothesis 131. Plans for the next five years include incorporating RMS in other graduate design courses in other engineering curricula.

General Analysis: 6 respondents answered yes, 12 answered no. Most schools will not incorporate RMS into other graduate design courses.

Comparative Analysis: No significant difference between private and public schools.

Hypothesis 132. Faculty participates in RMS research or scholarly RMS-related activities.

General Analysis: 29 respondents answered yes, 17 answered no. Most faculty participate in RMS research or scholarly-related activities

Comparative Analysis: While 33.3% of private school faculty participate in RMS research or scholarly activities, 69.4% of public school faculty participate in the same activity. Public school faculty is much more likely to participate in RMS research or scholarly RMS-related activities than their counterparts in private institutions.

Hypothesis 133. Students participate in RMS research or scholarly RMS-related activities.

General Analysis: 21 respondents answered yes, 23 answered no. Most students do not participate in RMS research or scholarly RMS-related activities.

Comparative Analysis: 22.2% of private school students participate in RMS research or scholarly activities, while 54.3% of public school students participate in the same or similar activities. Public school students are much more likely to perform RMS research or scholarly-related activities than are students in private institutions..

NOTE: For hypotheses 134-145, not enough schools offered the degrees to justify separate analyses. Therefore, one response will be given for these hypotheses.

Hypothesis 134. An undergraduate degree is offered in reliability.

Hypothesis 135. A graduate degree is offered in reliability.

Hypothesis 136. An undergraduate degree is offered in maintainability.

Hypothesis 137. A graduate degree is offered in maintainability.

Hypothesis 138. An undergraduate degree is offered in supportability.

Hypothesis 139. A graduate degree is offered in supportability.

Hypothesis 140. Plans for the next five years include offering an undergraduate degree in reliability.

Hypothesis 141. Plans for the next five years include offering a graduate degree in reliability.

Hypothesis 142. Plans for the next five years include offering an undergraduate degree in maintainability.

Hypothesis 143. Plans for the next five years include offering a graduate degree in maintainability.

Hypothesis 144. Plans for the next five years include offering an undergraduate degree in supportability.

Hypothesis 145. Plans for the next five years include offering a graduate degree in supportability.

No private schools offer the degrees now or are planning to offer the degrees in the future. One public school offers degrees in graduate reliability and graduate maintainability, and will continue to do so for at least the next five years. Another public school offers degrees in graduate reliability and supportability, and will continue to offer these degrees as well as offer a degree in graduate maintainability. Lastly, one public school offers none of the degrees presently, but will offer undergraduate and graduate degrees in reliability.

Hypothesis 146. Faculty and students develop or participate in RMS short courses.

General Analysis: 20 respondents answered yes, 27 answered no. Most faculty and students do not develop or participate in RMS short courses.

Comparative Analysis: Only 10% of private schools said that faculty and students developed or participated in RMS short courses, while 46.3% of public schools said yes. Public school faculty and students are more likely to participate in RMS short courses.

Hypothesis 147. More than 50% of the engineering faculty with RMS education are capable of teaching RMS.

General Analysis: 40 respondents answered less than 25 percent were capable of teaching RMS, 8 answered less than 50 percent were capable of teaching RMS, and one answered less than 75 percent were capable of teaching RMS. Most schools have less than 25 percent of their faculty capable of teaching RMS.

Comparative Analysis: All private schools answered that less than 25 percent of their faculty is capable of teaching RMS. 76.3% of the public schools answered less than 25 percent of their faculty is capable of teaching RMS, 21.1% answered less than 50 percent are capable of teaching RMS, and 2.6% answered less than 75 percent are capable of teaching RMS. Public institutions s are more likely to have faculty capable of teaching RMS than private institutions.

Hypothesis 148. More than 50% of previous graduates work within the general area of RMS.

General Analysis: 38 respondents answered less than 25 percent were working in the general area of RMS, 2 answered less than 50, percent, one answered less than 75 percent, and one answered less than 100 percent. Most respondents indicate that less than 25 percent of previous graduates work in the general area of RMS.

Comparative Analysis: No significant difference between public and private schools.

V. Conclusions and Recommendations

Overview

This chapter completes this research project by drawing conclusions from the answers to the hypotheses in chapter 4. First, conclusions will be drawn about academia's opinion of RMS education, followed by conclusions about the current state of RMS education. Future study and research of the issues relating to RMS education are then suggested and finally, overall conclusions for the research are summarized.

Academia's Perceptions of the Value of RMS

Hypotheses 1-3 show conclusively that the academic community believes that RMS is an integral part of the design process. All respondents believe RMS should be included in the design process and that RMS adds value to a product when designed into the product. This belief is reinforced by the fact that all but one respondent said RMS should be included in a design engineer's education.

This strong opinion of the value of RMS education is strengthened by hypotheses 4 and 5. Of those respondents who answered, all but three believe faculty and students should include RMS in their research and professional activities. This strong support of the value of RMS would lead you to speculate that RMS education is a vital part of engineering curricula. This is supported by the responses to hypothesis 9 which indicates that virtually all schools say they include RMS in their respective curricula. The question is, when RMS is broken down into its elements of statistical analysis, and engineering economics, which are the two most common mechanisms for teaching these principles, do the schools provide RMS education or is RMS given lip service?

Current State of RMS Education

Given the assumption that statistics and engineering economics are an integral part of RMS education, do schools include these critical aspects of RMS in their curricula? With few exceptions, the answer is no.

Hypotheses 10-29 clearly show that the majority of schools do not require statistics. In fact, in only three of ten cases do the majority of schools require statistics: undergraduate and graduate industrial engineering and other undergraduate engineering. Schools tend to relegate statistics to an elective role in the graduate degree programs. It is probable that aerospace, electrical, and mechanical engineering students either undergraduate or graduate could complete their degrees without ever being exposed to a statistics course.

Change requires time; America's realization that quality which equates to RMS in the design of products can no longer be ignored. Realizing this, are schools who don't offer statistics now going to offer statistics within the next five years? With only seven exceptions, the answer is again no. Those exceptions where schools will add a required statistics course are in undergraduate and graduate industrial engineering curricula. In addition, most schools will add statistics as an elective in undergraduate aerospace engineering and graduate aerospace, electrical, industrial, and mechanical curricula.

Closer examination of these results points out some interesting trends. First, most schools do not seem to think that a course in statistics is an integral part of engineering education. Only 38% of the respondents offer statistics as a required course and 51% offer the course as an elective. Compounding the contrast with this finding and the previously stated importance of RMS is that a majority of the schools who do not offer statistics now do not intend to add statistics in the future.

The only indication that schools even attempt to address statistics on a larger scale comes from the answers to hypotheses 50-69. In these hypotheses, a majority of schools indicated that statistics was included as a portion of another course. It is also interesting to note that when statistics courses are made available to engineering students, they were usually graduate level elective courses.

Engineering economics courses fared no better than statistics courses. The majority of schools required engineering economics in only three out of ten curricula: undergraduate industrial, mechanical, and other engineering disciplines. Engineering economics is offered as an elective by the majority of schools in graduate aerospace, electrical, and mechanical disciplines. Also, very few of those schools who do not offer the course now will add the course in the future. In no instance did a majority of schools not offering the course now (answered "no" to questions 75-94 in the survey) say they would add it in the future. In fact, one university accounted for all but three of the positive responses to these questions. It is probable that aerospace and electrical engineering students either graduate or undergraduate could complete their degrees without ever being exposed to an engineering economics course.

A further indication of lack of RMS education can be seen in questions 115-120 of the survey. Again, in no instance did a majority of schools indicate that reliability, maintainability, and supportability were even included in engineering economics courses if the course was offered. If the concepts of RMS and life cycle engineering are not discussed in engineering economics, it might be assumed that they are not discussed at all.

Overall, reviewing the results of statistics and economics courses hypotheses as a whole, a number of points can be made. First, there was little difference as to whether the school was private or public. Generally, neither private nor public schools showed a tendency to offer courses more than the other. This was unexpected, as the researchers initially believed that public schools, sponsored by the government, would be more prone to cover RMS in their course offerings. However, it should be noted that although there was not a significant difference between the majority of responses of private and public schools, public schools tended to emphasize RMS more than private schools. Next, schools tended to concentrate required statistics and economics courses in the industrial engineering area. In addition, graduate students are more likely to receive training in statistics and engineering economics than are undergraduate students. Lastly, there is a large disparity between the answer to question 14 in the survey (Is RMS included in any way in your engineering design curriculum?) and the responses to questions 15-120 which require respondents to specify their current and projected course offerings in statistics and engineering economics. Although most schools said that RMS was included in their curricula, a woefully low percentage of schools have or will have statistics and engineering economics in their curricula.

Other indications of the lack of RMS education in today's and the future's educational institutions can be seen when examining the percent of classroom and project hours devoted to RMS. The majority of schools devote less than 10% of classroom and project time to RMS, both in undergraduate and graduate programs. Also, no private schools will offer degrees in reliability, maintainability, or supportability within the next five years. Only three public schools either offer the degrees now or will offer the degrees in the future. RMS short courses are also lacking; only 10% of private schools and 46.3% of public schools develop or offer RMS short courses.

This lack of RMS education for students will continue. In only one area will formal courses in reliability, maintainability, or supportability be offered by a majority of the schools: graduate reliability. To further point out this lack of educational opportunities, the majority of schools will incorporate RMS into other graduate design courses only in industrial engineering.

If classes in RMS are lacking, does the same apply to research and/or professional activities? Most faculty seem to grasp the importance of RMS, as most participate in RMS research or professional activities. However, public school faculty participate in this research/professional activity much more frequently than their private school counterparts. 69.4% of public school faculty engage in these activities compared to only 33.3% of private school faculty. Interestingly enough, the faculty members are engaging in this research/professional activity with little or no incentive to do so. Of the 36 public schools who responded to the incentive questions (170-172 in the survey), only five offer promotions, five offer performance objectives, and eight offer other incentives. Only one school offered all three. 23 schools offered no incentive whatsoever. private schools responding, two offer promotions, two offer performance objectives, and one offers other incentives. Three schools offer no incentives whatsoever. (Perhaps this participation without incentive can be attributed to the need to publish.)

Students, on the other hand, tended to not participate in RMS research or professional activities. Again, a definite split can be seen between private and public schools. 54.3% of public school students engage in these activities compared to only 22.2% of private school students. In the student's cases, the lack of incentive may well be the driving force behind the lack of RMS research or professional activities. Of the 34 public schools responding to this question, five offer fellowships, ten offer grade incentives, and seven offer other incentives. 20 offer no incentives whatsoever. Private schools are no better; one school offers fellowships, one offers grade incentives, and two offer other incentives. Three schools offer no incentives whatsoever.

This lack of RMS education may be explained by the lack of trained faculty to teach the courses. 40 of the schools have less than 25% of their faculty capable of teaching RMS, 8 have less than 50%, and one has less than 75%. All private schools said they had less than 25%

capable of teaching RMS. 76.3% of the public schools have less than 25% of their faculty capable of teaching RMS, 21.1% less than 50%, and 2.6% less than 75%. It is impossible for a school to teach a subject when its faculty is incapable of instructing in the subject area.

The lack of education in the area of RMS translates into few students working in the area upon graduation. 38 schools said that less than 25% of their graduates were working in the area of RMS, two said less than 50%, and one each said less than 75% and less than 100%.

Future Considerations

This paper is by no means the last word on RMS and how it is being taught in engineering institutions. Hopefully it will provide some insight into some issues. Primarily, this analysis was conducted so that future studies would have a starting point to conduct future research. In today's environment of rapid change and technological growth, few things remain constant. It is our hope that this is true of the status of RMS education. Any study or survey that looks at the issues of RMS serves to further educate the population as to its presence and importance. In this light, we feel that additional surveys and follow on analysis would accomplish two main goals:

1) Increase awareness of the elements of RMS.

2) Shed light on aspects of RMS that will result in more global acceptance and application.

To achieve these goals, the following surveys and analysis could be conducted.

1) Survey the major firms and government agencies to find out their perceptions of RMS, RMS training, and how RMS is applied in their industries.

2) Survey foreign engineering institutions to find out their perceptions of RMS and if and how they teach the concepts of RMS.

3) Survey U.S. engineering institutions again, with statistical analysis in mind, and find out if their attitudes, perceptions, or activities in relation to RMS issues have changed.

4) Compare the results of foreign respondents with those of U.S. engineering schools.

These are just some of the ways that issues relating to RMS issues can be explored. It is necessary to continue to research these issues and bring the concept of quality of design into the forefront of our engineering education.

Conclusion

The results of this survey paint a gloomy picture for the future of RMS in the United States. RMS education is pitifully inadequate to meet the needs of an ever increasingly global market that insists on quality products. RMS education insures that engineers learn to design this quality into their products. Quality has taken the place of performance as the new standard for the assessment of value of a product.

To regain our competitive edge, the United States needs to regain the quality edge. In order to do this, we need RMS-trained engineers designing our products. The problem is that an "RMS education gap" has developed. Many of our engineering faculty are incapable of teaching RMS, hence schools do not offer the courses. Therefore, students cannot receive the training in this area. If the students don't receive the training, the products they design probably will not successfully incorporate the concepts of RMS. Today's students are tomorrow's teachers. Lack of training now means that there will be no one to pass on these principles in the future.

How can this cycle be broken? One suggestion is in the area of corporate recruiting. Corporate recruiters rarely look for RMS training when recruiting on America's campuses. Schools provide corporate America with engineers that meet the criteria that they demand. Because of the shortage of engineers as a whole, recruiters have not made it apparent that training in RMS makes a student more qualified for employment. This apparent lack of interest in RMS signifies that RMS education is unimportant and does not deserve more emphasis. Recruiters need to emphasize that RMS training is a vital ingredient of the education their future employees receive; schools may then increase the emphasis on RMS. 55% of the engineering institutions oppose RMS courses being part of their accrediting criteria. This is not surprising since few institutions, or people for that matter, like having additional restrictions imposed upon them. Despite this resistance, it may be that in order to break the cycle of indifference to RMS education, RMS courses need to be required for accreditation. Finally, government and industry must not expect schools to take on the burden of developing RMS courses and training on their own. They must provide financial assistance in the form of aid and grants intended to develop a cadre of instructors in the fields of reliability, maintainability and supportability.

Appendix A: SAE Survey With Accumulated Totals

S A E

RELIABILITY, MAINTAINABILITY & SUPPORTABILITY

ACADEMIC QUESTIONNAIRE

PURPOSE OF THE QUESTIONNAIRE

1) To find out what RM&S courses are being taught in the United States by schools of engineering.

2) To find out what RM&S courses are planned fc. the future.

3) To determine what RM&S research is ongoing at the academic institutions.

4) To determine if differences exist in the answers to 1-4 above based on the demographics of the schools.

RESPONDENT INFORMATION

University & Address

____

____

____

Responder (Optional)

____

Telephone (Optional)

____

Please send responses to:

Dr. Ben Williams AFIT/RQ
Air Force Institute of Technology
Center of Excellence for
Reliability/Maintainability/Quality
WPAFB, OH 45433 (513) 255-5836

ACADEMIC SURVEY

RELIABILITY, MAINTAINABILITY & SUPPORTABILITY (RM&S)

INFORMATION ON YOUR INSTITUTION:

1. Would you consider your school to be primarily a government supported (local, state, or federal) or private academic institution?

Government__41__ Private__10__

2-5. Please mark the blocks showing the size of your institution in terms of the typical number of degrees granted within a twelve month period:

	Undergraduate		Graduate	
Engineering	2) 0-50	_1__	3) 0-9	_3__
	51-200	_8__	10-25	_5__
	201-750	_25_	26-100	_15_
	751-2000	_7__	101-300	_14_
	2000+	_8__	300+	_10_
Supportability	4) 0-50	_18_	5) 0-9	_14_
	51-200	_2__	10-25	_3__
	201-750	_6__	26-100	_7__
	751-2000	_2__	101-300	_3__
	2000+	_1__	300+	_2__

6. Do you consider your academic institution to be primarily:

Liberal Arts__4_ Engineering & Science__6_ Multidisciplined_41_

7-10. Please indicate the age of your academic institution in terms of the number of years of granting degrees by checking the appropriate blocks.

Engineering	0	7) _0__	8) _1__
	1-5	_1__	_0__
	6-25	_6__	_13_
	26-100	_23_	_25_
	100+	_19_	_4__
Supportability (Logistics Management, etc.)	0	9) _16_	10) _12_
	1-5	_0__	_3__
	6-25	_5__	_8__
	26-100	_11_	_5__
	100+	_1__	_1__

DEFINITIONS:

Reliability - the probability of success in operating for a defined period in a specified environment.

Maintainability - the probability of restoration of performance within a specified period using approved procedures, equipment, parts and personnel.

Supportability - all activities required to achieve the proper levels of reliability and maintainability as economically as possible.

RM&S - any or all of the combination of reliability, maintainability, and supportability.

In your opinion:

11. Should RM&S be included in the engineering design process when a system or component is originally being designed? (Y=Yes N=No)

_51Y__

12. Would including RM&S in the design of a product add to the value of the product (Y=Yes N=No)

_51Y__

13. Should RM&S be included as part of a design engineer's education? (Y=Yes N=No)

_50Y__

14. Is RM&S included in any way in your engineering design curriculum? (i.e. statistics, a subset of design courses, etc.) (Y=Yes N=No)

45Y 6N

15-34. Do you have statistics as a part of engineering curricula: (Y=Yes N=No N/A=Not Applicable)

	Undergraduate		Graduate	
Curriculum	Required	Elective	Required	Elective
Aerospace	15)_5 Yes 10 No 10 NA	16)_10 Yes 5 No 8 NA	17)_2 Yes 6 No 8 NA	18)_10 Yes 4 No 8 NA
Electrical	19)_14 Yes 20 No	20)_17 Yes 11 No	21)_3 Yes 16 No 2 NA	22)_20 Yes 7 No 2 NA

Industrial	23)_26 Yes 3 No 9 NA	24)_7 Yes 2 No 7 NA	25)_16 Yes 4 No 8 NA	26)_9 Yes 2 No 9 NA
Mechanical	27)_18 Yes 18 No 1 NA	28)_22 Yes 10 No	29)_4 Yes 16 No 3 NA	30)_25 Yes 7 No 2 NA
Other	31)_18 Yes 11 No 2 NA	32)_12 Yes 7 No 2 NA	33)_5 Yes 11 No 4 NA	34)_8 Yes 5 No 7 NA

35-54. Do you have any plans in the next five years to include a statistics course as part of your engineering curricula?
(Y=Yes N=No N/A=Not Applicable)

	Undergraduate		Graduate	
Curriculum	Required	Elective	Required	Elective
Aerospace	35)_5 Yes 8 No 9 NA	36)_7 Yes 5 No 7 NA	37)_6 Yes 8 No 6 NA	38)_7 Yes 5 No 6 NA
Electrical	39)_3 Yes 16 No 3 NA	40)_10 Yes 12 No 2 NA	41)_7 Yes 16 No 2 NA	42)_12 Yes 10 No 2 NA
Industrial	43)_15 Yes 3 No 10 NA	44)_4 Yes 4 No 6 NA	45)_12 Yes 6 No 7 NA	46)_6 Yes 4 No 8 NA
Mechanical	47)_10 Yes 16 No 4 NA	48)_12 Yes 13 No 1 NA	49)_10 Yes 16 No 2 NA	50)_13 Yes 11 No 3 NA
Other	51)_12 Yes 9 No 3 NA	52)_5 Yes 11 No 4 NA	53)_7 Yes 12 No 3 NA	54)_7 Yes 10 No 5 NA

55-74. Do you include statistics as a portion of your engineering design sequence within other courses?
(Y=Yes N=No N/A=Not Applicable)

	Undergraduate		Graduate	
Curriculum	Required	Elective	Required	Elective
Aerospace	55)_10 Yes	56)_8 Yes	57)_8 Yes	58)_8 Yes
	6 No	5 No	5 No	4 No
	9 NA	6 NA	6 NA	6 NA
Electrical	59)_23 Yes	60)_13 Yes	61)_13 Yes	62)_17 Yes
	15 No	10 No	11 No	7 No
			2 NA	2 NA
Industrial	63)_24 Yes	64)_6 Yes	65)_18 Yes	66)_7 Yes
	3 No	3 No	2 No	3 No
	7 NA	5 NA	7 NA	7 NA
Mechanical	67)_25 Yes	68)_15 Yes	69)_15 Yes	70)_19 Yes
	14 No	12 No	10 No	8 No
			2 NA	2 NA
Other	71)_18 Yes	72)_10 Yes	73)_13 Yes	74)_12 Yes
	6 No	5 No	6 No	5 No
	4 NA	3 NA	4 NA	4 NA

75-94. Please indicate your requirements for an engineering economics course: (Y=Yes N=No)

	Undergraduate		Graduate	
Curriculum	Required	Elective	Required	Elective
Aerospace	75)_10 Yes	76)_10 Yes	77)_1 Yes	78)_10 Yes
	6 No	1 No	9 No	2 No
	9 NA	7 NA	6 NA	6 NA
Electrical	79)_20 Yes	80)_20 Yes	81)_3 Yes	82)_15 Yes
	13 No	3 No	18 No	7 No
			2 NA	2 NA
Industrial	83)_27 Yes	84)_5 Yes	85)_8 Yes	86)_12 Yes
	1 No	2 No	8 No	2 No
	9 NA	5 NA	8 NA	7 NA
Mechanical	87)_27 Yes	88)_18 Yes	89)_3 Yes	90)_18 Yes
	11 No	6 No	19 No	8 No
			3 NA	2 NA
Other	91)_19 Yes	92)_11 Yes	93)_4 Yes	94)_10 Yes
	7 No	4 No	13 No	5 No
	2 NA	2 NA	3 NA	3 NA

95-114. Do your future plans include engineering economics courses in the following areas? (Y=Yes N=No N/A=Not Applicable)

	Undergraduate		Graduate	
Curriculum	Required	Elective	Required	Elective
Aerospace	95)_5 Yes 9 No 10 NA	96)_9 Yes 2 No 8 NA	97)_3 Yes 8 No 6 NA	98)_10 Yes 3 No 32 NA
Electrical	99)_11 Y 16 N 3 NA	100)_16 Y 5 N 4 NA	101)_4 Y 15 N 3 NA	102)_13 Y 8 N 4 NA
Industrial	103)_17 Y 3 N 10 NA	104)_5 Y 4 N 8 NA	105)_8 Y 8 N 8 NA	106)_9 Y 3 N 9 NA
Mechanical	107)_14 Y 13 N 7 NA	108)_12 Y 10 N 2 NA	109)_4 Y 17 N 3 NA	110)_14 Y 10 N 3 NA
Other	111)_12 Y 10 N 5 NA	112)_10 Y 7 N 3 NA	113)_4 Y 13 N 3 NA	114)_12 Y 8 N 3 NA

115-120. Do your engineering economics courses include life cycle engineering by addressing aspects of RM&S?
(Y=Yes N=No N/A=Not Applicable)

	Undergraduate	Graduate
Reliability	115)__11 Yes_____ 31 No 5 NA	116)___12 Yes 18 No 7 NA
Maintainability	117)__14 Yes_____ 29 No 5 NA	118)___10 Yes 19 No 7 NA
Supportability	119)__13 Yes_____ 31 No 5 NA	120)___11 Yes 19 No 7 NA

121-126. How many students per year enroll in credit courses where RM&S are included in the curricula? (please estimate the # for each question)

	Undergraduate	Graduate
Reliability	121)__________	122)________
Maintainability	123)__________	124)________
Supportability	125)__________	126)________

127-132. During a typical 12 month period, how many students enroll in formal credit courses in the specific areas of:
(please estimate # for each)

	Undergraduate	Graduate
Reliability	127)__________	128)________
Maintainability	129)__________	130)________
Supportability	131)__________	132)________

133-138. Do your plans for the next five years include formal credit courses in the following? (Y=Yes N=No)

	Undergraduate	Graduate
Reliability	133) 11 Yes 24 No	134) 16 Yes 15 No
Maintainability	135) 6 Yes 28 No	136) 8 Yes 21 No
Supportability	137) 6 Yes 28 No	138) 9 Yes 21 No

FOR YES ANSWERS, PLEASE FILL OUT APPENDIX A WITH COURSE INFORMATION. THE COMBINED RESULTS OF RM&S EDUCATION WILL BE PUBLISHED FROM THIS INFORMATION.

139-148. Please estimate how many students participate in various engineering design classes that do address specific rm&s paramters. (i.e. durability, mean time to failure, ease of maintenance.)

	Undergraduate	Graduate
Aerospace	139)__________	140)________
Electrical	141)__________	142)________
Industrial	143)__________	144)________
Electrical	145)__________	146)________
Other	147)__________	148)________

149-50. How many classroom hours are devoted to RM&S in your typical engineering degree program? (enter estimate of hours)

	Undergraduate	Graduate
	149)__________	150)_______

151-152. What percent of classroom hours are devoted to RM&S in your typical engineering program? (enter estimate of percentage)

	Undergraduate	Graduate
	151)__________	152)_______

153-154. How many engineering design projects hours are devoted to RM&S in your typical engineering degree program? (enter estimate of a typical student's project hours)

	Undergraduate	Graduate
	153)__________	154)_______

155-156. What percent of the total project hours are devoted to RM&S in your typical engineering degree program? (enter estimate of percentage)

	Undergraduate	Graduate
	155)__________	156)_______

157-166. Do you plan to include RM&S parameters in other engineering design courses in the next five years? (Y=Yes N=No N/A=Not Applicable)

	Undergraduate	Graduate
Aerospace	157) 7 Yes 11 No 9 NA	158) 6 Yes 8 No 7 NA
Electrical	159) 12 Yes 20 No 1 NA	160) 8 Yes 14 No 2 NA
Industrial	161) 9 Yes 11 No 9 NA	162) 7 Yes 6 No 10 NA
Electrical	163) 12 Yes 24 No 1 NA	164) 8 Yes 16 No 3 NA
Other	165) 11 Yes 14 No 1 NA	166) 6 Yes 12 No 3 NA

167. Do your faculty participate in RM&S research, professional, or scholarly related activities? (Y=Yes N=No)

28 Yes 17 No

IF YES, PLEASE LIST INFORMATION ON APPENDIX B. THESE RESULTS WILL ALSO BE PUBLISHED FROM THE DATA RECEIVED.

168. Do your students participate in RM&S research or scholarly related activities? (Y=Yes N=No; if Yes, please list on chart)

20 Yes 23 No

169. Do you believe your faculty should include RM&S in their research and professional activities? (Y=Yes N=No)

43 Yes 3 No

170-172. What methods do you have to encourage faculty to include RM&S parameters in their research and professional activities? (Y=Yes N=No)

170) Promotions	_7 Yes	28 No
171) Performance Objectives	_7 Yes	24 No
172) Other	_9 Yes	19 No

173. Do you think it is a good idea to have students include RM&S in their student research? (Y=Yes N=No)

41 Yes 3 No

174-176. What methods do you have to encourage students to include RM&S parameters in their research? (Y=Yes N=No)

174) Fellowships	_6 Yes	25 No
175) Grades	_11 Yes	18 No
176) Others (i.e. awards-pls list)	_9 Yes	18 No

179-184. Do you grant degrees in the following? (Y=Yes N=No)

	Undergraduate	Graduate
Reliability	179)__47 No______	180)__2 Yes__ 38 No
Maintainability	181)__48 No______	82)__1 Yes__ 39 No
Supportability (Logistics, etc.)	183)__47 No______	184)__1 Yes__ 39 No

185-190. Do you plan on granting degrees within five years? (Y=Yes N=No)

	Undergraduate	Graduate
Reliability	185)__1 Yes_____ 47 No	186)__3 Yes__ 39 No
Maintainability	187)__47 No_____	188)__2 Yes__ 39 No
Supportability (Logistics, etc.)	189)__47 No_____	190)__1 Yes__ 40 No

FOR ALL YES ANSWERS FOR QUESTIONS 179-190, PLEASE LIST ON APPENDIX C. THIS DATA WILL ALSO BE PUBLISHED FROM THE DATA RECEIVED.

191. Do your faculty or graduate students develop or participate in RM&S short courses? (Y=Yes N=No)

20 Yes 26 No

IF YES, PLEASE PROVIDE THE INFORMATION ON APPENDIX D, FOR PUBLICATION ALONG WITH THE OTHER INFORMATION.

192. Do you believe RM&S parameters should become part of the accrediting process for engineering degrees? (Y=Yes N=No)

20 Yes 26 No

193. When recruiters come to your campus, how often do they say they are looking for RM&S educated students? (check one answer)

Never__15_ Infrequently__19_ Sometimes__7__ Frequently__2__

194. Do the recruiters consider RM&S training to be a bonus in a student, in addition to the rest of the education? (Y=Yes N=No)

22 Yes 16 No

195. Please estimate the percentage of your engineering faculty with RM&S education, capable of teaching RM&S material? (check one answer)

0-25__39__ 26-50__7___ 51-75__1___ 76-100_____

196. What percent of your previous graduates are working within the general area of RM&S? (check one answer)

0-25__38__ 26-50__2___ 51-75___1__ 76-100___1__

Thank you for your patience in taking the time and completing this detailed questionnaire. Analysis of the data will be published as soon as possible.

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Vita A

Captain Gregory T. Hurst was born on 13 May 1961 in Moline, Illinois. He graduated in 1979 from Fairport High School in Fairport, New York and subsequently entered the Rochester Institute of Technology, graduating in September of 1983 with a Bachelor of Science degree in Hotel/ Restaurant Management. In 1985 he received his commission from the Air Force Officers Training School. He was a Squadron Section Commander at Yokota AB, Japan from June 1988 until June 1991.

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Vita B

Captain Barry N. Kinter was born on 1 May 1955 in Lincoln, Nebraska. He graduated from Madison High School in San Diego, California. He attended Principia College in Elsah Illinois and completed his degree at Ball State University in Muncie, Indiana. He was awarded a Bachelor of Science degree in Marketing from Ball State in May of 1980. In November 1980 he received his commission from the Air Force Officers Training School. His Air Force career experience has ranged from Instructor Navigator, Senior Command Post Controller, to Deputy Commander of Current Operations at Yokota AB, Japan.

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13. ABSTRACT

The purpose of this research is to show how engineering schools, as a whole, perceive the role of reliability, maintainability, and supportability in the engineering field. This includes the degree to which these concepts are included in their curricula, whether industry recruiters look for reliability, maintainability, and supportability training when they visit college campuses and to what degree college faculties are teaching reliability, maintainability, and supportability. This is done through research of existing literature and the analysis of data from a survey completed by engineering schools. General analyses are presented of the overall responses and detailed analysis of contrasts and similarities between the responses from private and public institutions are presented. Based upon the knowledge gained in conducting this research, conclusions on the state of RMS education in engineering institutions are forwarded.

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AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/LSC, Wright-Patterson AFB OH 45433-9905.

1. Did this research contribute to a current research project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Please estimate what this research would have cost in terms of manpower and/or dollars if it had been accomplished under contract or if it had been done in-house.

   Man Years ____________ $ ____________

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3, above) what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments

____________________ ____________________

Name and Grade Organization

____________________ ____________________

Position or Title Address