QUALITY ASSURANCE IN THE UNIVERSITY SYSTEM

by

STANISLAV KARAPETROVIC

A Thesis

Submitted to the Advisory Committee

in Partial Fulfillment of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

Department of Mechanical and Industrial Engineering

University of Manitoba

Winnipeg, Manitoba

0-612-31997-0

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

COPYRIGHT PERMISSION

QUALITY ASSURANCE IN THE UNIVERSITY SYSTEM

BY

STANISLAV KARAPETROVIC

A Thesis/Practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Quality assurance is an industrial engineering discipline which focuses on providing confidence that the requirements for quality are met. Producers of goods and services must assure their customers of the quality of products and services provided. In light of this fact, university education is no exception. Interested parties, such as the government, industry and society in general, want confidence that the students will have the required knowledge when they graduate, that cutting-edge courses and programs are offered, and that new knowledge is created in research. To provide such confidence to the employers of graduates and the general public, professional institutions have introduced national accreditation of university programs. However, there is also a need to assure customers internationally of the quality of educational and research services being provided locally.

Such quality assurance efforts at an international level have been addressed with the introduction of the ISO 9000 Standards. The standards were developed by quality professionals originating mainly from the industrial sector, and provide a framework for developing quality systems, as well as making quality efforts visible to customers. The impact of the standards world-wide has been so extensive that it is now virtually impossible to bid for international manufacturing contracts if a company is not ISO 9000 registered. The time when universities encounter a similar situation is rapidly approaching. An established ISO 9000 quality system in the university today will pioneer the quality assurance efforts the competition will undoubtedly face tomorrow.

This thesis examines quality assurance issues in university education. Models of the quality system and the university system are developed and integrated to allow for the interpretation, documentation and implementation of the ISO 9001 standard in a university. These models facilitate the harmonization of quality assurance and management systems, as well as the integration with environmental, safety and other management systems. Quality control and improvement of the teaching process and learning outcomes are supported by various Statistical Process Control techniques. The goal to achieve a zero-defect output is set, and a process to achieve this goal is described, and is supported by a case study. Quality characteristics of university's products are developed in the modified Analytic Hierarchy Process framework. These characteristics can be used to monitor, control and continuously improve educational and research quality.

ACKNOWLEDGMENTS

I would like to thank my advisors, Dr. Divakar Rajamani and Dr. Walter Willborn for guidance and continual support. I would also like to express my sincere appreciation to Dr. Douglas Ruth and Prof. Rudi Schilling (Members of the Advisory Committee) for valuable comments and suggestions, and Dr. David Poock (External Examiner).

For assistance and support in the course of work on this thesis, I would like to acknowledge Dr. Earl Rosenbloom and Dr. Donald Shields.

Deep approciation goes to my fiancee Karla Staudzs, for her unfailing encouragement and support.

Last, but not the least, I thank my family, especially my parents and my brother.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

In the last decade or so, the quality of university education has become a subject of major concern. Students, their families, companies the graduates will work for, university professors and staff, the government and politicians, all have interests and stakes here. Numerous programs have been started to improve quality, Total Quality Management (TQM) being an example. Governmental and professional institutions have introduced the accreditation of university programs, in order to provide for the standardization at a national level. For instance, the Canadian Engineering Accreditation Board (CEAB) performs accreditation of engineering programs in Canada. Undoubtedly, incredible effort, money, human and other resources are put forth. However, many questions remain to be asked and thought of: 'What does quality in education mean?', 'How can universities assure the general public of the quality of educational services provided?', 'How can universities improve quality?'. This thesis will focus on the issues of quality assurance in a university environment.

1.1 QUALITY ASSURANCE AND QUALITY SYSTEM

Quality assurance provides confidence to customers that requirements for quality are met. In other words, quality assurance consists of methods and activities used to assure the customer of the quality of products and services provided. Quality is a dimension of a product, a totality of features and characteristics of a product that bear on its ability to satisfy needs and requirements (ISO 8402, 1994). Other dimensions or characteristics of a product include cost, ergonomic characteristics, health and safety factors, ability for recycling and so on.

Manufacturing a product means that certain new characteristics are added to the raw material, such as its shape, material and size. In a similar fashion, certain 'quality characteristics' are created, such as durability, maintainability and usability. Like manufacturing, quality assurance is a planned, designed, controlled and continuously improving process. If the output of production is the product or service, the output of quality assurance is the satisfaction of customer requirements and specifications on a continuous basis. In other words, quality assurance is a means to achieve the end result of satisfying the customer. In this thesis, the term "product" encompasses both tangible (material and hardware) and intangible goods (service and software).

In order to create a product or service, we need a process that will transform inputs, such as customer requirements and company objectives into outputs, i.e. products. We also need resources, such as material, information and people. Together, these elements form a *production system*. To create quality, we also need a system. This system is often referred to as the *quality system*. The quality system can be defined as a set of interdependent *processes* that function harmoniously, using various *resources* to achieve *objectives* related to meeting customer requirements (Karapetrovic and Willborn, 1998A). Much of the current literature views the quality system as an independent entity, created solely for the purpose of meeting and surpassing customer requirements, without observing the links with other systems, such as environmental management, accounting or manufacturing. Another problem is the perceived dichotomy between quality assurance and quality management systems. Some authors, even quality pioneers such as Juran (in Stratton, 1993), Crosby (1997) or Deming (1994) claim that, unlike quality management, quality assurance does not address improvement of quality. Juran even goes further, claiming that there is nothing in quality assurance about meeting the customer needs! (Stratton, 1993). These problems and concerns are largely due to the unclear structure of forefront quality assurance models, such as ISO 9000, as well as a lack of understanding of the underlying system concept (Karapetrovic and Willborn, 1998A). This thesis will attempt to develop a framework to address these issues.

1.2 UNIVERSITY SYSTEM

A quality system, as outlined in the previous section, is a subsystem of a larger, production system. This is apparent because the quality system creates certain quality characteristics, which represent one of many sets of product characteristics, created in the production system. Developing both the quality and production systems requires knowledge of the product market, customers, product and process characteristics, suppliers and so on. While this is a known fact for manufacturing organizations, educational institutions have rarely, if ever, viewed themselves as a production system in the past. However, since the quality of university education has become a subject of major concern, it has become evident that universities will have to embark on systematic quality assurance efforts if they want to survive in the global educational market. The same concerns that continue to worry manufacturers, such as market uncertainty and competition, now are knocking at university's doors. Luckily, industrial and system engineering can assist in facing these problems.

Viewing the university as a system means the identification of university's products and services, customers and suppliers, as well as teaching, learning and research processes. This approach has emerged only recently, and is presented mainly in quality and industrial engineering literature (Black, 1996; Evans and Lindsay, 1996; Sirvanci, 1996; Karapetrovic et al., 1997A). It provides a possibility for a systematic development of a quality assurance system, such as ISO 9001, in the university environment, as well as continuous improvement of educational and research activities. Chapter 4 of this thesis provides a detailed conceptualization of the University System.

1.3 QUALITY ASSURANCE (ISO 9000) IN THE UNIVERSITY

The need for implementing quality assurance programs has induced several studies on the applicability of the world-renowned ISO 9000 standards in education (Lewis and Smith, 1994; Willborn, 1994; Doherty, 1995A). The standards, written by quality professionals and engineers from large manufacturing companies, present a number of requirements for registering a quality system of an organization for the purpose of quality assurance. Although the standards are generic, meaning that they have been successfully applied not only in manufacturing organizations, but also in services, health care and small business, an interpretation of the standards for educational institutions is required. The majority of interpretations available in literature, however, do not consider all elements of the ISO 9001 standard (the most comprehensive quality system model) directly applicable to education. For instance, Lewis and Smith (1994) consider that only twelve out of twenty elements are applicable. Also, interpretations are not based on either the quality system or production system concepts, missing important benefits of a registered university quality system and controlled teaching, learning and research processes.

Some of the benefits of developing an ISO 9001 quality system for a university include:

- providing confidence to the students, industry, government and society, as well as the university and faculty management that the requirements for quality are continuously met
- unambiguous definition of the responsibility and authority of all persons involved in teaching/learning/research
- adequate determination of the customer requirements for quality,
- adequate documentation of program/course design activities and output
- teaching, learning and research process control
- internal quality audits for raising and resolving practical problems
- effective marketing tool
- advantages in national and international accreditation, such as CEAB and ABET
- integration with other emerging management systems, such as environment and safety

However, an ISO 9001 quality system in academia cannot guarantee cost reductions, a continuous process of benchmarking against other universities, nor can it guarantee that the university will immediately improve its reputation. The ISO 9000 effort also may be costly and time consuming (Doherty, 1995A). Chapter 5 examines the impact of the ISO 9001 quality system on the university and presents an interpretation based on the system approach to quality assurance and the university system.

1.4 QUALITY SYSTEM FOR THE UNIVERSITY

As it was mentioned previously, a quality system is a set of interdependent processes that function harmoniously, using various resources to achieve objectives related to quality and create quality characteristics that will meet customer needs. In the following sections, the underlined elements of the quality system are explained.

1.4.1 Quality System Resources

An established quality system requires certain resources, such as people, material and information, to achieve set goals and objectives. Organization, responsibility, authority and interrelationship between people whose work affects quality of the product must be defined. Documented resources are also needed to describe and control processes within the quality system, and to provide evidence of an effective and efficient quality system to interested parties, such as customers, external organizations or management. Quality system documentation is commonly designed in a four-tier fashion (Karapetrovic et al., 1997C). The top document is the *quality manual*, which describes the overall quality system and refers to the necessary quality system procedures. Each documented *procedure* illustrates one or more processes. For example, in the university environment, procedures may describe purchasing of material for teaching/learning or research activities, appointment of teaching assistants or the teaching process control. Responsibilities and authorities for different activities in the process must be provided, as well as the required steps in the processes. In other words, procedures explain who does what, where and when. Process activities that need separate written guidelines are addressed by appropriate *instructions*. Finally, to verify compliance with the quality system requirements, *records* are available. Chapter 6 addresses the issues of documenting and implementing the ISO 9001 quality system at a university.

1.4.2 Quality System Objectives

In order for the quality system to work, objectives and goals must be defined and documented. The ISO 9001 standard requires the objectives of an organization regarding quality to be stated in the quality policy. The policy, commonly a part of the quality manual, expresses the organization's commitment to quality and states meeting and/or surpassing customer expectations as the ultimate goal. However, it seems that much of the confusion and misunderstanding about ISO 9000 systems was caused by the lack of clear objectives in the overall system perspective (Velury, 1996). The arguments against ISO 9000 focus on the apparent failure to facilitate quality improvement and objectives to drive this improvement (Crosby, 1997, Stratton, 1993). Nevertheless, a well established quality system should be able to facilitate objectives beyond meeting customer expectations and transfer to the realm of surpassing them. For example, the ISO 9001 quality system in a university department, through process control, statistical techniques and internal quality audits can achieve an objective of creating zero-defect students, which would at this point of time certainly surpass the expectations of its customers. Chapter 7 of the thesis addresses this problem in detail.

1.4.3 Quality System Processes

The university creates its products and services with three production processes: teaching, learning and research. These processes must be planned, designed, implemented, controlled and improved. A myriad of techniques already exist for planning, designing and improving teaching and learning. Angelo's and Cross' (1993) classroom assessment techniques (CATs) present an example. However, when teaching, learning and research process control is focused on, literature reveals sparse accounts of the use of statistical process control (SPC) in universities or for that matter schools and colleges. The lingering questions are :'Without a systematic approach to the teaching process development and maintenance, do professors really have a valid proof that the instructional process is in-control? and 'Can they disprove a claim that their instructional systems are the cause of poor student performance, or can they claim credit when student performance is exceptional?' (Ensby and Mahmoodi, 1997). These questions can be answered in a positive manner for professors if SPC is applied to the teaching and learning processes. With SPC, special causes of students' malperformance can be found and eliminated, and proof that the instructional process is in-control can be provided. Chapter 8 concentrates on reducing the variation in the teaching/learning outcomes and presents the application of SPC techniques to control the teaching and learning processes.

1.4.4 Quality Characteristics

As it was previously mentioned, quality is a set of product characteristics that bear on the product's ability to satisfy customer requirements. For example, the ability of the car to run is its quality characteristic. Other characteristics include ergonomics of the interior, maximum speed, torque and so on. This is not different in the university environment. The ability of a structural engineer to apply the principles of the strength of materials is one of his/her quality characteristics. Quality characteristics, however, may be set out in different levels. The differentiation of critical and non-critical quality characteristics is common. Critical characteristics render the product unusable. For instance, the above-mentioned ability of the car to run is its critical characteristic. However, the ability to sustain a silver finish on the fender is not. This indicates that certain quality characteristics of the university products and processes may be laid out in a hierarchy of characteristics. Chapter 9 examines these characteristics and presents an improved Analytic Hierarchy Process (AHP) methodology for weighing quality characteristics.

1.5 ORGANIZATION OF THE THESIS

The remainder of the thesis is organized as follows. Chapter 2 presents a review of existing literature on quality assurance in university education and other relevant issues. Chapter 3 provides a systems approach to quality assurance, the ISO 9001 quality system, and proposes a new ISO 9001 model. A detailed conceptualization of the University System is provided in Chapter 4. Chapter 5 examines the impact of the ISO 9001 quality system on the university and presents an interpretation based on the system approach to quality assurance and the University System. Chapter 6 addresses the issues of documenting and implementing the ISO 9001 quality system at a university. In chapter 7, the objective of creating zero-defect students is set and a case study on reaching that objective is presented. Chapter 8 concentrates on reducing the variation in the teaching/learning process and presents the application of SPC techniques to control these processes. Chapter 9 examines certain quality characteristics of the university's products, and presents an improved Analytic Hierarchy Process (AHP) methodology for weighing quality characteristics. Finally, the contributions of the research and directions for future research are given in Chapter 10.

CHAPTER TWO

LITERATURE SURVEY

A survey of existing literature on topics that are covered in the thesis are presented. The topics of literature search include: quality assurance and ISO 9000 quality systems; university system; reported analyses of customers, suppliers and products of the university; quality assurance and accreditation in engineering education; interpretations, applications, advantages and concerns about ISO 9000 in education; review of statistical process control, control charts and their applications in higher education; and teaching and learning assessment techniques. Subsequently, the motivation for research emerging from existing literature, as well as objectives of the research are stated.

2.1 QUALITY ASSURANCE AND ISO 9000 QUALITY SYSTEMS

2.1.1 Quality Assurance

Today, customers expect quality in all aspects of their lives. Companies are restructuring to assure customers of the high quality of their products and services. To achieve this quality assurance, a number of engineering disciplines and programs which govern the quality, safety, reliability and dependability of products have been introduced. Halper (1978) refers to these disciplines, examples of which include quality control, reliability and maintenance engineering, as 'assurance sciences'. In the last two decades, quality assurance programs have been significantly influenced by quality standards, such as the Canadian Standard Z299, British BS 5750 and the International ISO 9000 standards.

2.1.2 ISO 9000

It is not an exaggeration to state that ISO 9000 International Standards have revolutionized quality assurance. The standards, drafted by the International Organization for Standardization have been used worldwide since the first issue in 1987, and tens of thousands of companies have developed ISO 9000 quality systems and became registered.

In a nutshell, the standards present three models (ISO 9001, 9002 and 9003), which stipulate a number of requirements on which an organization's quality system can be assessed by an external party (registrar) according to ISO 10011 quality system audits standard. A quality system involves the organizational structure, processes and documented procedures, that are designed to achieve quality objectives. If these minimum requirements are met, a registrar accredited by a national accreditation institution issues a certificate of compliance and the organization's quality system becomes ISO 9001, 9002 or 9003 registered.

The standards are designed as generic, i.e. ISO 9000 should be applicable to all organizations, regardless of size, background or area of business. However, the vast majority of registered firms are manufacturing oriented, while only a few are service organizations. Recently, the benefits of ISO 9000 registration have prompted health care and educational institutions to pursue the standards. Also, the integration of the current and future assurance standards and systems, such as quality, environment and health and safety is emerging (for example, see: Bokhoven, et al, 1996; Adams and Haker, 1996; Kiesgen and Wupperman, 1995; Hartig, 1995; Alexander, 1996; Struebing, 1996; Beechner and Koch, 1997; Hemenway and Hale, 1996; Karapetrovic and Willborn, 1998B, C, D).

2.2 UNIVERSITY AS A SYSTEM

2.2.1 System

Although there probably isn't a person in this world who hasn't been using the word "system" every day since the first day in school, theorists and practitioners rarely use the concept of a system to explain complex happenings in education. Even when they do use it, rarely do they explain what they mean by the "educational system" (for example, see: Przygodski, 1995). As Richmond (1993) emphasizes, "system thinkers have not effectively taught their framework, skills and technologies to the others".

Only recently have industrial engineers realized that the systems concept can and should be applied for the improvement of education. Jay Forrester, the father of system dynamics, emphasizes that the weaknesses in education arise not so much from poor teachers as from inappropriate teaching methods, and that the system's thinking and system dynamics offers a framework for giving cohesion and meaning to education (Forrester, 1993). Viewing education in general, or a school and a university as a system, not only helps to identify suppliers, customers and products of these institutions, but also assists in efforts toward quality improvement. It seems that the growing concern about the quality of higher education and employability of graduates has prompted recent efforts of industrial and quality engineers to analyze process flow in schools and conceptualize educational institutions as systems, with defined processes, inputs and outputs Generally, students coming from high-schools are viewed as "raw-material" or input. Processes of learning and teaching are then taking place, where students learn something they did not know before (value-adding activities), and then use this knowledge in companies where they work after graduation. Thus, graduated students are a university system's output (Sirvanci, 1996; Black, 1996; Evans and Lindsay, 1996; Bailey and Bennett, 1996; Karapetrovic et al, 1997A).

2.2.2 Customers and Products of the University

Most articles written on Total Quality Management (TQM) in education view students as the primary customers (e.g. Schargel, 1994; Horine, 1992; Cloutier and Richards, 1994; Helms and Key, 1994; Ho and Wearn, 1995). Gupta (1993), however, states that universities should consider that students are not the only customers. The customers include employers, who want well qualified and trained graduates, graduate schools that require the students to possess enough knowledge and skills to take up higher studies, professors and society that requires educated and responsible citizens. The author also proposes the systems approach to analyze and to improve the quality of teaching. A recent article by Reavill (1998), states that the definition of the customer in higher education depends on the type of product. If education and research are viewed as "products", then the customers are employers and the society in general. Otherwise, education and research are services and the primary customers are students.

An in-depth analysis of the customers in higher education is provided by Lewis and Smith (1994). The authors classify the customers into four categories: academic internal, administrative internal, direct external and indirect external. The first category includes students, faculty and academic departments. Internal customers for administration includes students, this time with administrative needs, such as service provided when requested and questions answered when asked, as well as university employees (academic and non-academic staff) and departments. Direct external customers encompass employers and other universities, and indirect external customers include the government, community, accrediting agencies and alumni.

Fram and Camp (1995) suggest that each university, based on its own circumstances, must determine who it's customers are from the broad base of students, parents, employers, government agencies and surrounding communities. Doherty (1995) views customers as contractual and secondary. Students, as well as firms who purchase consultancy and government boards are contractual customers, whereas employers and society at large are secondary customers in that the quality of the product has an indirect effect on them. To the contrary, Black (1996) considers faculty as internal and industry as external customers. Prados (1997) views employers, students, parents and funding bodies as customers of engineering education. Employers are also conceptualized as customers by Sirvanci (1996), Bailey and Bennett (1996) and Evans and Lindsay (1996). The first two articles even provide several reasons why a student should not be considered as a customer:

1. In business, the sales of a product is not restricted to a select group of customers, based on their personal abilities. Universities restrict admission to students achieving a certain scholastic level, thus not providing the freedom of choice customers in business have.

2. Customers generally pay for the products they consume. In higher education, students do not necessarily pay the full cost of education. At most state universities in the United States, tuition pays for 30% of the cost, while the rest is paid by taxpayers. This figure is supported by the findings of Weber (1996).

3. Businesses do not examine whether their customers deserve the products they want to buy. In education, students are continually tested to determine whether they deserve the degree (Sirvanci, 1996)

4. University education is not a consumption good, and does not provide immediate gratification to the student. Instead, it provides immediate gratification to the employer, who uses the graduate's knowledge (Bailey and Bennett, 1996)

Ultimately, however, students may decide not to come and study at a particular university or faculty, therefore being able to choose between different universities. In this sense, some universities can still consider students as customers.

In terms of the primary product of the university, virtually all available literature and handbooks for the application of ISO 9000 to education view it as "the learning opportunity" (NACCB, 1994), courses and/or curriculum (BSI, 1994), "learning experience" (Doherty, 1995) or dissemination of knowledge (Ludwig and Weseslindtner, 1996). The British Standards Institution (BSI, 1994) allows the output of an educational or training establishment also to be the "enhancement of skills and abilities gained by a person who undergoes the education process". In some articles, research degrees and research and consultancy services are also mentioned (Doherty, 1995). Teaching, research and community service are also commonly defined as products (AHEC, 1995). There are also views that products of the university depends on the type of the customer. For instance, for student as a customer the product is a marketable skill and knowledge, whereas for employers it is competence, attitude and communication, among other characteristics (Catania, 1995; Evans and Shank, 1992). Just recently, in a few industrial engineering journals and publications, the students or graduates are viewed as a product (Black, 1996; Bailey and Bennett, 1996; Sirvanci, 1996; Evans and Lindsay, 1996; Karapetrovic et al., 1998C). The difference in conceptualizing the university's product(s), nevertheless, may lead to the design of different quality systems all together to meet the requirements of the ISO 9000 standards. For example, reported registrations of higher education institutions (Doherty, 1995; Ludwig and Weseslindtner, 1996) have concentrated on learning experiences designed to meet specified standards, which led to the introduction of standards mainly in administrative services of the university.

2.3 QUALITY ASSURANCE AND ACCREDITATION IN EDUCATION

2.3.1 Quality Assurance

In the context of rapid change of university environment, growing concerns about quality of education and the employability of graduates, higher education institutions across the world have embarked on projects encompassing quality assurance. In Australia, for instance, a Committee for Quality Assurance in Higher Education was established, with the objective of ensuring and improving the quality of Australian higher education. Programs for evaluations of student learning outcomes and research have been set up at a national level (Duggins, 1996). However, according to Maling (1995), very few educational institutions have taken a comprehensive approach to evaluating the quality of their outcomes or establishing benchmarks to monitor changes intended to improve quality.

In Singapore, a number of schools and higher education institutions have developed quality assurance systems. Presenting the experience from the Ngee Ann Polytechnic, the first tertiary institution to obtain ISO 9000 registration in Asia, Chin and Chye (1994), emphasize that in the educational service context, quality control implies course and curriculum evaluation, academic activities to develop well accepted graduates, as well as staff training and development.

In Britain, the pressure for quality assurance has come from the government. According to Doherty (1996), "the government has set up a number of quality quangos, such as the Office for Standards in Education (OFSTED) and the Higher and Further Education Funding Council (HFEFC) to ensure that the educational institutions keep up to scratch in terms of public accountability". British universities have founded their own Higher Education Quality Council. As a result, educational institutions in Britain are now externally coerced to pursue quality assurance. Some, such as the Napier University, have established internal quality assurance units to provide administrative support for university's quality assurance functions (Pollock, 1995). Others, such as the University of Wolverhampton and the Norfolk College have turned to the ISO 9000 quality system, as a means to provide confidence of their quality.

In the United States, engineering faculties from different universities have formed coalitions with the objective of designing, implementing and assessing new approaches to undergraduate engineering education, as well as improving the overall quality of educational experiences. Six coalitions were formed altogether: NSF, Synthesis, Ecsel, Succeed, Gateway and Foundation. Each coalition combines several engineering faculties. For example, the "Synthesis" coalition comprises of the Cornell, Iowa State, Stanford University, University of California at Berkeley and four other engineering schools. All coalitions have some sort of quality assurance embedded in their projects. For instance, the Gateway coalition views quality assurance as Continuous Quality Improvement (CQI) in the educational aspects of the university, and evaluation as one of the means of achieving CQI. The coalition considers that the time when evaluation has been confined to end-point inspection of the student's curricular competence and faculty teaching quality through student exams and evaluations is over. Thus, the coalition has developed a comprehensive evaluation plan, together with an "evaluation information matrix" that is used as a tool for evaluations. The matrix consists of objectives (such as 'to develop students' concept of themselves as professional engineers prepared to engage in lifelong learning'), questions (such as 'to what extent did students develop a concept of themselves as professional engineers'), sources of data and the person responsible for data collection (Gateway, 1997).

The SUCCEED Coalition has developed an eight-step project evaluation model. The steps of the model are: 1. Define the purpose of evaluation, 2. Clarify project objectives, 3. Create "model of change", 4. Select criteria/indicators for evaluation, 5. Identify sources and frequency of measuring, 6. Design evaluation research and experiments, 7. Evaluate results, 8. Use and disseminate results. The model has been applied at the Georgia Institute of Technology in an introductory physics course, in a project called "precision teaching", and resulted in a significantly improved marks (Succeed, 1997). Other coalitions have developed their own assessment models (e.g. Synthesis, 1997).

2.3.2 European Initiatives for Quality Assurance

In recent years, European governmental and educational institutions have accelerated initiatives for formal and comprehensive quality assurance and quality improvement. In many countries, such as the United Kingdom (Tannock and Burge, 1994) and Russia (Alekseyev, 1994), new national legislation has emphasized the necessity of addressing quality issues in higher education. Numerous committees, councils and groupings have been established, and some, such as the Higher Engineering Education for Europe (H3E) are spanning across the borders of the European Union. This section will briefly address two of these initiatives, namely the Engineering Professors' Conference (EPC) model, and the H3E initiative for quality assurance.

2.3.2.1 Engineering Professors' Conference (EPC) Model

The Engineering Professors' Conference in the United Kingdom has developed a formalized model for quality assurance in higher education, based on the principles from the ISO 9000 international standards and Total Quality Management (TQM). It fosters an integrated quality assurance system with quality planning, quality control and quality improvement as main elements. According to Tannock and Burge (1994), the EPC working group concluded that the adoption of an ISO 9000 quality system "could introduce distortions and anomalies into the administration of an institution", and preferred to develop an equivalent quality systems standard, specially designed for higher education. Similarly to ISO 9001, the EPC model concentrates on the entire institution, i.e. the university, academic units, support and administrative services, rather than programs the institution offers. It requires documentation of all critical quality activities, the development of a quality policy, and a review process aimed at continuous improvement. This improvement effort and focus may be perceived as the main difference between the EPC model and ISO 9000 (Harris and Owen, 1994). However, ISO 9000 also has the leverage for continuous improvement using, among others, internal quality audits (requirement 4.17 of ISO 9001 - 1994) and statistical techniques (4.20 of ISO 9001). A top-down approach to the design and operation of a quality system is used in the model, starting with the identification of the quality policy of the institution, and subsequently polices, objectives and procedures of constituting departments and academic units. Overall, in a very similar fashion to ISO 9001, the model spells out eighteen specific requirements for the development of a formal and auditable system for quality assurance, including quality improvement, recruitment of staff, staff review / development and records (Tannock and Burge, 1994).

Although the model certainly has advantages of focusing on explicit quality improvement and being directly applicable to higher education without interpretation, several drawbacks include:

• The model does not precisely define the customers and the product / service of a higher education institution (Harris and Owen, 1994). The notion that the student is the primary but 'naive' customer (Tannock and Burge, 1994), certainly carries a few illogical aspects with it (for example, see Sirvanci, 1996; and Karapetrovic and Willborn, 1997).

• The model lacks several important elements of a well-established quality system, such as contract review, purchasing and inspection/testing (Harris and Owen, 1994).

• It is not clear whether this initiative will be able to reach the level of international acceptance ISO 9000 standards now hold.

2.3.2.2 Higher Engineering Education for Europe (H3E)

As a pan-European initiative, Higher Engineering Education for Europe was established by the Conference of European Schools for Advanced Engineering Education and Research (CESAER), the Board of European Students of Technology (BEST), and the European Society for Engineering Education (SEFI). The aim of H3E is to promote the development of a European dimension in higher engineering education throughout Europe. This is done through (H3E, 1997A):

• Identifying key factors influencing the development of the European dimension and publishing studies on these factors

• Stimulating discussion and publication of ideas and current practice in engineering education, as well as the development of pilot schemes to demonstrate identified best practice

• Fostering new developments which contribute to the European dimension

The H3E grouping has established five working groups covering developments in areas ranging from motivation for higher engineering studies to continuing education and lifelong learning. The specific theme of quality assurance is studied by the Working Group 2: 'Quality and Recognition in Higher Engineering Education". Its general aims and objectives include developing key principles of quality assurance, identifying possible methods of application of such principles throughout Europe and ultimately, the development of a system of accreditation and self-evaluation (H3E, 1997B). The working group argues that a voluntary self-assessment of educational institutions on the basis of commonly agreed and freely accepted comparison criteria will enhance the European dimension in higher education (H3E, 1997C). Indeed, if one of the greatest strengths of ISO 9000 is its world-wide acceptance and understanding, the broadly-based H3E initiative will certainly contribute to the enhancement of quality assurance in engineering education. However, due care must be given to overcoming drawbacks of existing accreditation schemes, clear definition of quality assurance principles and the emphasis on continuous quality improvement.

2.3.3 Accreditation in Engineering Education

2.3.3.1 Overview

Engineering in Canada and the United States is a regulated profession. What this means is that a national regulatory body, such as the Canadian Council of Professional Engineers (CCPE) in Canada, specifies requirements for people who want to enter the profession. Only the candidates with specified academic qualifications and experience can practice engineering. Applicants who seek registration as professional engineers in Canada must meet the admission requirements set out in CCPE Admission Guidelines (CCPE, 1992). Generally, if an applicant is a graduate of a CEAB accredited institution and possesses specified engineering experience, he/she is not required to pass qualification exams. Otherwise, a comprehensive set of examinations is given to the candidate, including preliminary, basic and complementary studies and discipline (such as Industrial Engineering) exams. Each year, the Canadian Engineering Qualification Board (CEQB), which is a body within CCPE, specifies the knowledge an engineer working in a certain engineering discipline is expected to possess in the Examination Syllabus (CEQB, 1992). For example, an industrial engineer must possess a knowledge of operations research, analysis and design of work, facilities planning, production management, quality planning and analysis, systems simulations, and so on. For each of these subjects, a list of topics covered is specified. In the United States, the Fundamentals of Engineering (FE) Examination is similar in content. There are two parts of an FE exam: general and specific. General covers the knowledge of basic engineering sciences, such as dynamics, mathematics and thermodynamics, and specific covers the knowledge of a specific discipline. The industrial engineering part consists of twenty subjects, among them statistical quality control, TQM and Design of Experiments (Kennedy, 1996).

In the next sections, an illustration of two existing accreditation schemes in engineering education will be presented, focusing on how the schemes address quality issues, as well as their advantages and disadvantages.

2.3.3.2 Canadian Engineering Accreditation Board (CEAB)

2.3.3.2.1 Overview

Engineering faculties in Canada have encountered accreditation of their programs since 1965. That year, the Canadian Council of Professional Engineers (CCPE) established the Canadian Accreditation Board, now known as the Canadian Engineering Accreditation Board (CEAB), to evaluate undergraduate degree programs and accredits those which meet minimum standards. At present, the CEAB is composed of thirteen professional engineers drawn from the private, public and academic sectors (Bilanski, 1996). The procedure for accreditation is the following. The CEAB publishes yearly revised guidelines for accreditation in the form of questionnaires. Questionnaires are completed by the interested engineering department, and sent to the CEAB. This is followed by a site visit, where the CEAB team examines the curriculum content, as well as "the academic and professional quality of the faculty, adequacy of laboratories, equipment and computer facilities and the quality of students' work" (CEAB, 1995). In general, the accreditation is granted for a period of six years.

The following are the highlights of CEAB accreditation criteria (CEAB, 1992):

- engineering degree programs, rather than institutions are accredited.
- criteria address university, engineering unit (faculty), curriculum, students, and facilities
- accreditation is voluntary
- there is only one level of accreditation
- institutions must demonstrate the ability to produce fully qualified graduates
- institutions must provide complete documentation of the means to achieve the objectives
- accreditation may be revoked if a program is not in compliance with CEAB criteria.
- emphasis is placed on faculty work loads, admission policies, academic progress of students, curriculum control, course specifications, and computer and library facilities

2.3.3.2.2 Advantages and Disadvantages

Presenting the experiences from accrediting a mechanical engineering undergraduate program at Queen's University, Jeswiet (1995) insists that the CEAB does not provide guidelines for specific course content. Also, there is a possibility of personal biases of CEAB team members toward a particular area or criterion, and the method of evaluation of necessary credit hours for different courses is not clear. Bilanski (1996) argues that the original mandate of CEAB, being the uniformity of standards for engineering education across Canada, is being carried out. However, the author points out that accreditation does not give a true picture of what is going on in a particular engineering faculty. The author states that "most programs are accredited. Those refused are revisited within two years, minor changes are made and accreditation is given". It is also stated that CEAB does not look into the current underemployment and unemployment of engineers, nor does it address increasing financial cutbacks at universities. To compensate the loss of revenue, many engineering schools, Bilanski argues, have to increase the number of students, lowering the entrance requirements, and thus decreasing the quality of an average graduate. "The present accreditation system is geared to increasing the number of students, rather than to improving the quality of the students" (Bilanski, 1996). Replying to the authors concerns at the 10th Canadian Conference on Engineering Education, the CEAB officials stated that a number of author's critiques are not in the CEAB's mandate, and that economic conditions are also causing underemployment of engineers, and not the CEAB's criteria.

Hyde and Karney (1996) argue that CEAB provides a convenient, standardized measure of adequacy in engineering schools. The biases, emphasized by Jeswiet, are prevented by measures such as not allowing engineers to assess their own institutions, and the ability of a faculty to request substitution of unsuitable CEAB team members. The scheme also provides an external referee to attest to the threat that resource erosion (such as lack of funding), is causing to an engineering program.

2.3.3.3 Accreditation Board For Engineering And Technology (ABET)

2.3.3.3.1 Overview

In the United States, the agency responsible for accreditation of engineering programs is called the "Accreditation Board for Engineering and Technology" or ABET. The primary focus of ABET is to develop accreditation policies and criteria, as well to conduct the evaluation of engineering degree programs according to these criteria. In general, programs that meet the minimum criteria are accredited for a period of six years. The present system of engineering accreditation was developed by The Engineers Council for Professional Development, now known as ABET, in 1932 (ABET, 1997A). The process of evaluating engineering degree programs and awarding accreditation started in 1936. Today, ABET is the sole agency in the United States responsible for accreditation of educational programs leading to degrees in engineering.

Quality of engineering education seems to be the focal point of the ABET accreditation process. ABET "seeks to assure high quality, encourage continuous improvement, and foster innovation in engineering" (ABET, 1997A). The agency's vision statement emphasizes that ABET is primarily responsible for monitoring, evaluating, and certifying the quality of engineering education. However, what is meant by the "quality of engineering education" is left unclear in both the vision statement, and the criteria for accreditation (ABET, 1996). The statement of overall objectives illustrates this: "The purpose of accrediting is to identify those institutions which offer professional programs in engineering worthy of recognition as such". Nevertheless, it is clear that one of the objectives of ABET accreditation is quality assurance, i.e. providing confidence to customers that the requirements for quality are met. In ABET's view, customers are prospective students, educational institutions, professional societies, potential employers, governmental agencies, and state boards of examiners (ABET, 1996).

The following are the highlights of ABET criteria for accreditation:

- educational programs, rather than institutions are accredited.
- criteria address faculty, curriculum, students, administration, facilities and commitment
- accreditation is voluntary, i.e. institutions ask to be accredited themselves, without pressure
- accreditation is possible at either basic or advanced level, the latter being for five-year programs
- broad programs, rather than specialized ones, are favored
- institutions must demonstrate the ability to produce fully qualified graduates
- institutions must provide complete documentation of the means to achieve the objectives
- accreditation is available only if students have graduated from a program prior to evaluation
- accreditation may be revoked if a program is not in compliance with ABET criteria.

If an institution deems to meet ABET criteria, the accreditation process may be started. Similar to the CEAB accreditation scheme in Canada, the procedure for accreditation consists of two basic steps. In the first instance, interested institutions submit a self-study questionnaire, provided by ABET. Subsequently, an ABET team performs a site-visit. The purpose of the site-visit is to assess factors that cannot be described in the questionnaire, as well as to assess the institution's weak and strong points.

2.3.3.3.2 ABET 2000 Criteria

Recently, ABET proposed new engineering accreditation criteria, named ABET 2000 (ABET, 1997B). The criteria have been approved for use in the Fall of 1998. Developed with strong industry input, the criteria foster the engineering faculties to clearly and openly become accountable to the public (Prados, 1997). While the current criteria require about 20 pages, new ABET 2000 has four pages only. The highlights are:

- there are two levels of accreditation: basic and advanced
- there are four objectives of accreditation:

(1) to assure that graduates are adequately prepared to enter and continue the practice

(2) to stimulate the improvement of engineering accreditation

(3) to encourage new approaches to engineering education

(4) to identify accredited programs to the public

- there are eight criteria: students, educational objectives, program outcomes and assessment, professional component, faculty, facilities, institutional support and financial resources, and program criteria
- documented educational objectives are mandatory
- objectives must be periodically reviewed
- there has to be a curriculum that ensures the achievement of these objectives, as well as a system of ongoing evaluation that demonstrates achievement of these objectives
- there are 11 explicitly stated requirements for student knowledge, such as an ability to design and conduct experiments, as well as to analyze and interpret data

It appears that ABET 2000 considers student knowledge to be the primary product of an engineering school, and as such should be evaluated. As Prados (1997) insists, the criteria have been adopted to force attention to the goals of engineering education as expressed in the characteristics and abilities expected of graduates. However, critiques of the new criteria mostly focus on the requirement to assess student learning as the output, rather than assessing the learning process. For example, Dalton (1995) points out that an "outcome" will be very hard to define and measure, questioning even the purpose of assessing outcomes, when well-established quality control techniques (such as SPC) suggest process, rather than product control. This is also the concern of Pagano (1995) who figuratively asks whether we should count beans or inspect the whole crop when assessing engineering programs. Dalton (1995) suggests that the outcome be defined as "what the student can do with what he/she has learned", and surveys of graduating seniors, alumni and employers, exit interviews of graduates, and comments from industrial advisory committees be used in assessing this outcome. This suggestion is in line with Willborn and Cheng's (1994) approach to the quality of results in education, i.e. "the degree to which students individually and collectively have benefited from attending a school". Nevertheless, these results depend on the quality of teaching and learning processes and resources, that should be effectively managed and controlled in order to achieve results (Willborn and Cheng, 1994).

2.4 ISO 9000 IN EDUCATION

2.4.1 The Need

The development of global training and education markets, as well as the decreasing public funding of higher education institutions will, according to Richard Freeman and Frank Voehl (Lewis and Smith, 1994), put universities into the position of being not only market oriented, but market driven. As it is happening in the manufacturing sector today, ISO 9000 registration could become a requirement for any university wanting to do business in the international marketplace. As Doherty (1996) projects, the times when government will apply coercive power to force universities to develop quality assurance systems may not be so far away. Due to the development of new technologies, such as satellite communications, video conferencing and the Internet, distance education is on the rise, allowing universities to penetrate new markets and local market niches that were once the monopoly of a single university or faculty. For example, the Faculty of Management at the University of Manitoba is now facing an increased competition from Eastern Canada and the United States. According to the "Semi-Radical Plan" of the faculty (Faculty of Management, 1996), Western Michigan University is offering a master's degree in health care administration in Manitoba, and several other US schools already offer MBA programs in the Toronto area, "signaling a trend where geographic boundaries are no longer a consideration in delivering programs". Thus, Freeman's and Voehl's suggestion to examine the applicability of ISO 9000 to higher education now, before the universities face the same fate as non-registered manufacturers bidding for international contract seems logical. The authors acknowledge the difficulty in applying ISO 9000 to teaching processes, due to the fact that the product is two folded: it is both the teaching and learning. However, the necessity for a documented quality assurance system is emphasized.

2.4.2 Interpretations

In this section, available interpretations of ISO 9001 standard for education and training institutions will be presented. They include Lewis and Smith's (1996) and Willborn and Cheng's (1994) interpretations, as well as interpretations by the British and French standards association, given in handbooks for the application of BS 5750 (ISO 9000) to education and training.

Out of twenty elements of ISO 9001, Lewis and Smith (1994) consider twelve to be directly applicable: 4.1 Management Responsibility, 4.2 Quality System, 4.3 Contract Review, 4.4 Design Control, 4.6 Purchasing, 4.7 Customer Supplied Product, 4.9 Process Control, 4.13 Control of Nonconforming Products, 4.14 Corrective Action, 4.16 Quality Records, 4.17 Internal Quality Audits and 4.18 Training. It is unclear why the other eight elements are not applicable, especially 4.10 Inspection and Testing and 4.20 Statistical Techniques, which are very important in the teaching/learning process. In fact, as the literature survey shows, much of student motivation to learn comes from the expectation of inspection and testing (see McKeachie, Pintrich, Lin and Smith, 1986).

The documentation process is conceptualized around four basic 'building blocks": Mission, Methods, Interface Points and Standards (from Freeman, 1992). While the mission expresses what the university should achieve, the methods explain what, how and who accomplishes tasks at the university. Points of interface between two functions or people should be documented, because at these points it is critical to assure quality. This actually represents the concept of internal customers and suppliers. Finally, agreed upon standards, e.g. what information a class list should include, must also exist and be documented.

A brief outline of each of the twelve elements of ISO 9001 Freeman and Voehl consider applicable to higher education is also given. The authors emphasize that the management commitment is essential for any ISO 9000 project in a university to succeed. It is not stated, however, who is considered to be 'the management" in a university environment. The difference between procedures and work instructions is clarified, followed by the author's view of the quality loop in higher education. The loop, starting with specifications and planning, through teaching and assessing courses and market research at the end is suggested as a springboard for further discussion and research. Contract review ensures that all parties understand what is expected of them, while design control includes the design of curriculum and course plans, learning and assessment materials and handouts. Purchasing encompasses learning materials and acquisition of consultants and external examiners. Teaching, tutoring, monitoring student progress and assessment of students are topics covered by process control. The authors suggest that the university should determine which of these processes require formal control, and only document these. Control of nonconforming products include damaged books, teaching material and incorrect assessment items. Internal quality audits, quality records and corrective actions are viewed as complementary processes (e.g. corrective action comes after audit to correct a non-compliance). Finally, it is anticipated that all university staff will require proper training, with the university required to identify the training needs, provide the training and keep training records. In summary, although the interpretation presented by Freeman and Voehl can be considered useful, it does not address the ISO 9001 quality system in whole, nor is it consistent in terms of the product of the university or its processes. For example, while in purchasing the product is interpreted as "learning materials and consultants", nonconforming products according to the authors may include "students who have failed tests and assignments". This illustrates the need for a systematic interpretation of ISO 9000 in university environment.

Willborn and Cheng (1994), consider the development of the ISO 9000 quality system beneficial for quality improvement and providing confidence to the interested parties that their expectations from the school or university are met. The authors have transformed the twenty elements of ISO 9001 into seventeen requirements applicable to education. Control of customer supplied product (4.7) has been replaced with "Admission and Support", product identification and traceability (4.8) and the inspection and test status (4.12) have been left out. Control of the inspection and testing equipment (4.11) has been translated as "Validation of Tests and Examinations", and quality records (4.16) are considered as "Student Performance Records". Student failure is conceptualized instead of a nonconforming product, while element 4.15 of ISO 9001 has been broken into two: safety/security and facilities and environment. Requirements 4.18 Training and 4.19 Servicing have been left out. The authors however emphasize that a more detailed interpretation is needed for a full implementation.

In an account of how the Software Engineering Applications Laboratory (SEAL) of the University in Witwatersrand in South Africa obtained an ISO 9001 certificate, Walker (1997) also provides a short interpretation of the ISO 9001 standard. This interpretation was made solely for SEAL's purposes, and is restricted to research activities only. For instance, elements 4.7 Control of customer-supplied product and 4.19 Servicing were not considered as "serious issues" for SEAL, and for the element 4.6 Purchasing, no new documents were created since "all standard university purchasing procedures were followed". It is also stated that contract review (ISO 9001, 4.3) "covers a few areas including the relationship of the student to the supervisor, and when contract work for outside entities is undertaken". Therefore, the focus of this ISO 9001 implementation were the areas where quality problems had been encountered before the introduction of standards.

National institutes for standardization in Britain and France have prepared the guidelines for applying the ISO 9000 series (1987. edition) in higher education (NACCB, 1994; BSI, 1994; AFNOR, 1993). These guidelines assume that educational institutions would be implementing the standards for the development and delivery of courses and programs, and are intended to provide assistance in documentation and implementation. The product is viewed as a learning opportunity, i.e. all processes, materials, skills and professional experience required to develop and deliver a program or a course (NACCB, 1994). It is suggested that where an institution designs courses not as a contractual requirement. i.e. through a standard program, ISO 9002 quality system is required. A typical university department should then conform to the ISO 9002, rather than the ISO 9001 model. This contradicts the findings of Doherty (1995A), who reports that applying the design control and servicing requirements benefited the University of Wolverhampton greatly in terms of a better understanding of the quality system as a whole.

Although the guidelines were meant to be applicable to all levels of education, the main thrust seem to have been placed on training institutes, community colleges and primary and secondary schools, rather than universities. Research activities and research output have not been considered. The management is interpreted as "the Principal, the Director and the Training Manager", which is not applicable to universities. The interpretation that the role of the 'Principal" is played by the Dean is not acceptable in a university, since their authorities and responsibilities are very different. Also, the guidelines often refer to the "middle and top management", and it is not clear what these would be in a university setting. Purchasers are limited to organizations that fund the educational institution or the learner, although the purchasing requirement includes innovative concepts, such as hiring sub-contracted tutors and lecturers. Process control is focused on the learning process, i.e. planning and documenting methods of delivery of courses/programs. It is not clear, however, why the guidelines insist that inspection and testing (sections 4.10 and 4.11 of ISO 9001) applies to the learning process, i.e. curriculum review and learner's feedback, and not the assessment of learner's knowledge through tests and exams. Also, section 4.13 Control of non-conforming product according to the guidelines (NACCB, 1994) applies to the correction of timetable problems, lecture room double bookings and learners' appeals, and not to the learner's knowledge. The BSI Guidelines (BSI, 1994) address these remarks, however, in less detail.

2.4.3 Applications

In an account of developing a quality management system using the ISO 9000 standards in higher education, Doherty (1995A; 1995B) describes how the University of Wolverhampton, England, achieved ISO 9001 registration. The university was formed from a polytechnic in 1989, incorporating the colleges of art, further education, higher education and technology. The motivation for quality management and standardization emerged from the diversity of procedures, policies, value systems and attitudes the colleges brought to the merger, as well as the policy of a newly formed university to broaden access to mature students and students from other areas of England and Europe. The pressure to develop an ISO 9000 quality system had increased when several community colleges in Britain gained the ISO 9000 registration. The faculty of technology considered these colleges as direct competitors.

The development of relevant knowledge, skills and competencies to meet the future needs of industry, commerce and society became the university's mission. At first, faculty and staff were introduced to the concepts of total quality management, such as internal and external customers and continuous improvement of processes. However, it was quickly understood that documenting the quality system first would provide a much better grasp of the university's internal processes and internal and external customers, and that the ISO 9000 system would provide a firm basis for continuous quality improvement. From the three year effort for the registration of the whole university, Doherty drew the following main experience. The key clauses of ISO 9001 were perceived to be 4.3 Contract Review, 4.4 Design Control, 4.5 Document and Data Control, 4.9 Process Control, 4.16 Quality Records, 4.17 Internal Quality Audits and 4.18 Training. While design control requires a university to clearly state what the nature of it's product is, sections 4.9 and 4.3 require the university to demonstrate how the quality of delivery is assured and maintained and how the contractual agreements are met. Keeping records and auditing them, as well as proper personnel training were also deemed important.

Other accounts of establishing ISO 9000 quality systems have emerged just recently, and almost exclusively in Europe and Asia. Several university-based research institutes have achieved registration (Pfeiffer and Wunderlich, 1997; Walker, 1997), as well as some business schools (Gelders et al, 1995). Nevertheless, reported studies have concentrated mainly on a single aspect of university's products and processes, such as just research, or just teaching and curriculum, or just administration. An integrated approach toward a comprehensive quality assurance system is yet to be proposed.

2.4.4 Advantages and Disadvantages

The benefits of ISO 9001 registration in higher education were perceived as:

- clearer grasp of roles, responsibilities and authority (Doherty, 1995A)
- wider understanding of university's objectives
- wider sense of ownership of quality, due to the fact that consultants did not participate

• market advantage nationally and internationally, since ISO 9001 is an international standard, well understood everywhere in the world (Doherty, 1995A; Harris, 1996)

• internal audit as a means of internal benchmarking and spreading good practice

• clearer articulation of the rights and responsibilities of students and staff bodies (Doherty, 1995A; Harris, 1996)

• constantly improving standards of program design, documentation and delivery

• usefulness of the quality system in accreditation by government bodies (Doherty, 1995A; Harris, 1996)

• the standards provide a sound formation for developing and maintaining a world class quality service (Doherty, 1996)

• educational institution can be accredited and internationally recognized after passing the audit

• gaining an image of outstanding quality

• students and staff identify themselves with their educational institution

• process improvement (Willborn and Cheng, 1994; Willborn, 1995)

• quality system saves staff time, increases efficiency and manages activities

Perceived disadvantages in literature were found to be the following:

• ISO 9000 may not be suited to the purposes of all higher education institutions

• fear of too much documentation and paper bureaucracy

• costs (about 600,000 US Dollars for the University of Wolverhampton)

• great amount of staff time and effort (Doherty, 1995A)

• developing quality systems outside of the university department which initially achieved the registration can be very hard (Walker, 1997)

• need for interpretation of the standard for education

• need to develop a method to allow for the flexibility of procedures (Harris, 1996)

The majority of these disadvantages occurred due to the lack of a systematic interpretation and perspectives on quality systems. This thesis, however, attempts to provide a framework which is to overcome the perceived shortfalls.

2.5 STATISTICAL PROCESS CONTROL

2.5.1 Overview

Since the first tool a human made from stone 1,000,000 years BC, mankind has faced and reacted to variation. Early humans dealt with the variation in raw material used for tools and weapons (Provost and Norman, 1990). Today, we are facing variation not only in raw material, but in processes, finished goods, services, and also in education (Lefevre, 1990). Educators have been coping with the variation in student knowledge and skills since the beginning of profession. In a class of 30 students, teachers have learned to expect some excellent students, some good and some not so good. As an engineer's dream is to design a technology that will create virtually identical products, the teacher's dream is to have a class of students that will learn everything he/she taught. However, no two products and no two students are alike. This is called variation. Nevertheless, it is important to recognize that the implications of variation go far beyond what we usually refer as "quality". In manufacturing, variation affects schedules, lead times, inventory levels, order sizes and frequencies (Ranney, 1990). In education, employability of graduates, student satisfaction, graduation lead time, reputation of the university depend on variation in teaching, learning and research processes and outcomes.

The first systematic efforts to control the variation have come from the manufacturing sector. Early last century, final inspection of products was introduced in American armories to control variation in rifles (Provost and Norman, 1990). Good rifles were separated from the bad ones. Later on, tolerances and specifications were introduced. Certain characteristics of a product were measured, and if they fit within established tolerances, the product was considered good.

In the 1930's, a fundamentally new approach to variation emerged, with Walter Shewhart's control chart (Shewhart, 1931). Shewhart recognized that variation exists in every process, but he added that it can be due to natural and unnatural causes. Unnatural or special causes of variation can be identified and eliminated in order to reduce variation. If only natural (common) causes of variation are present in the process, the process is stable over time, i.e. the results fluctuate randomly around a steady average and the magnitude of fluctuation (variation) is also steady (Kirby et al., 1990). In this case, the process should be left alone, otherwise the variation might increase (Boardman and Boardman, 1990). If special causes are present, the measured process statistic exhibits erratical patterns in time. Thus, special causes of variation must be removed. In order to distinguish between special and common causes of variation, Shewhart introduced a control chart (Nolan, 1990). A statistic is plotted on a chart which has three lines: the central line, which is the expected value (μ) of the statistic, the upper control limit (UCL), and the lower control limit (LCL). Control limits are calculated as follows:

$$UCL = \mu + 3\sigma$$

$$LCL = \mu - 3\sigma$$

where σ is the standard deviation of the statistic. The use of the number "three" in the calculation of limits is justified by empirical evidence (Provost and Norman, 1990). Shewhart's works have laid out the ground for modern Statistical Process Control (SPC), a methodology using control charts to control and reduce variation in quality of products and services. Different types of control charts will be outlined in the next section.

It is important to recognize, however, a fundamental difference between the tolerance / specification methods and SPC. The former approach is focused on the outcome of the process (what the customer wants), and not the process itself (see e.g. Mayo, 1990). It's goal is to sort outcomes into acceptable and unacceptable categories (Provost and Norman, 1990). Acceptance sampling is one technique that is used in this approach. On the other hand, SPC is focused on the process, and attempts to reduce the variation before the outcome happens, i.e. it's goal is to remove the causes of the process variation.

Control charts and six other tools (Histograms, Pareto Diagrams, Scatter Diagrams, Flowcharts, Cause-and Effect Diagrams and Checksheets) have been grouped into "The Seven Quality Tools" and are widely used in quality improvement. Design of Experiments (DOE), Taguchi approaches to tolerance design and the loss function, and attempts to even control the variation in people through Senge's learning organization

(Provost and Norman, 1990) have followed SPC. Excellent and comprehensive reviews of SPC and other techniques can be found in Stuart et al. (1996), Montgomery (1992), Tsui (1992) and Hosotani (1991).

2.5.2 Control Charts

A myriad of different types of control charts have been developed in the past decades. Commonly, control charts are categorized into two groups: charts for variables data and charts for attributes data. Variables data are those that are measured along a continuous scale, whereas attributes data assume only two values, such as good or bad, pass or fail and so on (Evans and Lindsay, 1996). The most common variable charts are the "Xbar" and "R" charts, where the Xbar chart is used to monitor the mean of the process, while the R (range) chart is used for monitoring the variance. The range is used as a measure of variation for convenience, although standard deviation (σ) can also be used but takes more time to calculate. The "Xbar" and "R" charts are usually paired for the analysis of data, creating the "Xbar-R" chart. The Xbar-R chart requires taking samples from a population at prescribed intervals of time (these samples are also called subgroups), measuring a statistic (X) from individual items in a sample, and plotting subgroup averages and ranges on the Xbar and R charts, respectively.

It is important to recognize that one of the main reasons for taking samples and plotting the average of subgroup readings, rather than individual values is the response time to detect process shifts. It can be shown mathematically that the first technique reduces the response time significantly with the increase of sample size (Grant and Leavenworth, 1996). Also, according to the Central Limit Theorem, it can be expected that the subgroup averages are distributed normally, which may not be the case for individuals. In some cases, however, it is not possible to take samples, due to the special characteristics of the process. Chemical industry is an example, where continuous processes limit possibilities for sampling. In such cases, a combined individual - moving average (or range) control charts can be used. Measurements are taken from individual observations, however, a moving average (range) of "n" successive observations is also plotted (n remains constant). Although these charts (called I-MA charts) allow direct comparison with specification limits, which is not possible on Xbar-R charts, they are less sensitive to process shifts and assume normal distribution of individual data (Evans and Lindsay, 1996). For short manufacturing runs, pre-control charts are used. The chart divides the tolerance zone into two subzones, and use a number of constructed rules to identify special causes of variation. This chart has similar advantages and shortfalls as the I-MA chart.

For attributes data, several different types of charts are used. The "p" chart monitors the proportion of nonconforming items in a lot, while the "c" and "u" charts monitor the number of defects per item. The "c" chart is used when the subgroup size is constant, and the "u" chart when the subgroup size varies (Evans and Lindsay, 1996). These charts are presented in all basic SPC books, e.g. Grant and Leavenworth, 1996 or Montgomery, 1991.

Much of the recent research on SPC has focused on extensions of the basic Xbar-R control chart methodology and variations of the Shewhart process model (Montgomery, 1992, Lowry and Montgomery, 1995). In order to further reduce the response time to detect process shifts and to improve detection of small shifts, the Cumulative Sum (CUSUM) and exponentially weighted moving average (EWMA) charts were introduced. The CUSUM chart incorporates all past data by plotting cumulative sums of the deviations of sample values from a target value. The EWMA chart is similar to the moving average chart, except for the fact that the data are weighted, with more weight being given to the most recent data (Evans and Lindsay, 1996). This chart is useful when the acceptable process limits are narrow, and is more sensitive to small shifts than the Xbar-R chart (Evans and Lindsay, 1996). However, the EWMA allows for the "inertia effect" (Montgomery, 1992) and may not detect a single large sustained shift as quickly as a Shewhart chart (Montgomery, 1992). These disadvantages are partially overcome by combined Shewhart-EWMA charts (Klein, 1996). Other recent developments in control charts include economically optimal designs (Castillo and Montgomery, 1996; Castillo, Mackin and Montgomery, 1996), multivariate control charts (Lowry and Montgomery, 1995) and charts with adaptive sample sizes (Prabhu et al, 1993; Runger and Montgomery, 1993).

2.5.3 SPC in Higher Education

One of the first articles that suggested the implementation of Statistical Process Control in education and training is Zaciewski's (1993) work on instructional process control. The evaluation of the capability and predictability of the instructional process is suggested, with examples given for the improvement of competencies of quality control instructors. However, it is not explained how the capability of the instructional process is to be measured, evaluated and improved. Some insight into these issues has been recently tackled by Ensby and Mahmoodi (1997). The authors emphasize the need for an implementation of a structured approach to eliminate common causes of variation in the classroom, and suggest that professors apply trend analysis to accomplish this. For example, a high miss rate on a test question indicates a potential common cause, resulting possibly from confusing wording or insufficient presentation of a concept during class. It is unclear, however, why the authors consider this a "common cause of variation", since a common cause is defined as "the result of many imperceptible changes that occur in the everyday operation of a process, creating natural, uncontrollable outcomes" (Deming, 1986). Special causes, on the other hand, can be attributed to specific actions of the process and individuals. Thus, it is apparent that the professor's failure to clarify the particular question on a particular test is a special, and not a common cause.

Application of statistical process control in education is addressed in a number of recently published books (Arcaro Jerome, 1995 A, B; Arcaro Janice, 1995; Lewis and Smith, 1994; Scholtes, 1994). The tools of statistical process control, namely time plots, as well as control and run charts are explained, followed by one or two examples of possible use in schools. While virtually all authors consider the applications in primary and secondary schools, no examples or applications in teaching or learning process control are available. The examples provided in the literature address administrative issues mostly, such as student movement in halls (Scholtes, 1994), faculty and staff turnover (Lewis and Smith, 1994) or individual student test scores (Arcaro Jerome, 1995A). Sampling for control charts is not addressed. An interesting idea about sampling, however, is presented in Bailey and Bennett (1996). The authors argue that since multiple testing of each student in each course in each semester is neither efficient nor effective, only some students each semester should be randomly selected for testing to determine if the teaching process is working. The size of the sample should be determined empirically and based on natural variation.

Lewis and Smith (1994) also provide a number of interesting case studies of applying quality tools at Oregon State University. For example, the time to process grants was focused. After flowcharting the process, several time-wasting loops were discovered. Procedures were improved and this resulted in decreasing the average time to process grants by 34% (Coate, 1992). However, it appears that the SPC efforts were concentrated in administrative areas, such as public safety, computer services, budgets and physical plant, and that the teaching/learning processes were not focused as much.

2.6 TEACHING/LEARNING ASSESSMENT

One of the problems educators have faced since the beginning of structured teaching/learning education process is how to understand what the learners - students, have learned from their teachings. Much like in the manufacturing environment, where products are tested and inspected on a continuous basis, the teachers have relied on inspecting students' knowledge using exams, tests, assignments, quizzes and other techniques developed over the centuries. When using these types of assessment techniques, teachers often expect that, both qualitatively and quantitatively, the matter taught equals the matter learned. However, this may not always be the case. As Angelo and Cross (1993) emphasize, college instructors who have assumed that their students were learning what they were trying to teach them are regularly faced with disappointing evidence to the contrary when they grade tests and term papers.

In order to prevent such surprises in final stages of student evaluation, a number of Classroom Assessment Techniques (CATs) have been developed. A compendium of fifty CATs is given in the Angelo and Cross's book "Classroom Assessment Techniques: Handbook for College Teachers" (Angelo and Cross, 1993). As the authors explain, classroom assessment "helps individual college teachers obtain useful feedback on what, how much, and how well their students are learning". The focus is on continuous evaluation of student learning, and improving the effectiveness and efficiency of interfaces between the teaching and learning processes. This movement from final exams as the only criterion for assessing student's knowledge toward continuous monitoring of the learning process is strikingly similar with the manufacturing approaches toward quality. While in the last century or so manufacturers were only performing final inspections distinguishing "good" parts from the "bad" ones, today they build in quality to the product by continuously monitoring manufacturing processes using such techniques as Statistical Process Control (SPC), Design of Experiments (DOE) and Quality Function Deployment (QFD).

In the aforementioned book, Angelo and Cross present twenty seven CATs for assessing course-related knowledge and skills, thirteen techniques for assessing learner attitudes, values and self-awareness, and ten CATs for assessment of learner reactions to instruction. All four examples of CATs reported to have been used in engineering faculties, out of 150 examples given, fall in the first category (course related knowledge and skills). They are the following: Approximate Analogies, Background Knowledge Probe, Pro and Con Grid, and Student-Generated Test Questions. Other techniques that may be useful in the engineering environment include: Focused Listing, Empty Outlines, Minute Paper, Application Cards, Chain Notes and Exam Evaluations. None of the techniques suggested in this book, however, is able to quantitatively present the degree to which the students have acquired the knowledge of most important aspects of matter taught, e.g. to answer the question: "In terms of the critical points taught, how many students have learned them from my lecture today?"

Another question that is often asked when assessing student knowledge is: what type of knowledge to assess. The famous Bloom's Taxonomy (Bloom, 1956; Bloom, Hastings and Madaus, 1971) categorizes cognitive abilities in the following six elements: knowledge, comprehension, application, analysis, synthesis and evaluation. In the past, engineers spent most of their time substituting values into formulas they usually knew by heart and obtaining numerical results. Today, however, almost all numerical calculations are left to computers. As Cengel and Boles (1994) state. "tomorrow's engineer would have to have a clear understanding and firm grasp of the basic principles in order to understand, formulate, and interpret the results of even the most complex problems". Without the clear understanding of the basics, computer generated results will be misinterpreted and will lead to serious errors. The results of the study of 2,824 university teachers indicate that the majority (66%) of engineering professors perceive their primary teaching role as developing higher-order thinking skills and fostering student development (Angelo and Cross, 1993).

The importance of adequate student evaluation is emphasized by research findings suggesting that student concentrate their learning on whatever they think they will be tested on (McKeachie, Pintrich, Lin and Smith, 1986). As the authors state, "students' goals are strongly influenced by tests or the other activities that determine grades".

Engineering educators have also focused their efforts on improving the assessment of student knowledge and skills. In the United States, these efforts have been recently channeled by evaluation and assessment projects of engineering coalitions, as well as new ABET 2000 criteria that require the assessment of student learning outcomes as a criterion for the accreditation of engineering faculties. In the process, several new techniques were developed and old methods improved. For example, Yokomoto (1995) uses pre-exam and post-exam quizzes for the assessment of effectiveness of short and long problems given on exams. The quizzes, containing short and multiple choice problems were administered before and after the exam, which contained a few formal and longer problems. While the pre-exam quiz was written without any knowledge of student capabilities, the post-exam quiz was prepared after marking the formal exam. The results of the study show that the correlation of the post-exam quiz with the formal exam in terms of students' scores was much higher than the correlation of the pre-exam quiz and the exam. The authors thus conclude that exams consisting of short problems, if intended as substitutes for formal problems must be carefully constructed, with at least some previous knowledge of the students' capabilities.

A similar 'before and after" method of assessing learning outcomes is suggested by Bold, Budny and Ward (1995). In the article, the authors present the student self-report method used by Purdue University to provide information on incoming knowledge of students and the quality of courses and resources. At the beginning and at the end of first year mathematics and chemistry courses, students completed a survey about their knowledge and background of mathematics and chemistry. They were asked if they had ever heard of certain concepts or words and if they had, to assess their knowledge about the subject on a 1-5 scale. The study has shown very large gains in self-reports of both mathematics and chemistry knowledge. Purdue university utilizes self-reports for assessing pre-college backgrounds and optimal placements of students in the first year courses. Yet another approach is provided by Schneider and Niederjohn (1995), who apply graduating senior exit surveys and alumni surveys in assessing learning outcomes. Bakos (1996), insists that a number of measures, such as accreditation, standard testing measures, teacher evaluations, alumni achievements, career services data and student internship feedback be used in evaluating outcomes.

Another issue that continues to be debated is teacher/professor evaluation, i.e. how to evaluate the performance of faculty? Universities usually rely on student evaluations of professor's performance in a course, thereby assessing the professor's teaching performance (Doyle, 1975). Peer review is used in most cases where the professor's research and service to the university community is assessed. The discussion on this matter is outside the scope of this thesis, nevertheless an interested reader could find a number of articles in current engineering education literature that deals with these issues. Examples include Janna and Jakubowski's (1991) article on a rating system for evaluating the performance of engineering faculty, articles on judging the quality of research (Doyle and Arthurs, 1996; Duggins, 1996) and Armstrong's and Sperry's (1994) article on research versus teaching.

2.7 MOTIVATION FOR RESEARCH

A number of authors have expressed concerns for the quality in university education and have emphasized the need for research in this area. For example, Lewis and Smith (1994), report a number of reasons for a renewed focus on quality in education:

- The environment is changing more rapidly than in the past: sensitivity of universities to these changes is imperative

• Structure of enrollment is changing: by the year 2000 over 50% of the student body will be over 25 years of age, with an ever increasing number of part time students

• Increased market forces: students believe that higher education will provide the key to employment and career growth and assess the value of a degree based on criteria such as service, quality learning, timeliness and price

• Technological developments shrink the world and increase competition among universities: Geographical location as a barrier is eliminated and universities will face competition from the private sector, which spent $48 million for training programs, partially due to dissatisfaction with products and services received from universities

As Farahmad and Ashtijou (1995) argue, engineering education in particular must focus on staying current with the most popular standard series in the global market today to remain flexible and respond to market needs. According to Yankelovich (Edgerton, 1993), 88% of the people think that a high school diploma is no longer a enough to qualify for a well paying job, and 73% agree that having a college degree is very important in getting a job. However, whether universities should teach what the employers want is still a question open to discussion and heated debates in academia. While the traditional approach conceptualizes universities as 'institutions for creating, preserving and communication of knowledge" (Mission of the University of Manitoba, 1997), and that higher education should not directly relate to the world of business, which is according to Lewis and Smith (1994) still the view of many academics, a number of papers and books challenging this view have emerged recently. For instance, Seymour (1993) emphasizes that the longer we refuse to address the gap between what universities produce in terms of learning and what industry requires, the more drag it will create on economy and global competitiveness. The importance of industry as customers of engineering education is further emphasized by the inclusion of cooperative education programs in the ten most outstanding engineering education and engineering technology achievements of the past century (Burnet and Greisch, 1993).

The gap between the quality practices taught in the university courses and those actually practiced by university presents an emerging and expanding danger. Quality Progress, a periodical of the American Society For Quality (ASQ), publishes yearly a list of universities and community colleges which practice quality in administration or teach courses in quality. The results are based on a survey sent to the universities which are part of TQM networks or appeared in the previous listings (Klaus, 1996). However, since audits of these institutions are not performed, it is not clear how the responses are verified. For that matter, a simple histogram of the response time of staff in a student cafeteria may be considered as enough evidence for the claim. Also, as Ensby and Mahmoodi (1997) point out, "while many post-secondary institutions are implementing quality practices in administration, few are implementing them in classrooms. If professors have no valid proof that their processes are in control, they cannot readily disprove a claim that their instructional systems are the cause of poor student performance; nor can they claim credit when student performance is exceptional". It is obvious that an international standard, such as ISO 9000, would greatly assist the universities in providing confidence to customers that quality is indeed practiced. Matthews' (1993) concerns illustrate this. The author argues that academia has tackled the easy elements of implementing TQM within its own walls by introducing courses on quality management, but there is a real danger of academia teaching one set of values and adopting a different set for itself.

To summarize, the words of the quality pioneer Armand Feigenbaum illustrate the importance of research in the quality of education: 'We must look at far more than just the curriculum issues; we cannot simply create a structure with some quality courses and a quality department, and label this a broad quality education initiative...Research in quality must be stressed as one of the keys to the growth of quality throughout the educational infrastructure" (Feigenbaum, 1994)

We can, therefore, conclude that the current literature on quality assurance systems and quality in university education illustrates a significant need for research. In terms of quality assurance systems and models, the following shortfalls are perceived:

- the structure of quality assurance models, including ISO 9001, 9002, 9003 does not allow for the integration of quality assurance and quality management systems, including total quality management and quality improvement
- current ISO 9000 models provide the composition of quality systems in a confusing manner, with a lack of focus on the systems concept

• integration with environmental management and workplace health and safety systems is impeded due to the lack of understanding of the underlying system concept

• documentation and implementation of the ISO 9000 quality systems is often ineffective and inefficient due to failed conceptualization of quality assurance and quality systems

Viewing the university as a system analog to a manufacturing organization certainly helps the quality assurance efforts in higher education. Customers and suppliers of the university can be defined, as well as the products and services that need to possess certain quality characteristics to satisfy the customer. Undoubtedly, there is an abundance of literature determining the university customers. However, most of the available analyses lack:

• a comprehensive outline of university's products

• identification of links between specific customers and products

• recognition that research output is indeed a product

• identification of student knowledge and competence as one of the measurable products

• explanations of product quality characteristics

• an outline of university suppliers in terms of the learning opportunity and research

• explanation of the difference between the 'learning opportunity', learning and teaching

As a world-wide accepted and generic quality assurance program, ISO 9000 standards have been introduced to educational institutions mainly in Europe. The survey on available literature on the subject reveals the following facts.

• in the majority of cases, the standards have been implemented in administrative functions and mainly in community colleges

• research, i.e. creation of new knowledge has not been covered by the ISO 9000 quality system

• interpretations of the standard have not used the system concept

• for reasons unknown to the author of this thesis, the interpretations have failed to include all twenty elements of the ISO 9001 standard, arguing that some of the elements are not applicable

• procedures for documentation or implementation of the standard in a university environment are not available

• quality improvement methodology, such as internal quality audits and statistical techniques are not addressed and procedures for implementation are not available

• lack of a quality system description

• emerging integration of quality, environmental and health and safety systems

The literature survey also indicates that ISO 9000 systems are rarely considered to facilitate process control and improvement in universities, especially in teaching, learning and research processes. Sparse literature on the implementation of Statistical Process Control in the university education almost always focuses on administrative processes, such as administration of funds or students' movement between classrooms, and not teaching and learning. Although a number of techniques for assessment of student knowledge exist, a comprehensive model for control of teaching and learning processes at various levels of university teaching, such as lectures, laboratories and tutorials is yet to be proposed. Also in terms of products and processes of the university, the literature survey indicates the lack of a set of measurable quality characteristics.

2.8 RESEARCH OBJECTIVES

The following are the objectives of the research presented in this thesis:

1• Develop a model of a quality system that will facilitate:

- integration of quality assurance and quality management systems, including total quality management and quality improvement
- integration with environmental management and workplace health and safety systems
- better understanding of quality assurance concepts
- documentation and implementation based on system engineering

2• Propose an improved model of the ISO 9001 quality system, considering:

- quality system structure and quality loop
- composition of quality system elements

3• Develop a model of the university education system considering:

- customers, suppliers and products
- research as an integral part of the university's products (services)
- links between specific customers and products
- product quality characteristics
- interrelationship of teaching, learning and research processes
- application of the ISO 9001 quality system in the university environment

4• Provide an interpretation of the ISO 9001 standard for a university, incorporating:

- the system approach to quality assurance
- model of the university education system developed
- examples of the impact of the quality system on the university

5• Compare the current engineering education accreditation schemes in Canada and the United States with the interpreted ISO 9001 quality system, and identify possibilities for developing the quality system on the basis of accreditation schemes

6• Develop a procedure for documentation and implementation of the ISO 9001 quality system in an engineering department, focusing on process control, internal quality audits and statistical techniques

7• Provide an example of the quality system objective in education and a case study of achieving the objective

8• Develop an SPC model for control of the teaching process considering:

- lectures
- tutorials
- laboratory experiments

9• Provide a set of product quality characteristics products using a modified Analytic Hierarchy Process (AHP).

The relationships of these objectives and specific chapters of the thesis are presented in Figure 2.1.

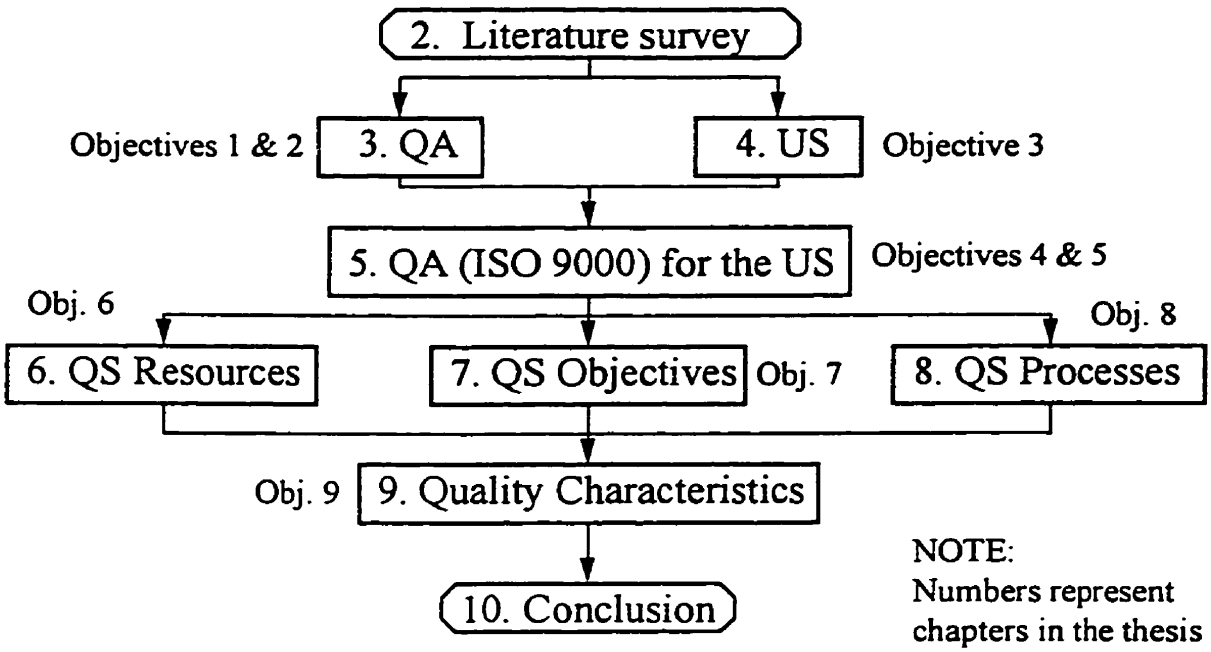


FIGURE 2.1: Research Objectives

CHAPTER THREE

QUALITY ASSURANCE: A SYSTEMS APPROACH

In this chapter, a model of the quality system considering processes, resources and objectives is developed. The model is based on the definition of a system as a set of interdependent processes that function harmoniously, using various resources to achieve objectives. Then, the control of the quality system is discussed, using a closed system model with a negative feedback loop. Certain processes, such as quality planning, quality control, quality improvement and quality assurance are clarified. Subsequently, the ISO 9001 quality system is restructured and recomposed using this model. Instead of the current twenty elements, two groups with a total of thirteen elements are proposed. The virtue of the presented quality system model is that it allows for the integration of quality assurance and other related assurance systems, such as environment and health and safety. Thus, an ISO 14001 environmental management standard is presented using this model.

3.1 QUALITY ASSURANCE AND A QUALITY SYSTEM

3.1.1 Quality Assurance

Since the dawn of humanity, people have been making goods to meet their needs. Moreover, this human need was the driving force for the creation of most, if not all products and services. As the proverb says, 'necessity is the mother of invention'. Today, the ability of the product or service to satisfy needs is often called 'quality'. As the complexity of products grew with time and technological advances, it was no longer possible for an individual to produce everything he/she needed, and exchange of goods and services emerged. People started to make products that would meet someone else's needs, in order to meet their own. This second party was later named 'the customer'. The customer, however, did not have control over the production, and thus had to be convinced that the product would indeed do what it was intended to, i.e. be fit for use. Apart from this fitness-for-use, the customer wanted the product to be safe, inexpensive, dependable and repairable. Indeed, the customer wanted assurance that his/her needs and requirements would be met. Quality assurance was born.

Today, as in the past, producers of goods and services must provide confidence to their customers that the requirements for quality are and will be met. To achieve this quality assurance, a number of engineering disciplines and programs which govern the quality, safety, reliability and dependability of products have been introduced. Halper (1978) refers to these disciplines, examples of which include quality control, reliability and maintenance engineering, as 'assurance sciences'. In the last two decades, quality assurance programs have been significantly influenced by quality standards, such as the Canadian Standard Z299, British BS 5750 and the International ISO 9000 standards. As it was illustrated in Chapter 2, these standards present models and guidelines for quality assurance in an organization.

It is widely recognized that quality assurance must be a 'systematic effort' (Kirstein, 1996; Deming, 1986). Quality pioneer Dr. W. Edwards Deming further emphasized that the appreciation of the system is crucial (Deming, 1986). Also, thinking in terms of systems is necessary for successful implementation of any quality related project, such as ISO 9000 (Velury, 1996). Nevertheless, the current structure of ISO 9000 standards, an abundance of failed or ill-implemented quality programs and a serious confusion in quality terminology and communication indicate the need for a clear, engineering conceptualization of the system in-general. An example of one such shortfall is provided. ISO 9000 standards define the quality system as the 'organizational structure, resources, processes, procedures needed to implement quality management' (ISO 8402, 1994). This definition only states the necessary elements of the quality system, not implying that the quality system is really *a system*. While the *composition* of the quality system (elements) is indeed illustrated, it's *structure* (interrelationships between the elements) is left out. The definition does not point out that the system is driven by certain objectives, nor that it is embedded in its environment and interacts with the environment.

Another upcoming major issue is the integration of quality assurance and other systems, such as environmental management, health/safety and maintenance. The current structure of quality assurance models does not allow for this integration.

3.1.2 System

When parts, resources, activities or processes perform interdependently within a unified whole to achieve a common objective, this whole is viewed as a system (Cleland and King, 1983). In fact, we can claim that everything in our real and conceptual world can be viewed as a system, or at least as a part of one. The Earth as a planet is a part of our solar system, the heart belongs to the human body, and the steering wheel to an automobile. With resources such as gasoline and oil, and the internal combustion process in the engine, the driver of an automobile can achieve his/her objective of moving from place A to place B. Thus, we can define the system using it's main elements: resources, processes and objectives.

DEFINITION 3.1: **System** is a set of interdependent *processes*, that function harmoniously, using various *resources*, to achieve an *objective*.

It is important to recognize that, at least in an engineering perspective, the *objective* defines and drives the system. We build cars in order to transport people and goods. The car, as a system, is meant to accomplish this objective. *Processes* within the system transform input into output, using various *resources*. Another common feature of a system is that it is embedded in its *environment* and is connected with other systems. We often define the system boundaries by relating it to other systems or its environment. The interrelationships among objectives, processes and resources can be explained using a simple graphical model of a system illustrated in Figure 3.1.

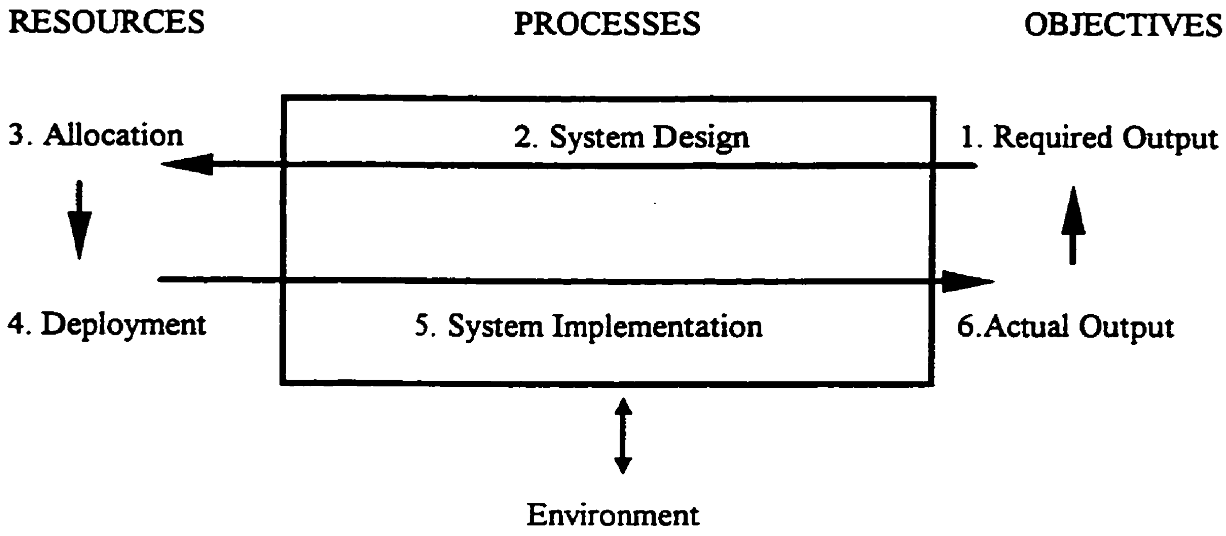


FIGURE 3.1: A Simple Graphical Model of a System (Karapetrovic & Willborn, 1998A)

Firstly, the objective of the system must be defined, in terms of what the required output is. This is followed by the design of the system that will achieve the required objective. Necessary resources are procured (step 3) and deployed (step 4) into the processes that transform input into output (step 5). The result is the actual output, which is compared with the required output (step 6). Definition 3.1 and the model presented in Figure 3.1 will now be applied to quality and quality assurance.

3.1.3 Quality System

Quality does not just happen. It is planned, designed, created and improved. In other words, quality is the result of a "systematic" effort. It is the objective we strive to accomplish. Therefore, in order to create quality, we must have a system. We often refer to this system as the "Quality System". Using the definition of a system, we can now define the Quality System.

DEFINITION 3.2: **Quality System** is a set of interdependent processes that function harmoniously, using various resources, to achieve the objectives related to quality.

The objectives of the quality system are focused on meeting and exceeding customer expectations and requirements. Processes within the quality system transform customer requirements (required output) into the product bearing the ability to satisfy the requirements (actual output). Under the system approach, quality is the actual output of the quality system (Figure 3.2).

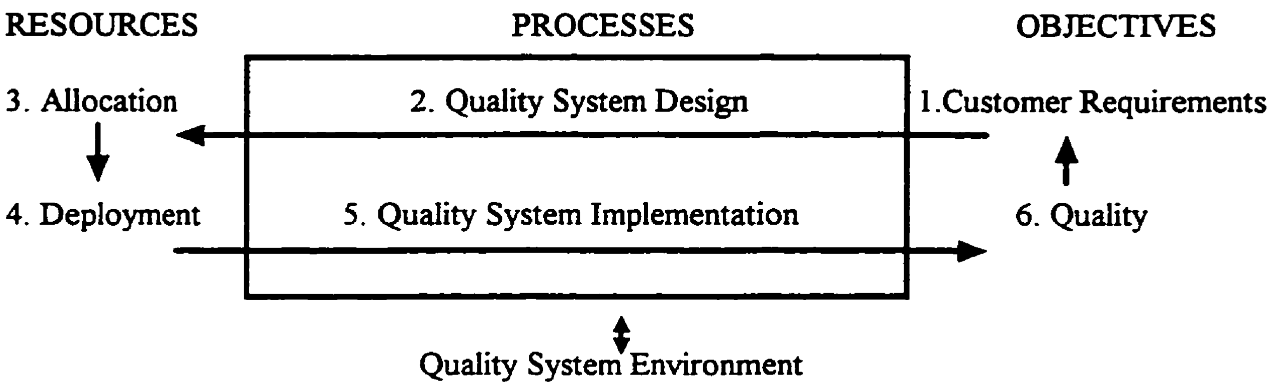


FIGURE 3.2: A Simple Graphical Model of a Quality System (Karapetrovic & Willborn, 1998A)

DEFINITION 3.3: **Quality** is a set of characteristics of a product that satisfy needs and requirements.

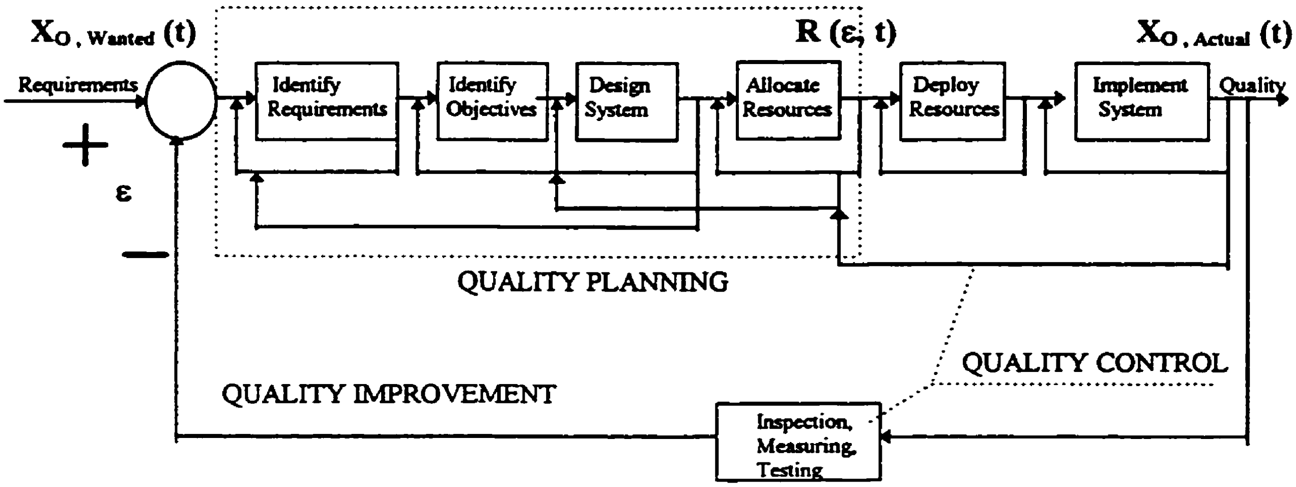
The Quality System, as any system, must be designed once the mission, objectives and requirements for quality are specified. As shown in Figure 3.2, the design process (Step 2) moves from the requirements (Step 1) to the procuring of the required resources (Step 3). Quality Function Deployment is one of the methods applied in the first two steps (see Chapter 7). The human and material resources are then deployed (Step 4) into various production and control processes (Step 5). The achieved quality should be compatible with the specified requirements. Otherwise, corrective action is taken, and the six steps start again. This resembles the Shewhart's Plan-Do-Study-Act circle (Deming, 1986). Of course, this is a simplified and a condensed view of the quality system. A more detailed model is presented in the next section.

Like any system producing meaningful outputs, a quality system must be controlled. Otherwise, the entropy of the system increases, and according to the first rule of organization (Klarin, 1994), the system becomes chaotic and is not able to produce desired output, i.e. quality. The quality system model presented in figure 3.2 indicates that a quality system is a closed-loop system, because the actual output is compared with the desired output to analyze the effectiveness of the system (Ogata, 1970; Phelan, 1977; Hale, 1988). Therefore, a quality system can be illustrated with a block-diagram of a closed system with a negative feedback loop (Figure 3.3).

As mentioned previously, objectives for quality are focused on the customer's expectations, needs and requirements, as well as the needs and interests of the organization itself. These objectives represent the desired output [$X_{O,\ Wanted}(t)$] that defines and drives the quality system. The ISO 9004-1 standard (1994) states: "A quality system should be developed and implemented for the purpose of accomplishing the objectives set out in the organization's quality policy". In order to accomplish the objectives, customer's requirements must be identified. Both the customers expectations and the organization's needs can change with time, so the desired output is dependent on time. Then, we need to evaluate whether it is possible to meet these requirements effectively and efficiently.

If the requirements are feasible, we set the objectives for quality, design the system that will accomplish these objectives, and allocate the necessary resources. Quality planning is a process which encompasses these "sub-processes". Each subprocess is subject to some sort of quality control, represented by feedback loops. For example, objectives represent the input to the subprocess of designing the system. The output of this subprocess, i.e. system design, is compared with the objectives. System design may or may not meet the objectives. If it does not, it has to be modified. Also, system design may or may not meet the requirements, requiring an additional feedback loop to compare design with the system's requirements. Yet another example of a quality control feedback loop is when the deployment of resources is compared with the planned allocation of resources, i.e. the question whether adequate resources are being used (Figure 3.3).

QUALITY SYSTEM: PROCESSES



QUALITY SYSTEM: RESOURCES

- PEOPLE
- MATERIAL
- INFORMATION (Documentation)

QUALITY SYSTEM: OBJECTIVES

- QUALITY POLICY
- MISSION
- LONG AND SHORT-TERM GOALS

FIGURE 3.3: Quality System Processes, Resources and Objectives

Based on quality planning, resources are then deployed and the system is implemented. Essentially, the latter two processes are controlled by quality planning, or more precise with it's output: quality plans. This is analog to an automatic control system where the controller (quality planning) regulates the object (quality system) with it's output (quality plans). The regulating function R is dependent on the difference between the desired and actual output (ε) and time (t). Finally, an actual output (quality) is created and, at a certain point of time (t_i), compared with the initial customer's requirements ($\varepsilon = X_{O,\,Actual} - X_{O,\,Wanted}$). The comparator is symbolically presented with a circle in Figure 3.3. If requirements exceed output quality, a defect is created ($\varepsilon < 0$). If they are equal, then the requirements are met ($\varepsilon=0$). If the output quality exceeds requirements, customer's expectations are surpassed ($\varepsilon>0$). These three cases are represented by equation 3.1.

EQUATION 3.1:

$$\varepsilon = X_{O,\,Actual} - X_{O,\,Wanted} < 0 \quad \Rightarrow \text{Defect}$$

$$\varepsilon = X_{O,\,Actual} - X_{O,\,Wanted} > 0 \quad \Rightarrow \text{Requirements Surpassed}$$

$$\varepsilon = X_{O,\,Actual} - X_{O,\,Wanted} = 0 \quad \Rightarrow \text{Requirements Met}$$

However, we can still strive to achieve a level of quality never achieved before. We can set new objectives (such as "zero-defect students", Chapter 7), and create an output that, over time, is approaching this objective. Consequently, the difference between the required and actual output will become zero. We have increased the effectiveness and efficiency of our quality system. This process is called "quality improvement". Quality assurance (QA) is a process comprised of quality planning (QP), quality control (QC) and quality improvement (QI): Equation 3.2.

EQUATION 3.2:

$$\mathbf{QA = QP + QC + QI}$$

To execute the processes of quality planning, creating, control and improvement, resources are needed. Resources within the quality system consist of people, material and information. Part of the information resources is quality system documentation, such as quality manuals, procedures and records. Objectives are stated in the quality policy, mission and long/short term goals statements. A quality manual describes the quality system, and makes references to quality system procedures. These procedures, along with work instructions, describe the processes within the quality system.

With an established and controlled quality system, an organization can provide confidence to customers that their requirements for quality will be met. In doing so, it can concentrate on the product, departmental functions creating products, or both (Figure 3.4). The latter actually focuses on a matrix-type organization (Klarin, 1994). A well accepted quality system for this kind of assurance is provided by the ISO 9001 model. In the next sections, the model is re-engineered to facilitate the system approach.

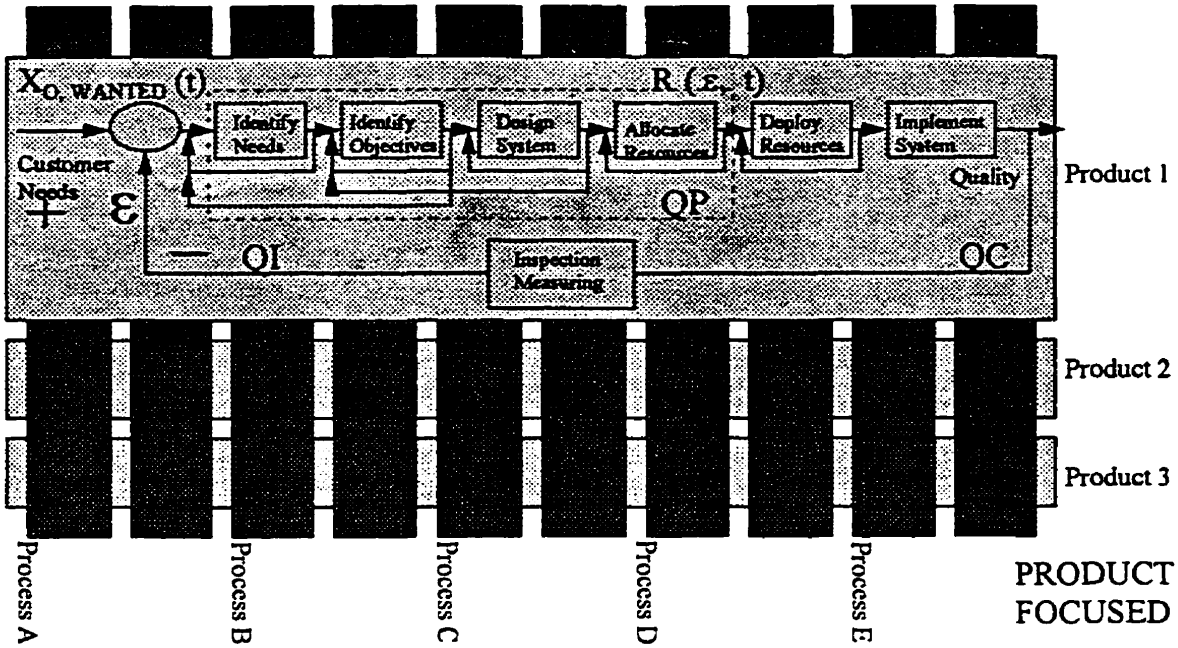


FIGURE 3.4: Product and Function Focused Quality System

3.2 ISO 9001

3.2.1 Systems Approach to the Structure of ISO 9001

In the ISO 9001, 1994 standard, a quality system consists of twenty elements, laid out as requirements of the standard. The following is the list of these elements, as arranged in the current standard (Figure 3.5).

4.1 Management responsibility	4.11 Control of inspection, etc. equipment
4.2 Quality system	4.12 Inspection and test status
4.3 Contract review	4.13 Control of nonconforming product
4.4 Design control	4.14 Corrective and preventive action
4.5 Document and data control	4.15 Handling, storage, packaging, etc.
4.6 Purchasing	4.16 Control of quality records
4.7 Control of customer supplied product	4.17 Internal quality audits
4.8 Product identification and traceability	4.18 Training
4.9 Process control	4.19 Servicing
4.10 Inspection and testing	4.20 Statistical techniques

FIGURE 3.5: Current ISO 9001 Standard

It is evident that the interrelationships between these twenty elements are not clearly stated. Thus it is hard to understand the interdependencies of the processes designed to achieve the set objective. Definition 3.2 and the schematic model from figure 3.2 have been applied to rearrange the elements under the system approach (Figure 3.6).

Requirements for quality are set in the contract and subsequently reviewed by the customer and supplier. This process corresponds to the element 4.3 Contract review. The product is then designed (4.4 Design control), and a quality plan (4.2.3 Quality plans) prepared. This is followed by the procurement of necessary resources. The requirements for these processes are set in sections 4.6 Purchasing, 4.7 Control of customer-supplied product, and 4.11 Control of inspection, measuring and test equipment. Then, the resources are deployed. In addition, human resources have to be trained to effectively accomplish the objectives (4.18 Training). The product undergoes processing (4.9 Process control), handling, storage packaging and delivery (section 4.15). It is inspected and tested (section 4.10), and its inspection status recorded (4.12). Nonconforming products are removed (4.13), and corrective actions implemented (4.14). Finally, servicing (4.19) is available if required. This sequence of elements represents a typical "quality loop" (see ISO 9004-1, 1994), a model of interacting activities that influence quality at various stages of a product life cycle.

The processes described above are supported by the remaining seven elements of ISO 9001, which have been named "supporting resource elements". Management responsibility is implied in each element, and in the quality system as a whole. Sections 4.2 Quality system, 4.5 Document and data control, and 4.16 Control of quality records illustrate the necessary documentation resources for successful management of the quality system. Throughout its life-cycle, the product is identified and its traceability provided (section 4.8). Two of the remaining elements, 4.17 Internal quality audits and 4.20 Statistical techniques support and improve the quality system in whole, as well as its individual elements.

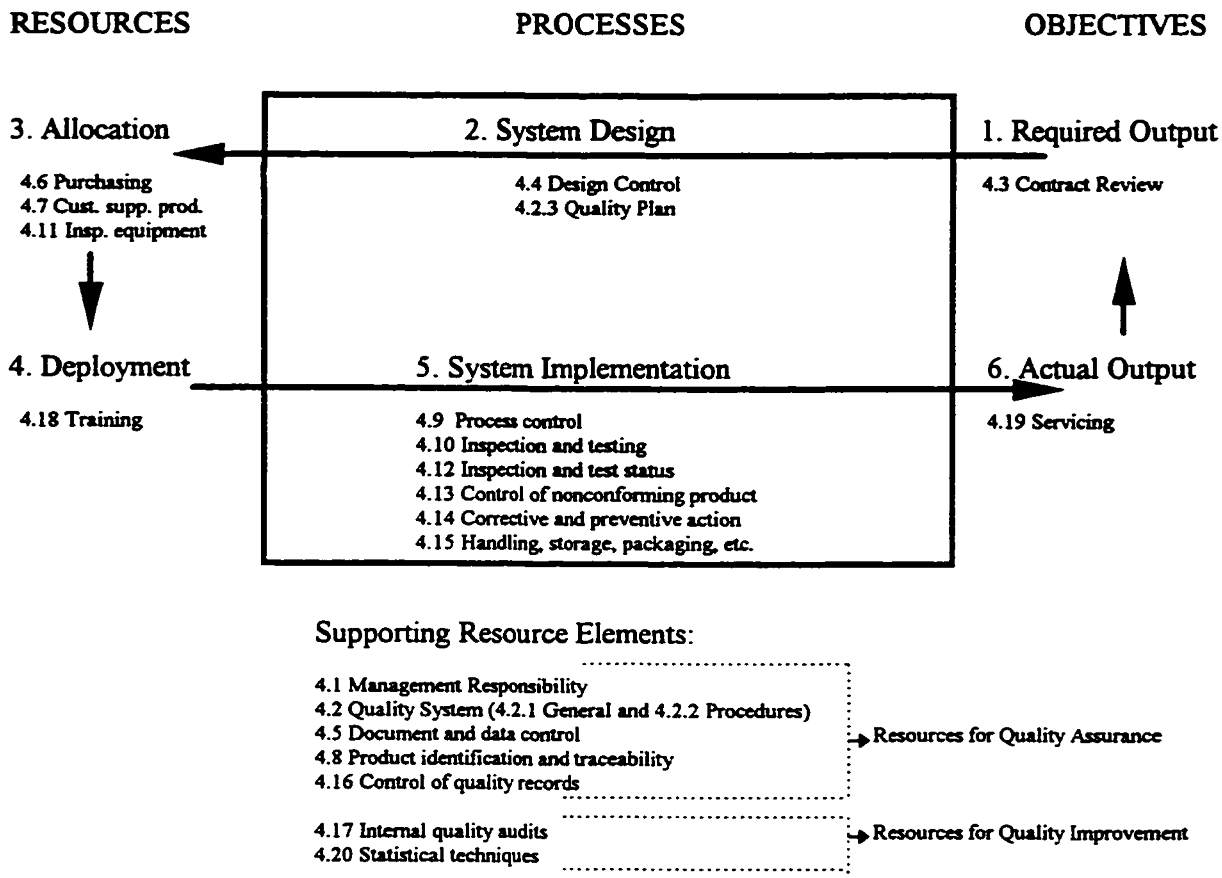


FIGURE 3.6: Graphical Model of an ISO 9001 Quality System (modified from Karapetrovic & Willborn, 1998A)

One important advantage of this systems approach is that it allows us to show basic interdependencies of the twenty elements of ISO 9001. Furthermore, these interrelated processes can be identified as separate subsystems. In fact the quality system, here ISO 9001, comprises several interlinked sub-systems. Design control, purchasing, process control and testing are such subsystems. Each of these subsystems complies with the basic "system" concept. It comprises certain processes and activities that move towards achieving a common objective. In other words, the quality system is actually a "system of systems". The more complex the quality system, the more interlinked subsystems will exist. Also, these subsystems may be a part of another system within an organization. For instance, material handling and preservation may be considered as a part of the environmental management system. This shows that the system approach allows for the integration of different systems and/or subsystems into a supra-system, that may be referred to as the "production" system (see section 3.3 and chapter 4).

Another advantage of this regrouping is in the implementation aspect of the ISO 9001. Assuming that there is a logic behind the ordering of elements of the ISO 9001, some organizations document and implement these elements in the order in which they are written, i.e. 4.1 Management Responsibility first, then 4.2 Quality System, then 4.3 and so on. While the necessity of providing management commitment first is not questioned here, documenting and implementing document control (4.5) just after design control (4.4) and before purchasing (4.6), for instance, may cause an organization to lose it's focus on the quality system. Instead of focusing on designing the system, it focuses on the design of the documentation (Velury, 1996). The systems approach to ISO 9001 facilitates a better understanding of the quality system's structure, and focuses the implementation efforts on the thirteen quality loop elements first (Figure 3.6). Documentation and implementation of these elements will then induce the development of the seven other supporting elements. For example, while documenting process control, responsibility of management for process control must be defined, as well as the need for training and statistical techniques. With the system's view, focus on the quality system will never be lost.

In the above section, the *structure* of the ISO 9001 quality system has been discussed. However, in order to streamline the current system, we must also take into account its *composition*, i.e. the ISO 9001 elements themselves. Thus, in the next section, suggestions for a new, systematized ISO 9001 are proposed.

3.2.2 Systems Approach to the Composition of ISO 9001

The system approach presented in this chapter essentially categorizes the twenty elements of the current ISO 9001 quality system into two groups. The first group consists of elements addressing the processes that influence the quality of the product throughout its life cycle: from market research and product design and development to disposal or recycling at the end of useful life. This group is called 'Quality Loop Elements', since the quality loop is the underlying concept of main activities having an impact on quality (ISO 9004-1, 1994). The second group consists of elements supporting the quality system, with resources such as quality system documentation and processes such as internal quality audits. The composition of both groups is now analyzed under the system approach.

3.2.2.1 Quality Loop Elements

The first step in the product life cycle is the determination of the need for a product, market demand and customer requirements. This is usually done by the marketing function in an organization. A quality system must ensure that these activities are performed on a continuous basis and records of activities and results maintained. Subsequently, customer requirements and needs are translated into a statement or outline of product specifications. This is sometimes referred to as 'the product brief'. This brief presents a preliminary set of specifications that is a direct input for product design work The organization must then review and confirm that it is capable of meeting customer requirements. In the current ISO 9001 standard, the above activities are reduced to the requirements for contract review, i.e. for review of contract with the customer to ensure that the requirements are adequately documented, and any differences between the contract and tender are resolved. This is mainly due to historic reasons, since the three quality system models, namely ISO 9001, 9002 and 9003 were to be used for contractual purposes, i.e. when a contract with the customer exists. To clarify this element of ISO 9001 and develop a more generic quality system requirement, it is proposed that the current section 4.3 Contract review be replaced with 'Defining customer requirements'. This section would address all processes from determining the need for a product to specifying the product brief (Figure 3.7).

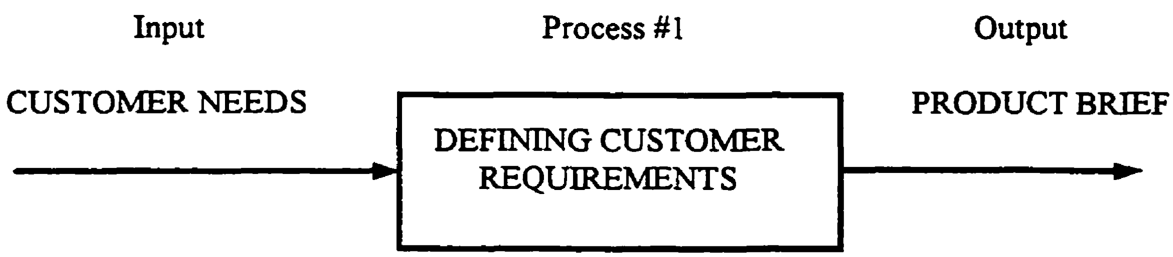


FIGURE 3.7: Quality Loop Element #1- Defining Customer Requirements

The next step in the product life cycle is the product design. On the basis of customer requirements defined in the product brief, as well as applicable statutory and regulatory requirements, the product is designed and developed. Design activities are planned, organizational and technical interfaces between designers are defined, and design input is transformed into the design output, i.e. the product blueprint. The design is then reviewed, verified to ensure that design output meets design input requirements, and validated, to ensure that design output meets customer requirements. Product design is also tested, e.g. in prototype measurement and testing. The output of design process is the input into the process planning and development (Figure 3.8).

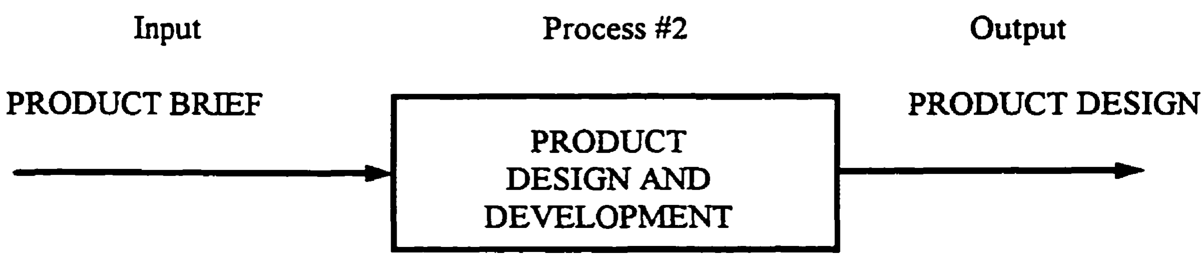


FIGURE 3.8: Quality Loop Element #2 - Product Design and Development

Next, the production process is planned and designed. Planning of processes must ensure that these proceed under controlled conditions, including appropriate equipment, machines, tools, supplies, utilities, software, environment and personnel. Once designed, the process should be verified as being capable of producing the product according to specifications. Monitoring and control of processes must be planned and designed, as well. The output of the process planning is commonly referred to as 'the process plan' (Figure3.9).

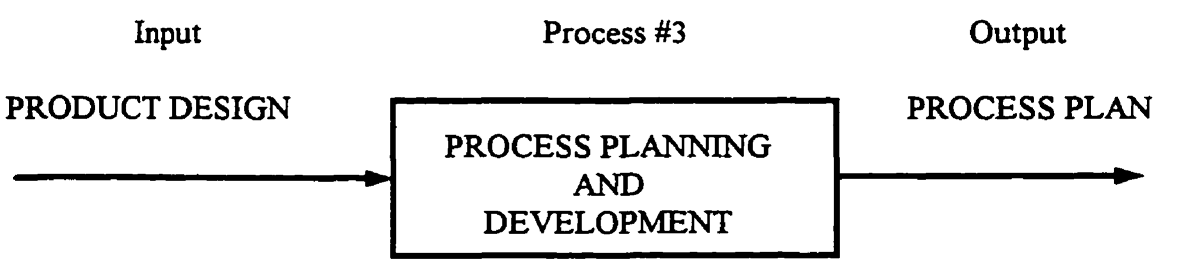


FIGURE 3.9: Quality Loop Element #3 - Process Planning and Development

According to product design and process plans, necessary resources are then acquired. This not only includes material resources, such as machines, equipment, supplies and software, but also human resources. Appropriate training must be provided to all personnel affecting quality. Thus, a merger of elements 4.6 Purchasing and 4.18 Training into the 'Acquisition of Resources' is proposed (Figure 3.10).

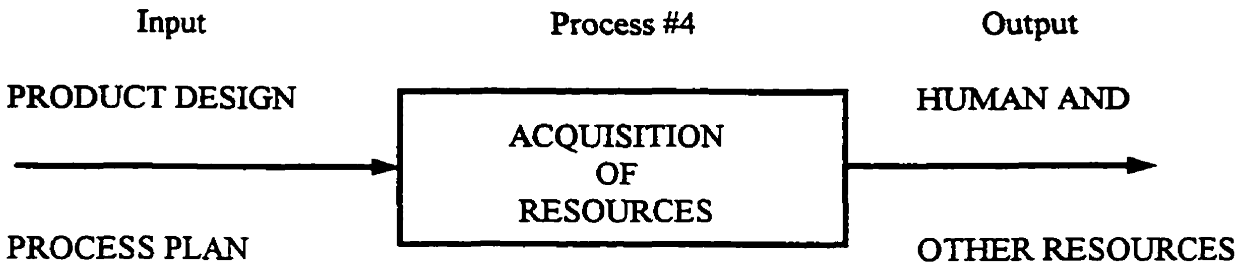


FIGURE 3.10: Quality Loop Element #4 - Acquisition of Resources

Acquired resources are subsequently deployed into the production processes. All processes must be adequately controlled to ensure the quality of the product, i.e. that the customer specifications are maintained throughout the production. Control of processes includes material control, traceability and identification of the product throughout the process (section 4.8 of ISO 9001). Also included are machine/equipment control and maintenance, as well as material and product handling, storage, packaging and preservation (sections 4.7 and 4.15 of ISO 9001). Monitoring and control of process parameters and product quality characteristics is encompassed, as well (Figure 3.11).

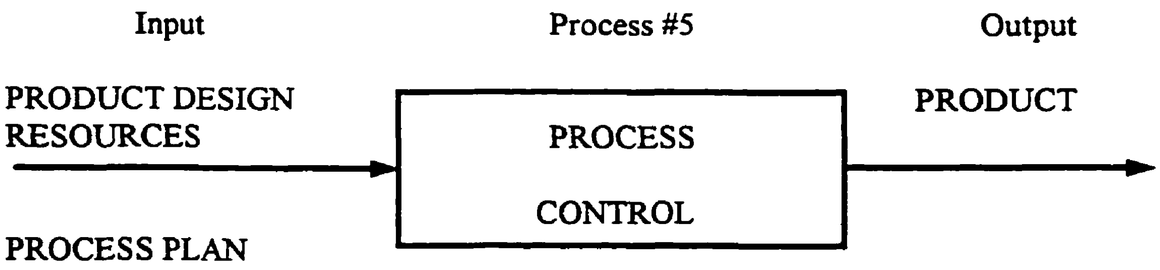


FIGURE 3.11: Quality Loop Element #5 - Process Control

In order to verify that the specified requirements for products and processes are met, measurement, inspection and testing activities are performed. This includes inspection and testing at all stages of the product life cycle, from the receiving inspection of incoming material and equipment, through in-process inspection to final inspection and testing of products. Inspection and testing status of the product must be identified by suitable means (section 4.12 of the current ISO 9001), and records of such activities maintained. Also, inspection, measuring and test equipment must be controlled, calibrated and maintained according to established and documented procedures (section 4.11 of ISO 9001). Inspection and testing thus represent the Quality Loop Element #6 (Figure 3.12).

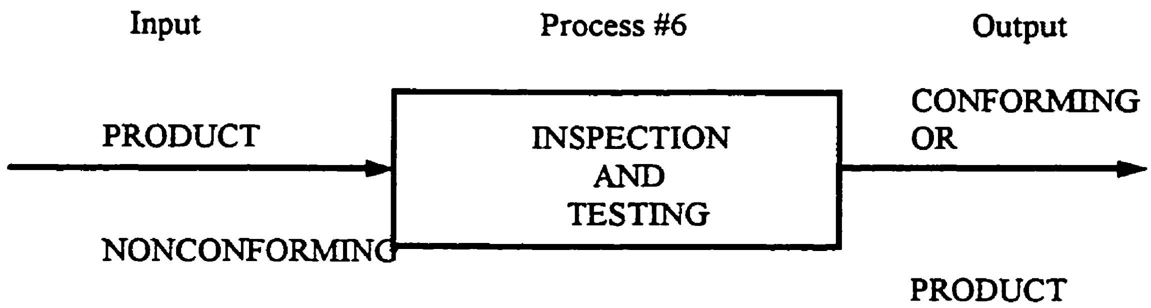


FIGURE 3.12: Quality Loop Element #6 - Inspection and Testing

Inspection and testing essentially determines whether the product conforms or does not conform to the specified requiremer. s. In the latter case, the product must be prevented from unintended use or installation. Thus, a nonconforming product must be adequately controlled (Figure 3.13).

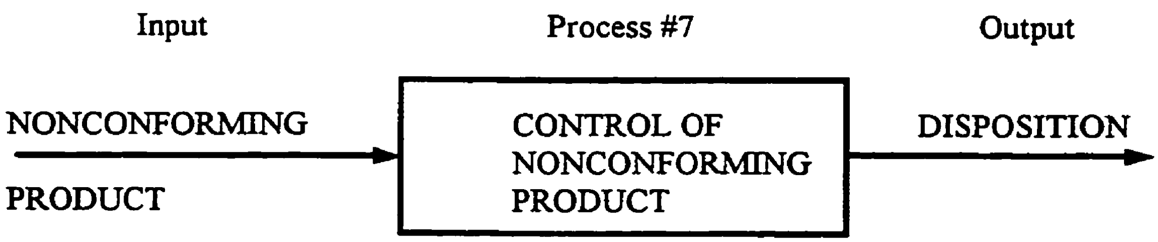


FIGURE 3.13: Quality Loop Element #7- Control of Nonconforming Product

For the purpose of determining the causes of existing or potential nonconformities, adequate corrective and preventive actions must be planned, executed and reviewed (Figure 3.14) . This is done throughout the life cycle of the product.

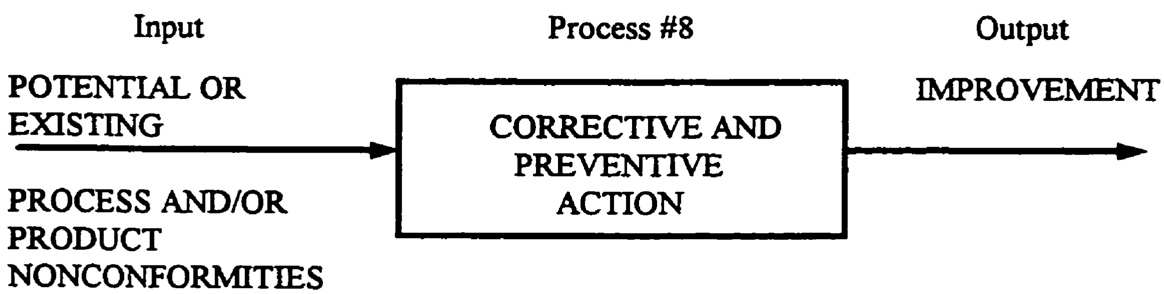


FIGURE 3.14: Quality Loop Element #8 - Corrective and Preventive Action

Finally, a conforming product is sold, delivered, installed, serviced and disposed of or recycled at the end of its life cycle (Figure 3.15). Customer's feedback on the product must be collected and used for the following cycle.

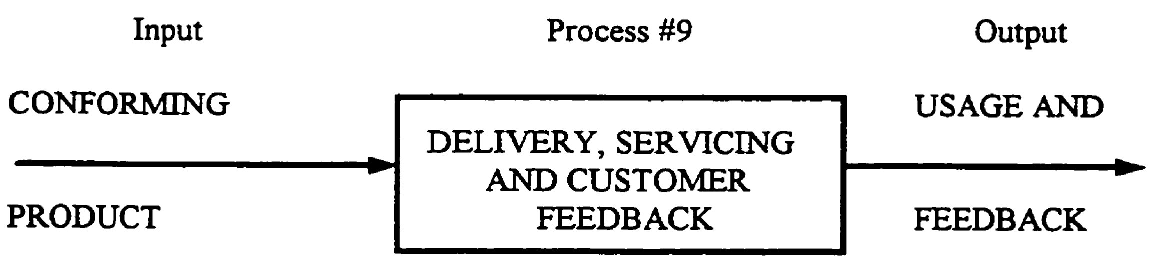


FIGURE 3.15: Quality Loop Element #9 - Delivery, Servicing and Customer Feedback

3.2.2.2 Supporting Elements

A quality system is supported by certain resources and processes. Above all, human resources must be organized to manage, perform and verify work affecting quality. The responsibility, authority and interrelation of personnel must be defined and documented. Quality leadership must also be ensured through the appointment of the quality champion or quality (ISO 9000) representative. The above activities are defined in the supporting element named 'Quality System Organization'.

The objectives of the quality system are briefly underlined in the organization's quality policy, which includes the organization's commitment to quality. The quality policy is part of the quality system documentation, which includes the quality manual, quality system procedures, instructions and records. The first three types of documents are created 'a-priori', i.e. before the execution of processes and activities. Records emerge 'a-posteriori', since they represent the results and evidence of processes and activities. All quality system documentation must be adequately controlled. In the current ISO 9001, two separate elements cover the control of documents and data, namely 4.5 Document and data control and 4.16 Control of quality records. Since there really is no reason for the two to remain separate under the system approach, it is proposed that these two elements be merged and presented as subheadings in the element 'Quality System Documentation'. Quality plans, as another resource, should be included in this element, too. The quality plan relates to a specific product, project or contract and addresses the whole product life cycle.

Finally, internal quality audits and statistical techniques facilitate quality improvement throughout the quality loop and the quality system in whole. Using the system approach, a new structure and composition of the ISO 9001 quality system is presented in the next section.

3.2.3 Proposed ISO 9001 Quality System

Of the three quality system models in the ISO 9000 series, ISO 9001 is the most comprehensive. Furthermore, the upcoming revision of ISO 9000 is expected to merge all three models into the ISO 9001 standard, with more emphasis on processes and improved linkage with other systems, such as environment and health and safety (Caillibot, 1997; Campbell, 1996). However, the quality system presented in this thesis provides a more comprehensive approach, since not only processes, but also resources and objectives are addressed, conceptualizing ISO 9001 as the *quality system*, and not as a 'process standard'. Moreover, the integration of quality and environmental systems is easily feasible with the system approach (see section 3.3).

While the structure and composition of the proposed ISO 9001 system was discussed in the two previous sections, Table 3.1 presents a comparison with the current ISO 9001-1994 model, and Figure 3.16 illustrates the proposed system.

PROPOSED ISO 9001 SYSTEM	CURRENT ISO 9001 (1994)
PART 1: QUALITY LOOP ELEMENTS 1. Defining Customer Requirements	4.3 Contract review
	ISO 9004: 7.1 Marketing requirements
	ISO 9004: 7.2 Defining product specification
2. Product Design and Development	4.4 Design control
3. Process Planning and Development	4.2.3 Quality planning (excluding quality plans)
	ISO 9004: 10 Quality of processes
4. Acquisition of Resources	4.6 Purchasing
	4.18 Training
5. Process Control	4.8 Product identification and traceability
	4.9 Process control
	4.7 Control of customer-supplied product
	4.15 Handling, storage, packaging and preservation (excluding 4.15.6 Delivery)
6. Inspection and Testing	4.10 Inspection and testing
	4.11 Control of inspection, measuring and testing equipment
	4.12 Inspection and Test Status
7. Control of Nonconforming Product	4.13 Control of Nonconforming Product
8. Corrective and Preventive Action	4.14 Corrective and Preventive Action
9. Delivery, Servicing and Customer Feedback	4.15.6 Delivery
	4.19 Servicing
	ISO 9004: 7.3 Customer feedback information
PART 2: SUPPORTING ELEMENTS 10. Quality System Organization	4.1.2 Organization
	4.1.3 Management review
11. Quality System Documentation	4.1.1 Quality policy
	4.2 Quality system
	4.5 Document and data control
	4.16 Control of quality records
	4.2.3 (part) Quality plans
12. Internal quality audits	4.17 Internal quality audits
13. Statistical techniques	4.20 Statistical techniques

TABLE 3.1: Comparison of the Current and Proposed ISO 9001 Quality System

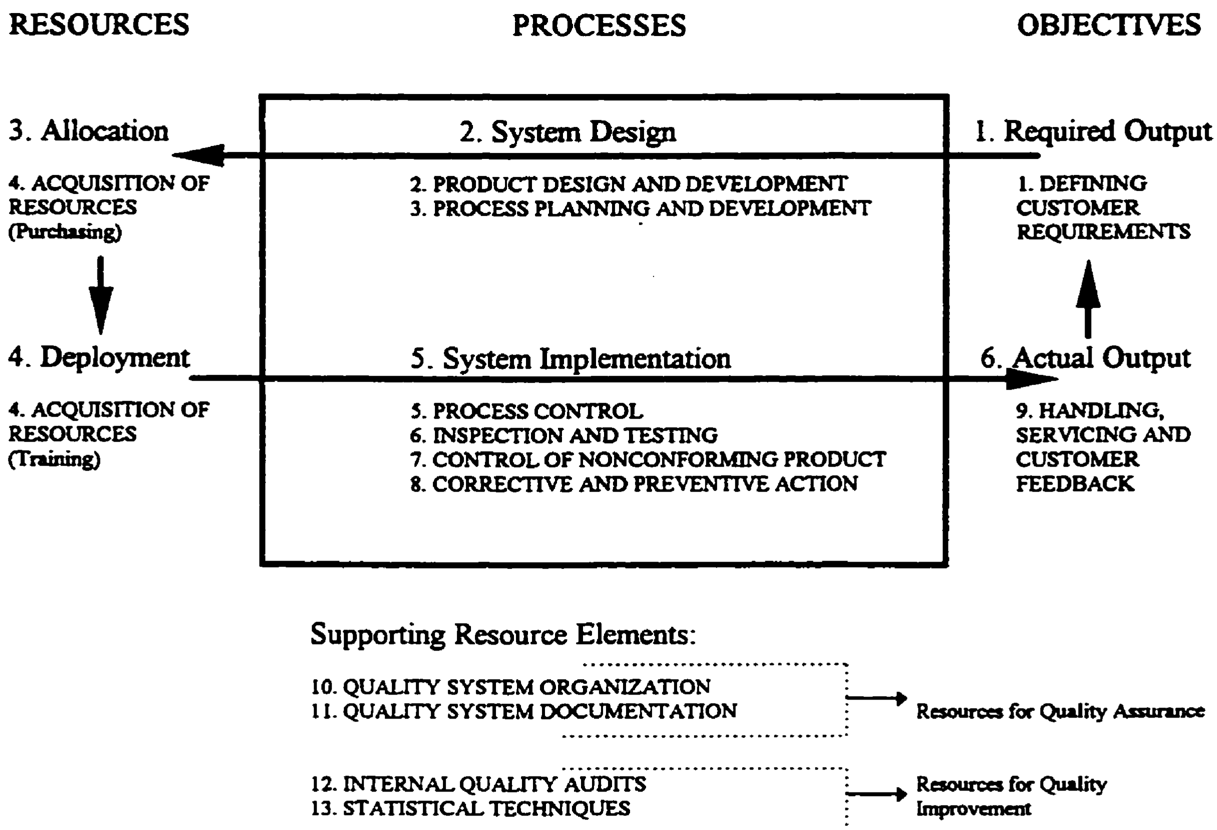


FIGURE 3.16: Graphical Model of the Proposed ISO 9001 Quality System

3.3 INTEGRATED PRODUCTION SYSTEMS

Another benefit of the system approach is that it allows for the cohesion of the quality, environmental and other assurance systems into one integrated - "supra" production system. For example, figure 3.17 illustrates the application of the system approach to ISO 14001 Environmental Management System.

Quality is just one dimension of the product. It is a set of characteristics of a product that bear on its ability to satisfy customer's needs. However, a product also must have environmental characteristics that will satisfy interested parties, or cost characteristics that will satisfy both the customer and the supplier. In the same vain, health and safety characteristics of products are focused and will remain among the most important issues in the 21st century. The product must also be serviceable, maintainable and dependable. All these make up the product's characteristics.

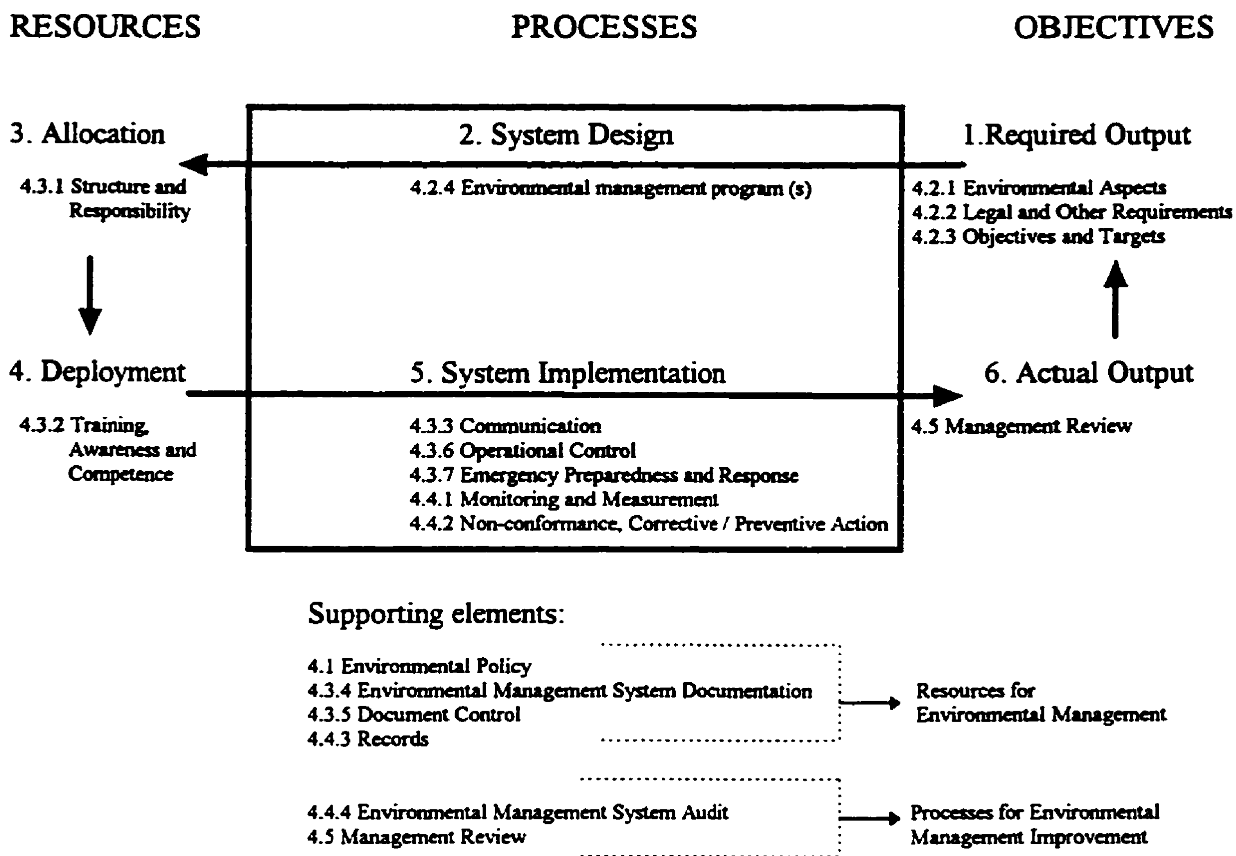


FIGURE 3.17: Graphical Model of an ISO 14001 Environmental Management System

As blunt as it may sound, it is important to recognize that all these product characteristics are made in a unique system, often referred as the 'production system'. Because products are becoming more and more complex, and encompass a number of different sets of characteristics, the tendency in the past was to develop separate systems to create these sets of characteristics. Thus, the 'quality system' is developed to create 'quality'. An environmental management system is another example, an accounting system yet another. This departmentalization has led to serious organizational problems (Klarin, 1994). It is now evident that the integration of these systems is needed in order to successfully compete in the global market. A good example of such integration is concurrent engineering, where people from different departments, such as marketing, design, engineering and process planning work together in conceptualizing and manufacturing a product.

Therefore, it can be concluded that the quality system is just a sub-system of the production system. As are the environmental and the costing (accounting) system. On the other hand, a part of the production system is the management system, which the management uses to manage quality, environment, cost, human resources and so on. The part of an overall management system that manages the quality dimension is actually the quality management system. Environmental aspects are managed by the environmental system, and so on (Figure 3.18).

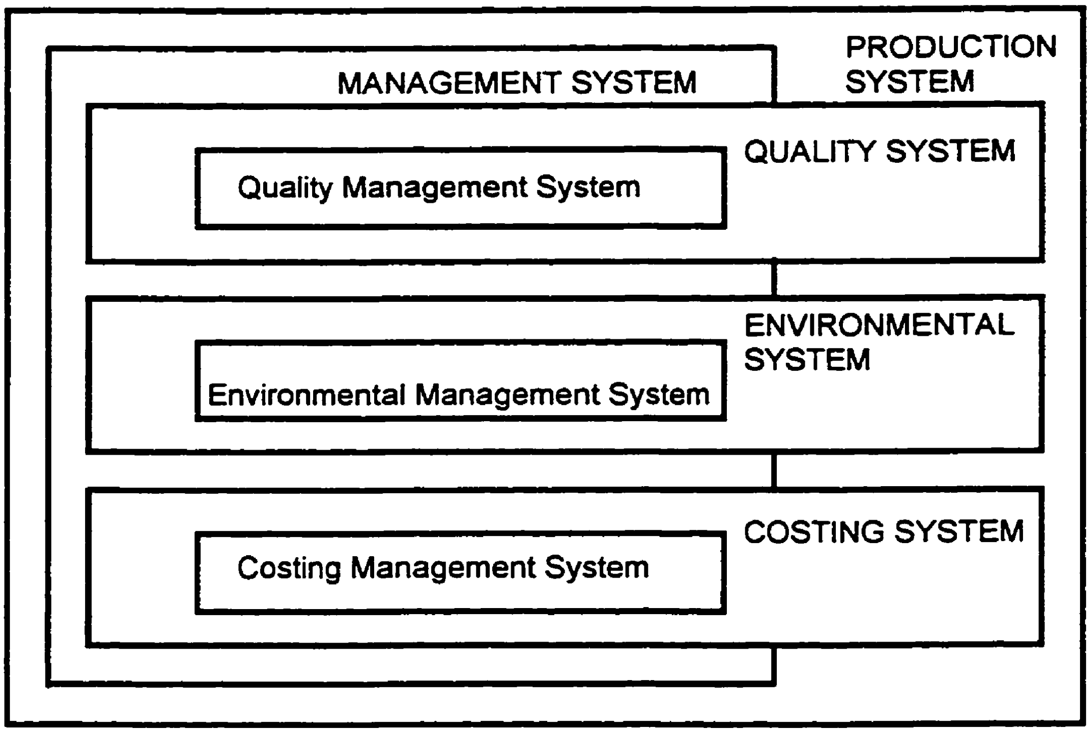


FIGURE 3.18: Production System and Related Subsystems

In the next chapter, one such production system is addressed and conceptualized in detail. This is the production system in the educational environment of the university, called 'The University System'.

CHAPTER FOUR

UNIVERSITY SYSTEM

In this chapter, a black-box analysis of the university's customers, products, suppliers and inputs is performed first. Then, three identified university products: student knowledge/abilities, programs/courses, and research will be focused on, as well as the processes creating them: learning, teaching and research. A three-dimensional model of the university system is subsequently proposed, and the interrelationships between teaching, learning and research discussed.

4.1 BLACK BOX ANALYSIS

Universities are commonly considered as service organizations, which provide educational and research services to students and the community in general. While it is not the intention of this thesis to argue whether this categorization is really necessary, it is certainly possible to conceive that service is just one kind of a product (Karapetrovic and Willborn, 1998A). In a seemingly opposite view, Reavill (1998) argues that the output of higher education can be defined as either a product or a service. In the first case (output is a product), customers are employers and the community, and in the second (output is a service), customers are students. However, the following black box analysis of the university system shows that both the employers and the students may be viewed as customers, depending on a particular product of the university. Employers are customers receiving the product in the form of the knowledge and skills of a graduate, while students are customers in the case that a specific course or a program is perceived as a product.

Therefore, in this thesis, it is assumed that the act of making a product, i.e. production, accounts for the generation of both goods and services (Riggs, 1987). Thus, a product may be tangible, in which case it is referred to as "material" and/or "hardware", intangible, in which case it is referred to as "service" or "software", or a combination thereof. The product is the actual output of a production process. Using various resources, production processes work to achieve objectives in a *production system*.

This thesis views the university as a production system. To conceptualize the university system (US), a black-box analysis of the system's inputs and outputs, as well as suppliers and customers is required (Figure 4.1).

FIGURE 4.1: University System as a Black Box

The analysis starts from the back end of the black box. What is(are) the product(s) of the university? The answer can be perceived as three-fold. The first product is the student, or to be more precise, the knowledge, experience, skills and overall competence the student gains in the course of his/her studies. A course/program can also be viewed as a product. However, courses and programs are developed by a university for its own purposes, that is to create student knowledge. In this sense, a course/program is just a means to produce the first product - student's education, and is a part of the process, rather than a product. Nevertheless, with emerging communication technologies such as Internet and tele-conferencing, university courses and programs may be offered, marketed and 'sold' as distinct products. With these limitations in mind, we can finally identify the third product of the university as research: new theoretical and practical knowledge.

Subsequently, we can determine the customers of the university system. Although accounts on who really is the customer were detailed in the literature survey, this analysis is based on the criterion that the customer sets the requirements for the product and product quality. The requirements for student's engineering knowledge, for instance, are set by the companies he/she will work for, as well as government and professional institutions, such as the Canadian Engineering Accreditation Board (CEAB). After graduation, the student's knowledge is used by the employer, or the student for his/her own purposes. Thus, employers and alumni, together with government and society in whole are the final customers of the university, who set the requirements for the quality of student knowledge and competence. These customers specify quality characteristics, such as employability, the ability of students to solve engineering problems and the ability to upgrade individual knowledge. Industry specifications are 'market driven', and CEAB specifies engineering knowledge fundamentals. Therefore, university students should not be considered as customers in this sense, since they do not specify knowledge requirements. For example, a second year engineering student does not define what he/she should know in the area of heat and mass transfer in order to graduate. These specifications are then translated into university programs, and detailed in courses students are required to take. Thus, the students are customers of the second product of the university: courses and programs. Finally, customers of the research output are research sponsors, industry, government, other universities and society in whole.

On the front end of the black box, incoming students represent the input for the first product, i.e. student knowledge and competence. In other words, the students come to an engineering school with certain knowledge of mathematics, physics and other basic sciences, which is the raw material that will be transformed into the knowledge of a graduated engineer. The suppliers of students are high schools, other universities and community colleges, where the students have acquired this 'raw material knowledge'.

Input into course/program design and delivery is represented by course specifications, regulations, available equipment and material, course designs from other universities, available delivery methods and so on. The suppliers are governmental or professional institutions, such as CEAB, other universities and industry. Since courses/programs are also part of the process, they create input into student's education (represented with a dotted line in Figure 4.2). For research, existing knowledge of certain theoretical or practical area is input. For example, the existing knowledge and theories of quality assurance in the university environment, identified in the literature survey (Chapter 2), represented the raw material for this research. Research input is supplied by industry sponsors of research, surveys of literature, fellow researchers and so on. Finally, the analyzed black box is illustrated in Figure 4.2.

Bearing in mind the definition of the system given in Chapter 3, the university system can be defined as a *"set of teaching, learning and research processes that function harmoniously, using various human, material and information resources to* *achieve university's objectives"*. As in the quality system, three main elements exist: processes, resources and objectives. Processes transform inputs, such as available theories and practical methods in the case of the research process, into outputs, such as new knowledge, theories and methods. It is important to note that other processes, such as administration and financial management, also exist in the university. However, if the main mission of the university is to create and preserve valuable knowledge, the actual processes that achieve this mission are limited to teaching, learning and research. Part of the mission of every university is to create "quality" knowledge, i.e. certain objectives are related to quality. In this vain, consistently with the description of systems presented at the end of Chapter 3, a quality system of a university is a sub-system of the university system (US), achieving the objectives related to quality. The quality system encompasses all activities that are aimed toward meeting and surpassing customers' expectations and needs. Therefore, some activities, such as managing finances of the university, may not be a part of the quality system, although they are part of the overall system.

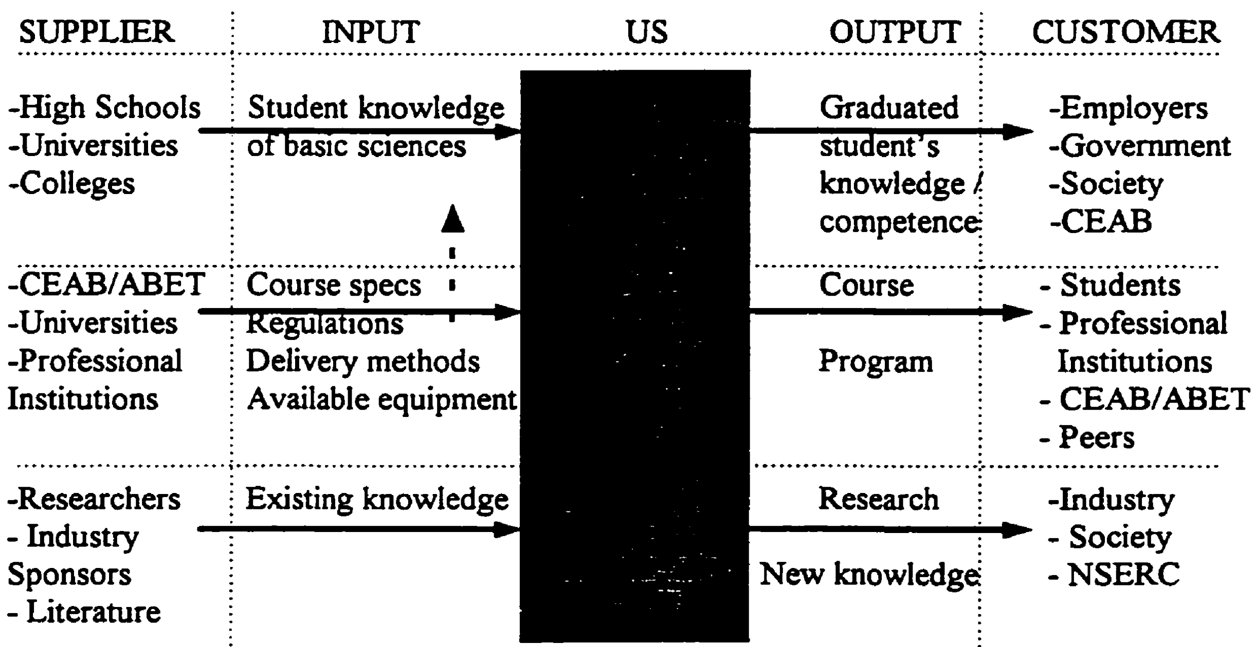


FIGURE 4.2: Black Box Analysis

In order to fully understand the university system we need to perform a white-box analysis, i.e. to understand its main processes. Essentially, each of the three products is created by a certain process. Student knowledge is created by *learning*, courses and programs are *taught*, and new knowledge is created by *research*. The following sections will address student knowledge, courses and research output as products of the university system, as well as the basic processes producing them: learning, teaching and research.

4.2 STUDENT KNOWLEDGE

A student comes into the first year of university studies with the knowledge of basic arts and sciences acquired in a high school. This knowledge is the raw material the university receives from its subcontractors: high-schools and/or colleges (Black, 1996, Evans and Lindsay, 1996). The university performs incoming inspection of the student's knowledge, by accepting only the students who received high school grades which meet the university entrance requirements, and/or students who passed required entrance exams (Figure 4.3).

The curriculum usually consists of four years of study. Students are required to attend and pass a certain number of courses each year. For example, in mechanical engineering at the University of Manitoba, a student has to pass twelve courses each year. As a student attends courses of the first through the fourth year, he/she accumulates the knowledge in a process analog to assembling of parts in manufacturing. The final product (e.g. knowledge of a mechanical engineer) consists of the knowledge of matter taught in the courses: (e.g. thermodynamics, strength of materials, design, etc.). Thus, a part in manufacturing is analog to the knowledge of a student acquired in a specific course (Figure 4.4). Manufacturing operations on a part are analog to lectures in the university system. For example, a part is manufactured using the cutting, milling and drilling operations. In the same vein, a course is taught using a number of lectures. Each operation (lecture) adds a new surface/volume characteristic (new knowledge) to a part (course knowledge). The sequence of operations in manufacturing are provided in a document called 'Process Plan'. In the university, it is the 'course plan' or 'course outline'. The operator in manufacturing is the teacher is the university, and machines are represented by the methods used for teaching / learning (Figure 4.4).

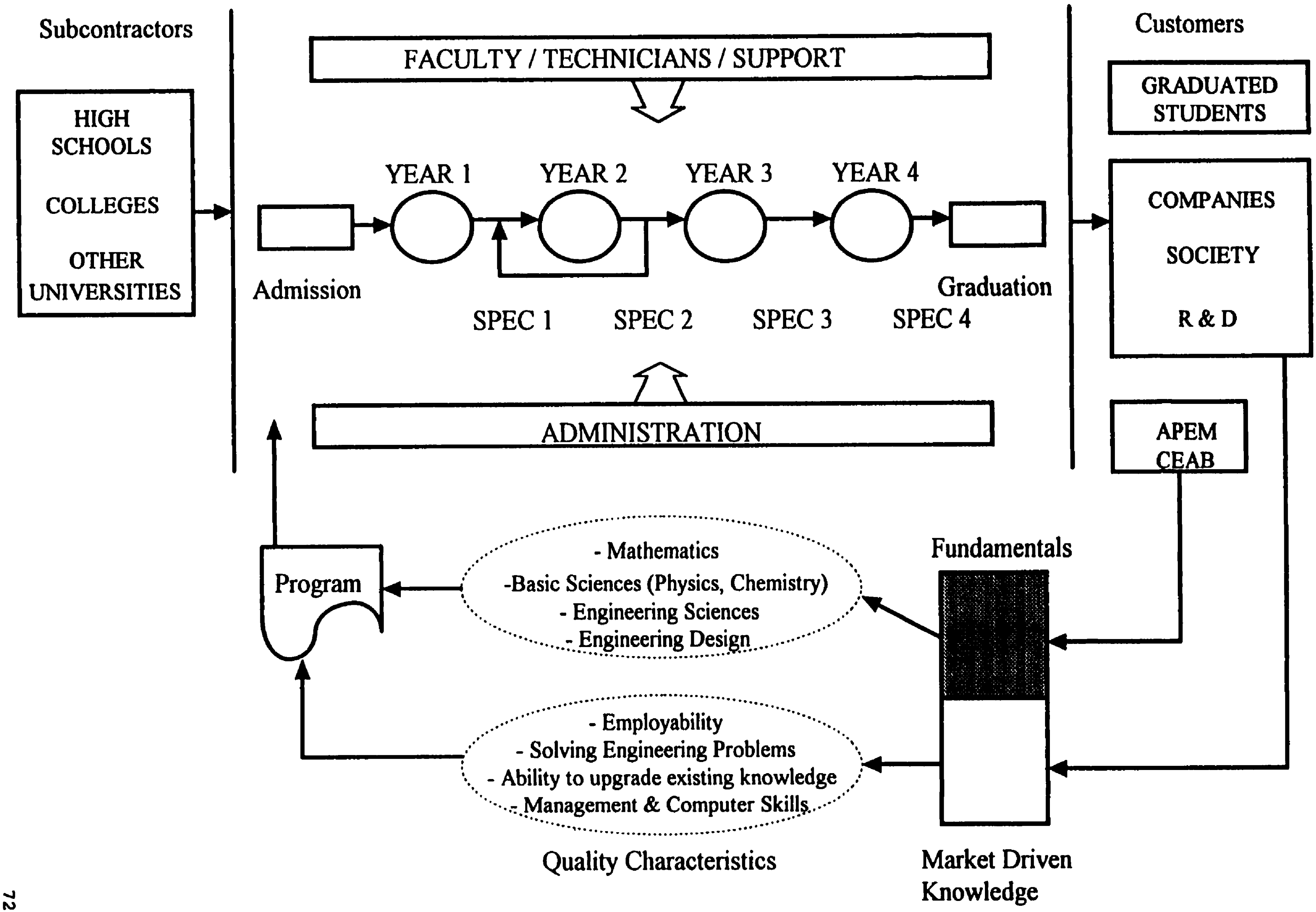


FIGURE 4.3: The University System (Student Knowledge and Competence)

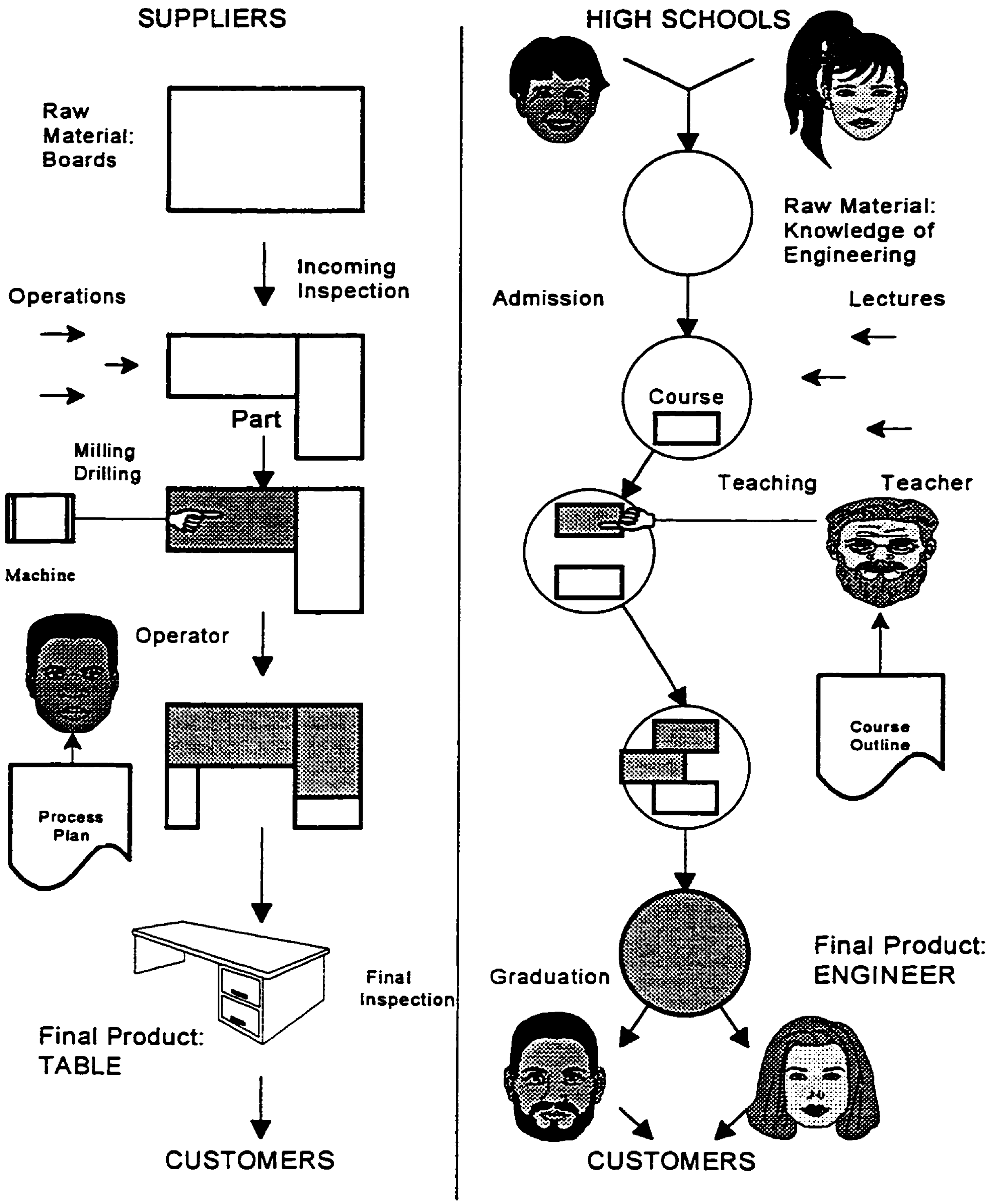


FIGURE 4.4: Production Process Flowchart (White Box Analysis)

A student's achievement (courses taken and grades) is inspected at the end of each year, in order to (dis)allow the student to proceed to the subsequent year. This in-process inspection is followed by the graduation, or final inspection to confirm that the student has met all the requirements. After graduation, a student is employed by industry, government, the private sector, self-employment or society in general. These companies and society are the final customers of student's knowledge. They are the market the university provides its product to.

The customers set the requirements for the product. For example, industry may want mechanical engineering graduates to possess knowledge on time management, quality control and automation, while the government wants them to be familiar with workplace health and safety regulations and quality standards. The knowledge of a graduate must also contain certain implied theoretical principles and fundamentals. For example, a mechanical engineer must be familiar with thermodynamics principles, and be able to solve conceptual problems in this area. These fundamentals, for engineering arts and sciences, are set by the provincial association of professional engineers (such as the Association of Professional Engineers of Manitoba - APEM) and the CEAB (Figure 4.3). In so-called "regulated" professions requiring a university degree, medicine and engineering being two examples, the requirements for student knowledge and competence are relatively clear cut. Professional regulatory bodies, such as national medical boards or councils of professional engineers, specify in detail the fundamentals of knowledge and competence a student should possess in order to graduate. Other disciplines, like physics, chemistry, behavioral sciences and arts may not have such clear-cut knowledge requirements, but a certain and usually well-known body of knowledge exists for each discipline. Every historian knows who Alexander the Great was, every physicist, with the right equipment and material, can make a nuclear bomb, and every fine arts graduate knows the most important characteristics of the Impressionist movement.

These customer requirements are then translated into programs and courses of study, much like in manufacturing, where a product brief is translated into a set of design specifications.

4.3 COURSES/PROGRAMS

The university, or faculties and departments therein, design the programs, with design specifications including a list of courses offered, and brief descriptions of course content. These are usually given in the University's General Calendar. In engineering, these programs must meet the requirements set by the appropriate regulatory bodies, such as CEAB in Canada or the Accreditation Board of Engineering and Technology (ABET) in the United States. Based on the course content specifications, professors design and plan how the courses are to be executed (Figure 4.5). They plan methods of teaching (using computers, or the classical "ex-catedra" method), the matter to be included in the course, lectures and/or laboratory experiments. The Teaching Process plan is provided in the course outline, handed out to the students at the beginning of the course. The document describes the order of lectures, the topics covered in each lecture, and how he/she plans to perform the lectures. It also prescribes when the exams, tests, assignments and/or quizzes are to be performed, what characteristics of the student knowledge are to be inspected and how. At this point of time onwards, the real teaching and learning process takes place.

For each topic planned in the course outline, the teacher performs lectures. With each lecture, the teacher is creating new dimensions to the student knowledge. These dimensions must be within the specification limits, set in the course outline. For example, if a student received more than 60% on a test, he/she will pass. After a student has gone through the course and passed the final exam, he/she leaves to attend another course. His/her knowledge gained from the course adds to the knowledge acquired from the courses previously passed. Thus, it is important to recognize that each professor is an internal customer to the previous one.

One fact has to be considered at this time, however. There is no tangible knowledge gain if there are no students attending a course, even though a teacher may theoretically teach in front of an empty auditorium. There is no product without the raw material. Without students the course has no meaning. It is a simple blueprint of what a teacher would like to teach. Therefore, the mechanical engineering program is only a set of design specifications. The course content is only a process plan.

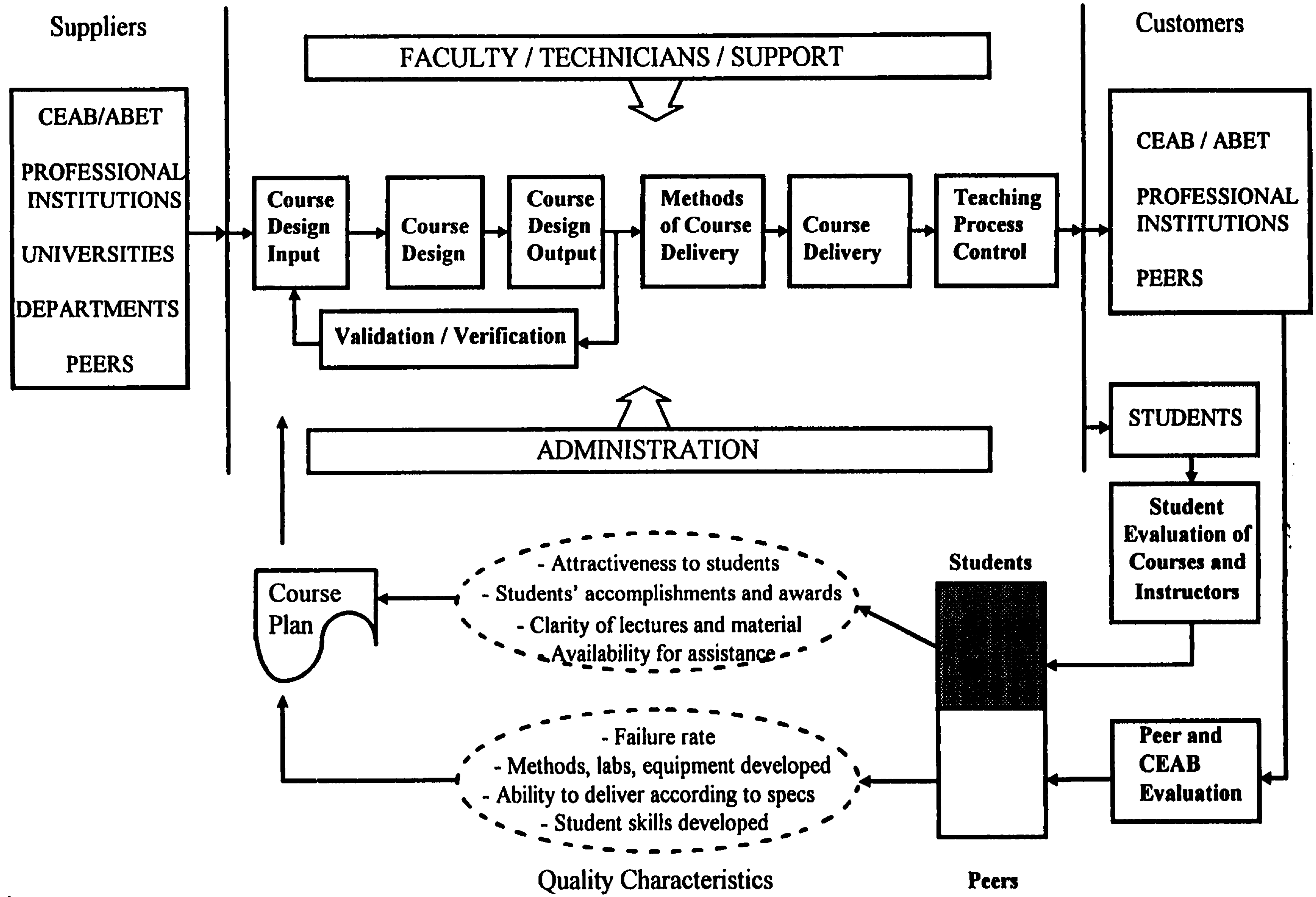


FIGURE 4.5: The University System (Course/Program)

Materials, skills and expertise required to develop and deliver courses (the 'Learning Opportunity') constitute the technology which is being used to produce knowledge. Mechanical engineering departments from different universities use different technologies to manufacture the same product: the mechanical engineer. There are different ways to make a car. You can use different machines, different tools, and still come up with similar cars. The learning opportunity is created by the university as a product for its own purposes. The university is analog to a manufacturing organization that produces the machines it will use for manufacture of their primary product. For example, one of the largest producers of industrial robots in Europe is surprisingly a German automotive company. However, the company does not sell its robots: they are used to make cars.

4.4 RESEARCH OUTPUT

The university also performs research activities, upgrading the existing knowledge. The outcome of these activities (new technologies, tools, published papers) is considered to be one of the final products of the university system. This is where universities differ from schools and community colleges, which do not produce new theories and practices. Although in some cases research is considered to include any systematic search for some facts or theories, such as a student's library search for his/her term project, this thesis conceptualizes the term differently. Research herein is the creation of new, previously unknown or non-existing knowledge.

The customers of research are the companies encountering problems for which solutions are not already available, society and governmental agencies, such as the Natural Sciences and Engineering Research Council (NSERC) of Canada. Research can be contractual, in which case there is a contract or agreement between the researcher and the external organization sponsoring research, or non-contractual, where the researcher is performing research on his/her own. Raw material is the existing knowledge in the area of research, supplied by libraries, fellow researchers, interested industries. A research process, led by one or more faculty members, involves graduate students, technicians and support staff. The process encompasses data acquisition, conceptualization, development

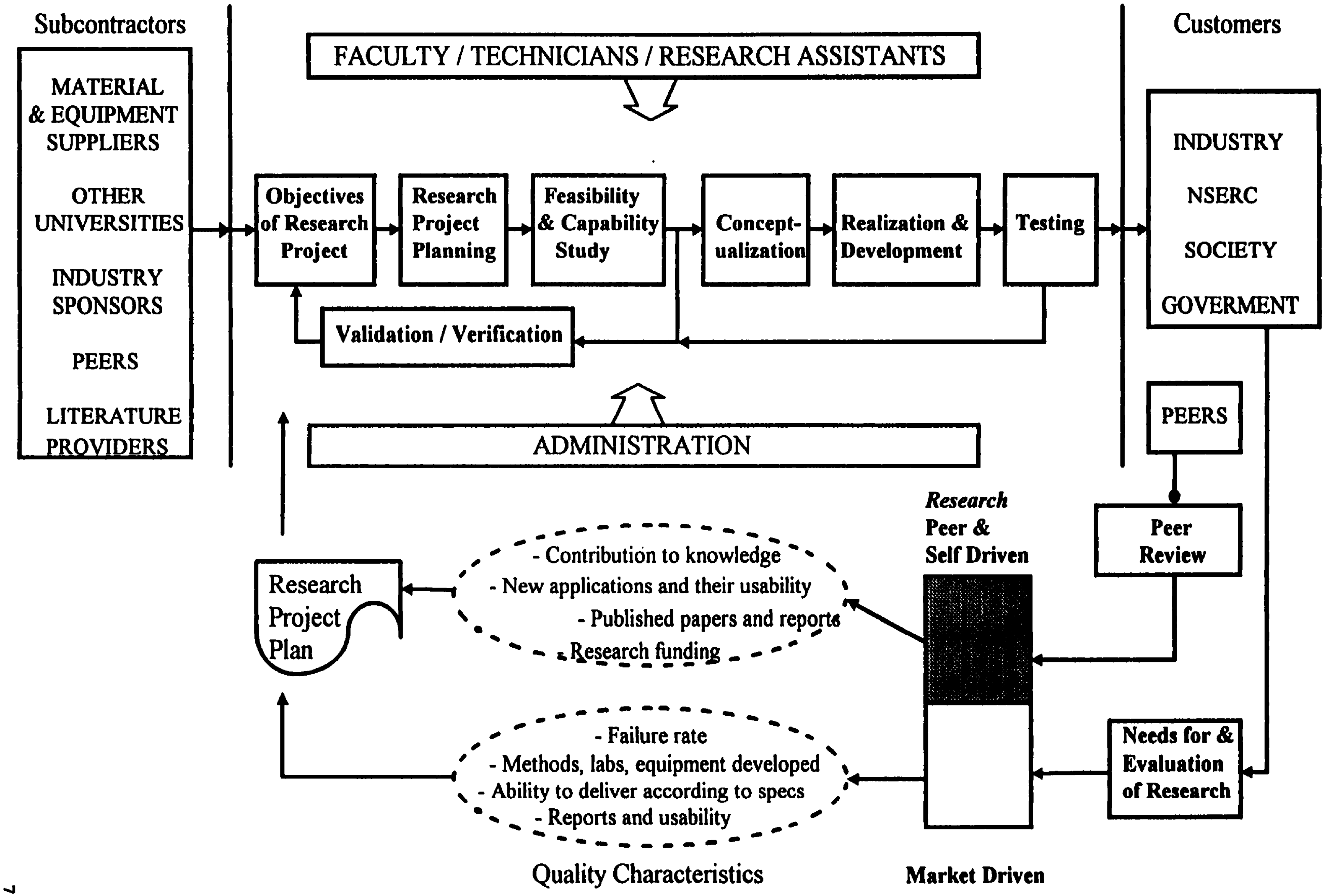


FIGURE 4.6: The University System (Research)

and final inspection (Figure 4.6). The results of research, presented in research project reports, conference and/or journal papers are supplied to customers and the general public.

4.5 TEACHING, LEARNING AND RESEARCH INTERRELATIONSHIPS

4.5.1 Three-dimensional Model

As illustrated in previous sections, the university system creates three products: student knowledge and competence, courses and programs, as well as research. These products are created using certain processes. Student knowledge is gained by learning, courses are taught, and new knowledge is achieved by researching. The products and main processes of the university can be presented in a three-dimensional coordinate system (Figure 4.7). Each axis belongs to one product or a process.

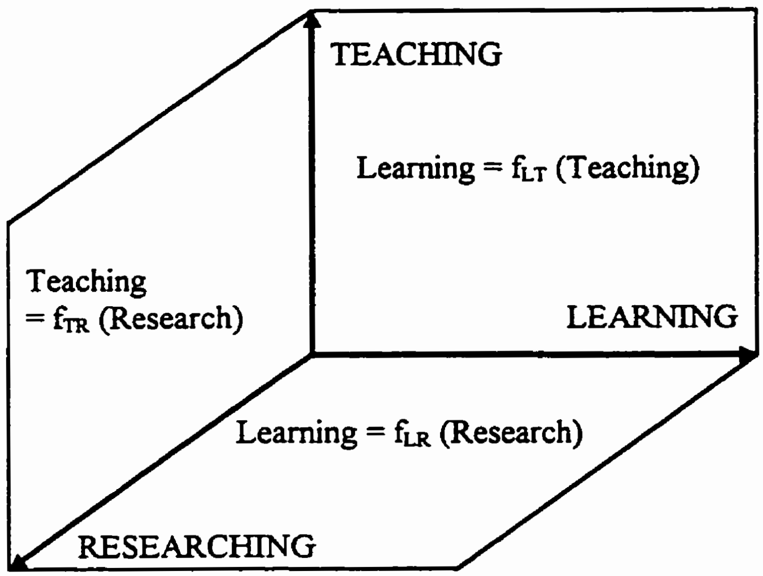


FIGURE 4.7: Three-dimensional Model of the University System

In a university environment, there is an interrelationship among these processes, that has an impact on the quality of the products. All three products have certain quality characteristics (examples of which are given in section 4.5.3) and the quality of teaching/learning/researching are inspected versus certain specifications. The teacher has to meet the specifications set in the course outline, and is evaluated by the students and his/her peers. The student has to meet the specifications the teacher has set in the outline. A professor's research output is evaluated by his/her peers. However, these three processes are interdependent. For instance, learning is dependent on teaching. With a teacher's intriguing and well organized lecture, chances of students learning the planned material increase. Also, learning is a function of research. With the creation of new knowledge, both the teacher (professor) and the student learn. The latter will learn if the professor incorporates recent research findings into his/her courses, thereby creating an interdependence between teaching and research. Because these three processes are interdependent, assuming that they are measurable, we can establish certain dependence functions:

- f_{LT} is the function of learning depending on teaching, i.e. learning = f_{LT} (teaching)
- f_{LR} is the function of learning depending on researching i.e. learning = f_{LR} (researching)
- f_{TR} is the function of teaching depending on researching, i.e. teaching = f_{TR} (researching)

It can be foreseen that one will encounter difficulties in measuring variables such as teaching or researching. However, the quality of learning, teaching and researching should be measurable. Articles presented in Chapter 2, such as Janna and Jakubowski (1991), Doyle and Arthurs (1996), and Duggins (1996), provide quantitative models for the evaluation of quality of teaching and research in a university environment. Thus, similar to the automatic control field where functions in the time domain are transferred into the complex domain using the Laplace Transformation for easier calculations, we could transform the hard-measurable teaching, learning and research into the quality of these processes, i.e.:

- F_{LT} is the function of the quality of learning depending on the quality of teaching, i.e. Quality of Learning = F_{LT} (Quality of Teaching)
- F_{LR} is the function of the quality of learning depending on the quality of researching i.e. Quality of Learning = F_{LR} (Quality of Researching)

- F_{TR} is the function of the quality of teaching depending on the quality of researching, i.e. Quality of Teaching = F_{TR} (Quality of Researching)

Quality of teaching, learning and research should be measured using the quality characteristics (section 4.5.3). A hierarchical model of product quality characteristics is developed later in the thesis (AHP, chapter 9). Then, an empirical study of the interdependencies of the quality of teaching, learning and research is suggested. Although these suggestions are well beyond the scope of the thesis, a brief examination of the interrelation of the teaching and learning is given, followed by an illustration of a few quality characteristics for each product of the university system.

4.5.2 Teaching Versus Learning: Examination of the f_{LT} Function

Learning is performed by students. The objective of teaching is to lead the students through the course and provide an opportunity for learning. As a part of this process, a professor teaches certain prescribed materials, and discusses the relevant issues in class. A student is expected to understand the material, and by self-learning, enhance his/her knowledge to meet specifications. However, there is a need to identify the difference between teaching and learning. In teaching, if a professor does not cover all the material, there is a discrepancy with respect to specifications set in a course outline. This leads to the following. Some students might not gain knowledge in the area the professor has taught, while others, due to self-learning, might. In spite of the professor not performing according to specifications, students may conform to the requirements. On the other hand, if the professor meets all the requirements, a student still may not learn it all. These relationships are best described in figure 4.8.

At this point, a distinction between manufacturing and education becomes evident. In manufacturing, a part rarely "talks back" to the operator (adaptive production systems have that ability). In education, the feedback from students assists the professor in fine-tuning the learning opportunity. In this sense, the students can be treated as customers. However, we treat them as 'passive customers', since they cannot change the customer specifications, at least not until they graduate.

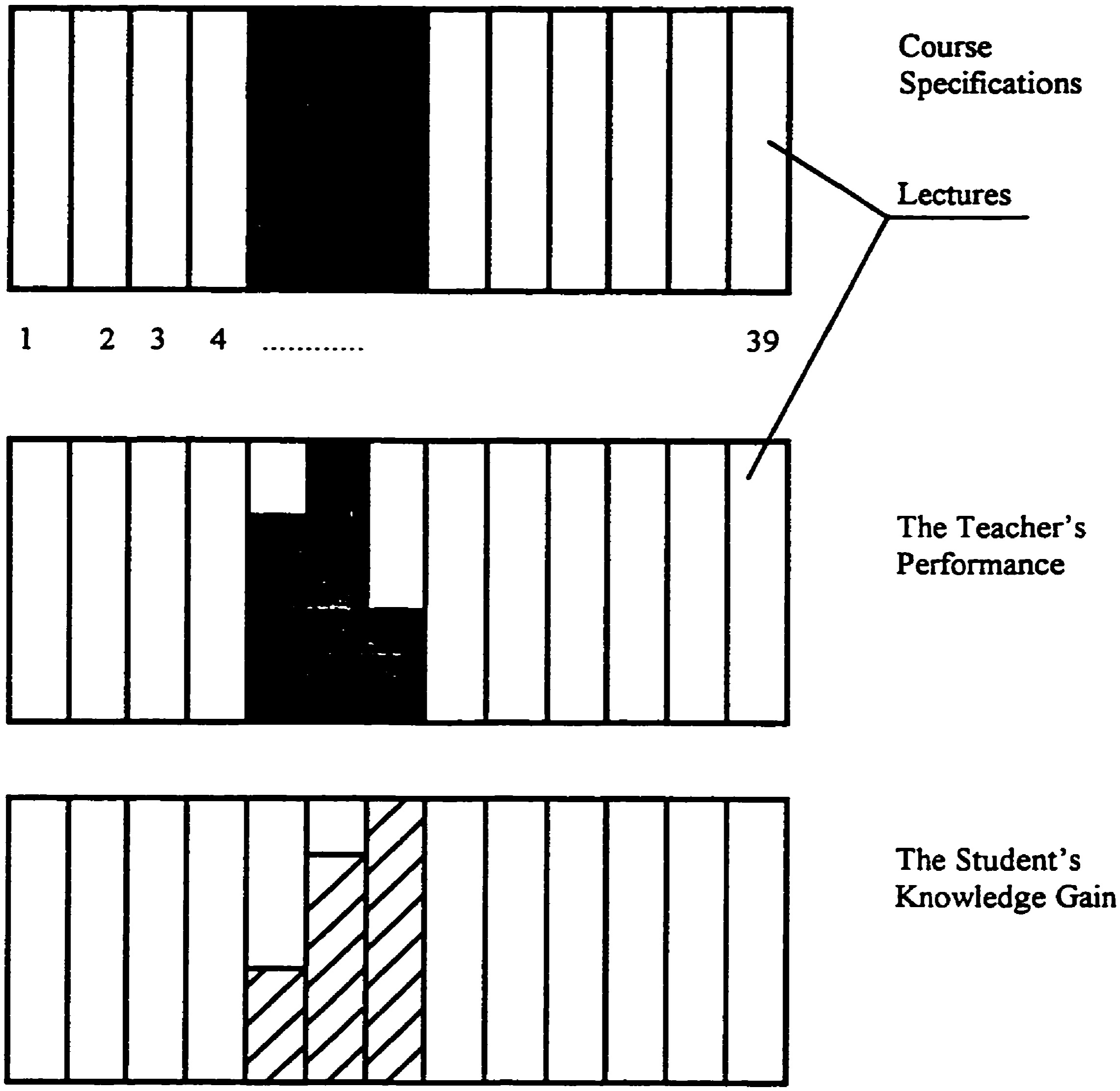


FIGURE 4.8: Teaching vs. Learning- f_{LT} function (Karapetrovic et al., 1997A)

4.5.3 Quality Characteristics

The quality of university's products is measurable. Each product encompasses certain quality characteristics, which can be measured against specifications. While Chapter 9 of the thesis is completely devoted to the development of input, throughput and output quality characteristics using the systems approach, the following are examples of the three products characteristics in the engineering faculty:

(1) STUDENT KNOWLEDGE:

(a) Employability of graduated students, measured by:

- the percentage of recent graduates employed
- the average starting salary

(b) Ability of graduates to successfully solve engineering problems

- percentage of graduates registered as professional engineers
- number of awards received by students in engineering competitions

(2) COURSES

(a) Attractiveness to students

- student evaluation
- failure rate

(b) Availability of resources

- professor to student ratio
- percentage of faculty registered as professionals engineers

(3) RESEARCH OUTPUT

(a) Contributions to existing theories and/or practices

- number of papers published in refereed journals and/or conferences
- number of patents

(b) Reputation

- reputation rank by academics and practicing engineers
- research funds received from the government, industry and society

Quality characteristics are considered to be crucial for measuring 'quality'. Universities should define what the critical quality characteristics are in the quality manual.

CHAPTER FIVE

ISO 9000 FOR THE UNIVERSITY

In this chapter, the purpose and objectives of the development of the ISO 9001 quality system for the university environment are discussed. Subsequently, illustrative examples of the impact of ISO 9001 on the university are provided. Then, all twenty elements of the current ISO 9001 (1994) standard have been interpreted for the application in a university department. Finally, this interpreted standard is compared with the two engineering accreditation schemes: Canadian Engineering Accreditation Board (CEAB) and the Accreditation Board for Engineering and Technology (ABET). Similarities and differences of these schemes are addressed, as well as a cross-reference of elements provided.

5.1 PURPOSE AND OBJECTIVES

5.1.1 Quality Assurance in the University Environment

In the last decade or so, the quality of university education has become a subject of major concern. Students, their families, companies the graduates will work for, university professors and staff, government and politicians, all have their interests and stakes in this issue. They all want to be confident that universities provide excellent education and research. To provide confidence that the students have adequate knowledge in their particular area of expertise, governmental and professional institutions have introduced the accreditation of university programs. For instance, the Accreditation Board for Engineering and Technology (ABET) and the Canadian Engineering Accreditation Board (CEAB) perform accreditation of engineering programs in the United States and Canada, respectively. This provides a platform for standardizing degree programs, such as mechanical engineering, across North America. There is also a need to assure customers internationally, of the quality of educational services being provided locally. This is especially important in engineering education, because "engineers live in an increasingly global village. They are highly mobile and often practice their profession in a country other than where they were trained" (Jeswiet, 1995).

Such quality assurance efforts at an international level have led to the introduction of the ISO 9000 Standards. Developed by quality professionals originating mainly from the industrial sector, the standards provide a framework for emphasizing the organization's commitment to quality, as well as making quality efforts visible to customers. The impact of the standards world-wide has been so extensive that it is now virtually impossible to bid for international contracts if a company is not ISO 9000 registered. Since ISO 9000 standards are generic, they can be applied to service organizations, such as software companies, health care and education. The following section will outline the main purpose and objectives of the ISO 9001 quality system in the university environment.

5.1.2 Why ISO 9001?

What is the purpose of implementing ISO 9001 in a university? ISO 9001 is focused on providing confidence to customers and university management that the requirements for quality will be continuously met. In terms of customers, these requirements may be collected and documented through surveys of interested industries, governmental agencies, society, graduates and students. In terms of university management, requirements for quality are expressed in the quality policy, or university mission. On the other hand, ISO 9001 is not meant for ensuring that the university produces students and/or research at the world class level, nor will it ensure cost reduction and total quality management practices. Tables 5.1 and 5.2 provide an insight to what a university can expect from the implementation of a quality assurance system that complies with the ISO 9001 standard, and what does not, respectively.

WHAT ISO 9001 WILL PROVIDE
Confidence to: ♦ the students, industry, government and society ♦ the university and faculty management that the requirements for quality are continuously met
An effective marketing tool. A registered quality system makes quality visible both internally and externally.
Unambiguous definition of the responsibility and authority of all persons involved in teaching/learning/research, including: professors, teaching assistants, students, administrative staff, technicians and support staff
Adequate determination of the customer requirements for quality
Continuous information-monitoring and feedback system
Adequate documentation of program/course design activities and output
Adequate and unambiguous documentation of the student entrance requirements, hiring new staff and material
Adequate evaluation of high-schools, colleges and universities students come from
Streamline and make documentation clearer
Identification and traceability of all records, student/course/research progress
Control of the teaching/learning/research processes, including: reliability of laboratory, computer, library equipment, student counseling, as well as continuous feedback to the student
Adequate procedures for conducting and reporting the results of all tests, assessments, exams, quizzes, including graduation
Adequate documentation of professor advancements, merit awards and/or nonconformance
Adequate control of student/staff/research failure
Internal Quality Audits for identifying and resolving practical problems
Adequate use of statistical techniques
Basis for complying with the standards for the control of environmental (ISO 14000) and workplace health and safety systems

TABLE 5.1: ISO 9001 Benefits

WHAT ISO 9000 WILL NOT PROVIDE
Assurance that the university produces students and/or research at the world class level
Cost cutting tools
Total Quality University
Employee and/or student participation and empowerment
Benchmarking (in all cases)
More documentation

TABLE 5.2: What ISO 9001 Is Not Meant to Provide

5.1.3 Illustrative Examples

Examples to illustrate the impact of ISO 9001 on the university follow. Eleven examples focus on some of the customer quality assurance concerns.

- *Does the professor know the quality policy of the university?*

ISO 9001 will ensure that the quality policy is defined, implemented and understood at all levels of the university (section 4.1.1).

- *Is the equipment working (overhead projector stopped working during class, the computers are not working, inappropriate software was loaded on the network, or the software does not work)?*

ISO 9001 provides means of proper documentation of nonconformances (4.13), as well as adequate corrective and preventive actions (4.14).

- *Are the courses regularly updated on the current scientific events?*

The professor's training and updating on the current theories/practices is ensured in the section 4.18 Training.

- *What if the professor decides to change a course without a customer's reference?*

Course design changes must be reported and documented (4.4). Obsolete documents must be destroyed or disposed of (4.5).

- *Is a student given a precise plan of what he/she is supposed to learn, when the exams are going to be and what will be tested on the exams and tests ?*

ISO 9001 ensures that there are procedures in place for administration of the course, including a standardized course outline, and ensures that this outline is handed out and understood by the students at the beginning of each course (4.4 and 4.9)

- *Do graduate students know when they have fulfilled the thesis requirements?*

The faculty should identify the critical quality characteristics (section 4.4), so that there is an exact criteria for evaluating quality of research. Also, section 4.9 ensures that adequate process control of the graduate student's progress is established and maintained.

- *What if the professor is not following the course outline?*

The student is entitled to raise a nonconformance report to the department. If the department does not perform corrective and preventive actions upon this request, ISO 9001 registration will not be granted, or, if already granted, will not be renewed (4.13).

- *Is course material available?*

The availability of necessary resources, such as textbooks and other course material, is ensured in sections 4.2 Quality System, 4.3 Contract Review and 4.6 Purchasing of ISO 9001.

- *How can a student be assured that his/her assignment will not be lost?*

ISO 9000 (4.7 and 4.8) prescribes documented procedures for the identification and traceability of a document supplied by the student, as well as proper care to ensure that it is not lost or damaged.

- *How are possible inconsistencies in evaluating student work addressed?*

With the implementation of the process control element of the ISO 9001 quality system, professors should have in place procedures for control of the teaching and learning processes. In other words, evidence that the teaching process is in control will be available. Also, section 4.11 addresses the design and evaluation of marking and grading schemes. However, ISO 9000 can not ensure that students will stop complaining about their marks, but it can be expected that the number of students complaining will be significantly decreased.

- *How is the customer assured that his/her specifications are known by the University?*

Section 4.3 Contract review ensures that procedures are in place for the precise definition of what is expected from the university and for regular review of these requirements.

5.2 INTERPRETATION OF ISO 9001 (1994) FOR UNIVERSITIES

5.2.1 Overview

The ISO 9001 standard was written by engineers and quality professionals from large industries with a manufacturing organization in mind. Although the standards are generic, i.e. they are universally applicable to service and non-profit organizations, health care and education, the documentation and implementation of an ISO 9001 quality system in the university environment requires an interpretation of the standard. For the purpose of implementing this standard in the department of mechanical and industrial engineering at the University of Manitoba, the 1994 (latest) edition is interpreted using the concepts of quality assurance and quality system (Chapter 3), as well as the University System (Chapter 4). To further clarify the terms and concepts necessary for the interpretation of ISO 9001 and the implementation of the quality system in the university, two tables are provided. Table 5.3 defines selected quality assurance terms for use in a university, and Table 5.4 illustrates the meaning of certain manufacturing concepts in the university environment.

TERM	EXPLANATION
Quality Assurance	All those planned and systematic actions necessary to provide adequate confidence to the customers & faculty (department) executive management that the product will satisfy given requirements for quality.
Quality System	Set of interdependent process that function harmoniously, using various resources to achieve objectives related to quality.
Quality Policy	The overall quality intentions and direction of the faculty (department), as formally expressed by the dean (department head).
Quality Management	Process consisting of quality planning, quality control and quality improvement.
Quality Planning	Process of identifying the customer's requirements and objectives for quality, designing the quality system and allocating resources.
Quality Control	The operational techniques and activities that are used to fulfill requirements for quality at the department level.
Quality Improvement	Process of increasing the effectiveness and efficiency of the quality system
Quality Plan	Document setting out the specific quality practice, resources and sequence of activities relevant to a particular product, project or contract. Examples: research project plan, course plan.
Management Review	Management review is conducted by the executive management of the department and includes: (1) Internal Quality Audits; (2) An overview & analysis of quality policy; (3) The analysis of customers requirements and their relationship to the policy

TABLE 5.3: Summary of Quality Assurance Terms

TERM	EXPLANATION
Quality System Review	A formal evaluation by the dean and department heads of the status and adequacy of the quality system in relation to quality policy and new objectives resulting from changing circumstances.
Design Review	A formal evaluation by the department head or faculty member of the product design to evaluate product requirements and the capability of the product to meet these requirements.
Inspection	That aspect of the faculty-wide quality control that measures, examines and tests one or more characteristic of the product and compares these with specified requirements to determine conformity.
Nonconformity	The nonfullfilment of specified requirements. Examples include: student failure, course failure, research project failure
Defect	The absence of one or more quality characteristics from intended specifications.

TABLE 5.3: Summary of Quality Assurance Terms (Continued)

MANUFACTURING	UNIVERSITY: Faculty of Engineering
Product	(a) Students knowledge, experience & skills (b) Programs and Courses (c) Research Output
Customers	(1) Industry, Community and Research Sponsors (2) Association of Professional Engineers of Manitoba (APEM) and the Canadian Engineering Accreditation Board (CEAB) (3) Alumni
Supplier	The Department of Mechanical/Industrial Engineering
Subcontractors	High-Schools, Colleges and other Universities
Executive Management	(1) Faculty: Dean, department heads and directors (2) Department: Head and associate heads
Design Plan	(a/b) Industrial Engineering Undergraduate Program, Mechanical Engineering Undergraduate Program, M.Sc (ME) program (c) Research objectives and purpose
Designer	Faculty member
Process Plan	(a) Individual student curriculum (b) Course outline (plan) (c) Research Project Plans

TABLE 5.4: Summary of the University System Concepts

MANUFACTURING	UNIVERSITY: Faculty of Engineering
Raw Material	(a/b) Students knowledge of basic sciences before entering the faculty (c) Existing theoretical and practical knowledge
Value Adding to Material	(a/b) Value adding to students knowledge, experience and skills (c) New knowledge
Manufacturing Process	Teaching/Learning/Research process
Lead Time	(a/b) For programs: 4 years, for courses: 1 or 2 semesters (c) For contractual research: from contract to delivery
Part	(a/b) Students knowledge accumulated in a course (c) Phase of a research project
Operation/Tool	(a/b) Lecture (c) Work on a research project phase
Machine/Technology	(a) 'Learning Research Opportunity' (b) 'Research Opportunity'
Operator	(a/b) Instructor, Teaching Assistant (c) Researcher, Research Assistant
Part Specification	(a/b) Course Specification in General Calendar (c) Specification of deliverables in the contract (for a phase)
Inspection	(a/b) Exams, Tests, Assignments, Quizzes, Projects (c) Inspection, measurement, testing

TABLE 5.4: Summary of the University System Concepts (Continued)

In the following section, each of the twenty requirements of the ISO 9001 (1994) standard will be interpreted for use in the university environment. The elements are addressed in the order in which they appear in the standard.

5.2.2 A Detailed Interpretation of the ISO 9001 Elements

5.2.2.1 Management Responsibility

A quality policy, stating the commitment of the faculty (department) to provide the best quality in teaching, learning and research should be drafted and signed by the dean (department head). The executive management ensures that the quality policy is understood, implemented and maintained.

In terms of the responsibility and authority of all persons whose work is affecting quality, it should be noted that all employees of the faculty have an impact on quality. This includes the faculty/department administration, professors (instructors), teaching/research assistants/associates, technicians and administrative/support staff. Organizational charts are required to define and document responsibility and authority.

The executive management must identify the need for appropriate resources (instructors, assistants, courses, laboratory equipment, library, audio/video/computer equipment), as well as appoint an ISO 9000 Representative. The representative should have a thorough understanding of the ISO 9001 quality system, and the educational and research processes in the faculty (department). His/her responsibilities include liaisons with external parties, such as other faculties and/or universities, university administration, student records office and customers /subcontractors of the faculty (department).

At prescribed intervals, or when required, the executive management conducts management review activities. A management review includes:

- internal quality audits (see section 5.2.2.17),
- overview and analysis of the quality policy and objectives,
- analysis of customers requirements/needs, and
- interrelationship between customer requirements and policy and objectives

While quality audits are performed against the departmental goals and objectives, management reviews are performed by the executive management against the faculty mission (quality policy). A management review may include the review of documentation from the audits. Records of management reviews must be kept and evidence of actions arising from the reviews must be available.

5.2.2.2 Quality System

This requirement considers the three products of the university (student knowledge gain - STU, programs and courses - PRG and research - RES). If the faculty (department) plans not to include certain products in the quality system, such as research, the range of products and services included in the quality system must be stated.

A quality system must be documented with appropriate quality manual, procedures, instructions and records. The quality manual describes the quality system and refers to quality system procedures. The faculty (department) may decide to prepare one procedure for each requirement of the standard. The procedures explain in detail who does what, when and where, i.e. they describe processes. Procedures make reference to instructions that define how an activity or part of a process is performed. Examples of instructions may include the teaching assistant's instruction for conducting laboratory experiments, librarian/technician instructions, and so on.

Quality planning covers:

- product planning, i.e. identifying, classifying and weighting the characteristics for quality, as well as establishing the objectives, requirements and constraints for quality
- preparing the application of the quality system including organizing and scheduling
- preparation of quality plans.

Quality plans are documents setting out the specific quality practices, resources and sequence of activities relevant to a particular product, project or contract. Each course and a contracted research project should be covered with a separate quality plan, or these plans should be included in the course or research project plans.

5.2.2.3 Contract Review

The objective of the contract review element of the quality system is to provide the faculty (department) with a clear understanding of customers' requirements, specifications and needs, to evaluate if these requirements and specifications can be achieved, and to provide the customers with a clear understanding of the manner in which the faculty (department) shall meet them. It is important to recognize that students also have certain contractual obligations, emerging from their enrollment at the university.

The following processes may be covered:

- Defining and documenting the industry and society requirements with respect to undergraduate and graduate programs offered, and the assessment of the faculty's (department's) ability to meet the requirements
- Accreditation of programs by regulating bodies (such as CEAB in Canada)

• Contract reviews with the employers participating in the cooperative program

• Ensuring and reviewing that the students understand the admission requirements, program content and context, graduation requirements, and their responsibilities and authorities

• Review of industry and government-sponsored research contracts

5.2.2.4 Design Control

This element of the quality system covers design control of the programs and courses offered by the faculty (department), design control of individual student's programs of study, and design control of the research conducted in the faculty (department). The objectives are:

• to demonstrate the department's ability to translate customers specifications into design input requirements,

• to perform the design of programs, courses, student knowledge, individual student's program of study and research,

• to verify design output against design input requirements,

• to validate design output against customers' requirements and specifications, and

• to identify, document, review and approve design changes and modifications.

Design input may include the output of contract review activities, such as suggestions for new programs from CEAB or industry, analysis of customer needs and market position of the faculty (department), feasibility studies for new programs or research. Design output should include the statement of factual content, skills and competencies to be developed, as well as show that course/program content is relevant to its aims and objectives. The responsibilities and authorities and the vertical and lateral interrelationships between the personnel which input into the design process should be defined and documented.

The following processes may be covered:

• Design planning, review, verification and validation of new undergraduate mechanical and industrial engineering programs, as well as graduate level programs

• Design planning, review, verification and validation of specific undergraduate and graduate courses

• Identification, documentation, review and approval of program design changes, including the addition of new courses and deletion of existing courses and programs

• Design control of the individual student program (curriculum)

• Research project design control, including contractual research with industry and government agencies

5.2.2.5 Document and Data Control

Document control ensures that accurate, up-to-date documents are readily available when and where required. All documents and data pertaining to the quality system must be adequately prepared, reviewed, revised, approved and maintained. Thus, the issuance and approval of quality system documents and data, including the preparation, updating and maintaining the Master List of Quality System Documents, as well as the document and data changes are covered here. Quality system documents include the quality manual, procedures, instructions, records and course and research project plans.

5.2.2.6 Purchasing

The objective of this element is to ensure that the high schools, colleges and universities the students come from, students entering the faculty's (department's) programs, as well as the material and products purchased for teaching, learning and research purposes, conform to the specified requirements. This is necessary because the faculty (department) builds the acquired resources into it's products. For example, only the students who meet entrance standards should be allowed to enroll. Purchased material or equipment which is defected, such as a faulty overhead projector, may negatively affect the teaching, learning or research processes.

The following processes should be covered: purchasing of material. hardware and software required for the proper delivery of programs, courses and research projects, the appointment of teaching and research assistants/associates, and admission of undergraduate and postgraduate students. Appropriate verification of a purchased product or an acquired resource must be planned, executed and reviewed. Where specific contracts require the department or faculty/staff members to verify purchased products or acquired resources at subcontractor's premises, this verification is planned, conducted and recorded according to the particular contract. Also, where specific contracts require the customers to verify purchased products or services at the faculty's (department's) premises, this verification is planned, conducted and recorded according to the particular contract. This, in general, pertains to research contracts. In terms of student knowledge, experience and skills, as well as the programs/courses, this may pertain to visits by the representatives of industry and governmental agencies, such as the CEAB.

5.2.2.7 Control of Customer-Supplied Product

The objective is to demonstrate the capability of the faculty (department) to identify, maintain, store, preserve and properly handle all material provided by students in the course of studies, and all products provided by external organizations with which the department has contracts for research projects. The identification, verification and handling of student-supplied material, such as exams, tests, assignments, reports, theses, software and books, as well as the examination, storage, maintenance, preservation, handling and proper usage of hardware and software provided by research sponsors, industry and governmental institutions and/or agencies are covered.

5.2.2.8 Product Identification and Traceability

The objectives are to ensure proper identification of all courses, research projects, students, faculty and staff, as well as to provide adequate traceability of nonconformancies in student academic progress, courses/programs and research projects. The following processes are addressed:

- issuing and safekeeping of student numbers and identification cards,
- issuing and safekeeping of faculty and staff identification cards,
- handling of department and course numbers
- issuing and distributing registration calendars to students

• assigning numbers and codes to research projects

5.2.2.9 Process Control

In general, this requirement addresses the teaching, learning and researching processes. The objective is to ensure proper identification and planning of these processes, and to ensure that they are carried out under controlled conditions. Controlled conditions include:

- documents defining the manner in which the processes are carried out,
- use of suitable equipment and working environment,
- compliance with reference course and research project quality plans,
- monitoring/control of critical quality characteristics and suitable process parameters,
- preventive/corrective maintenance of equipment used in teaching, learning and research

It is important to note that the control of learning is focused by the inspection and testing requirement (see section 5.2.2.10), rather than here. Process control activities may be categorized into four groups: process control design, control of resources, process control implementation and process control improvement. Table 5.5 illustrates the activities of teaching and research process control, respectively.

TEACHING PROCESS CONTROL	
GROUP	ACTIVITY
PROCESS CONTROL DESIGN	review of course design and quality plans
	assessing the need and selection for course/program prerequisites
	identification of critical quality characteristics for the course
	identification of teaching process parameters to be monitored and controlled
	planning the methods for monitoring and control of critical quality characteristics and suitable process parameters
CONTROL OF RESOURCES	identification of adequate teaching equipment
	ensuring proper maintenance of teaching equipment
	identification of proper teaching and learning environment
	review of equipment, facilities and services admissibility for the course
PROCESS CONTROL IMPLEMENTATION	assessment of student's admissibility to a course
	assessment of topics and matter taught in course prerequisites
	course delivery
	monitoring, measuring and control of critical quality characteristics and teaching process parameters
	student course evaluation

TABLE 5.5: Process Control Activities

TEACHING PROCESS CONTROL	
GROUP	ACTIVITY
PROCESS CONTROL IMPROVEMENT	planning, implementing and reviewing preventive and corrective actions
	assessment and review of critical quality characteristics, suitable process parameters, equipment, environment, facilities and services

RESEARCH PROCESS CONTROL	
GROUP	ACTIVITY
PROCESS CONTROL DESIGN	identification of critical quality characteristics for a research project
	identification of research process parameters to be monitored and controlled
	planning of the methods for monitoring and control of critical quality characteristics and suitable research process parameters
CONTROL OF RESOURCES	identification of adequate equipment required for the research project
	ensuring proper maintenance of research equipment
	identification of proper research environment
	review of equipment, facilities and services admissibility for the research project
	research project quality planning
PROCESS CONTROL IMPLEMENTATION	research project delivery
	monitoring, measuring and control of critical quality characteristics and research process parameters
PROCESS CONTROL IMPROVEMENT	planning, implementing and reviewing corrective actions
	assessment and review of critical quality characteristics, suitable process parameters, equipment, environment, facilities and services

TABLE 5.5: Process Control Activities (Continued)

5.2.2.10 Inspection and Testing

The objective of the inspection and testing element of the ISO 9001 quality system is to ensure that student knowledge, experience and skills, programs/courses and research are inspected and tested against the requirements set in appropriate procedures, documents and quality plans, as well as to ensure that appropriate records of these activities are kept. The element applies to:

- Receiving, in-process and final inspection of undergraduate students' knowledge and skills in a course,
- Receiving, in-process and final inspection of undergraduate students within a program, including admission into an engineering program, the evaluation of the student's academic status and graduation

• Receiving, in-process and final inspection of graduate students, including course-work and thesis-related work

• Receiving, in-process and final inspection of a research project against the requirements set out in the research contract and/or the research project plan

Specific activities are outlined in Table 5.6.

PROCESS	ACTIVITY
RECEIVING INSPECTION AND TESTING AT A COURSE LEVEL	selection of course prerequisites and corequisites
	assessment of student admissibility to a course, including review of the student's performance in prerequisite courses, the ability to attend lectures and laboratory sessions, the ability to use the required level of mathematics and natural sciences in the course, and may include short tests to inspect the knowledge of fundamental principles required to enroll in the course
	keeping records of receiving inspection and testing activities
IN-PROCESS INSPECTION AND TESTING AT A COURSE LEVEL	design and design review of inspection and test plan for the course
	distribution of the course inspection plan, which is a part of course outline, to students
	assessment of the scheduling of inspection and tests activities
	design and review of term tests, quizzes, projects, case studies and other forms of inspection and testing activities to be performed during the term
	distribution and collection of tests
	marking and grading
	handling of marking and grading appeals
	keeping records of in-process inspection and testing activities
FINAL INSPECTION AND TESTING AT A COURSE LEVEL	design and design review of the final exam
	conducting the final exam
	marking and grading of the final exam
	review of marking and grading
	handling of appeals
	review of final exam results
	conducting deferred and special exams
	keeping records of final inspection and testing
RECEIVING INSPECTION OF UNDERGRADUATE STUDENTS	application for admission into the department's undergraduate programs
	review of the application and eligibility of student to enroll
	inspection against specified entrance requirements and criteria
	handling of student appeals
	keeping records of aforementioned activities
IN-PROCESS INSPECTION OF UNDERGRADUATE STUDENTS	determination and review of the student academic status in the first year of engineering program (faculty level)
	determination and review of the student academic status in the second and consecutive years of engineering programs (department level)
	handling of student appeals
	keeping inspection records
FINAL INSPECTION OF UNDERGRADUATE STUDENT'	Graduation

TABLE 5.6: Inspection Processes and Activities

PROCESS	ACTIVITY
RECEIVING INSPECTION OF GRADUATE STUDENTS	application for admission into the department's undergraduate programs
	review of the application and eligibility of student to enroll
	inspection against specified entrance requirements and criteria
	handling of student appeals
	keeping records of aforementioned activities
IN-PROCESS INSPECTION OF GRADUATE STUDENTS	advisor's assessment of the student's progress
	annual review of progress
	establishment of the M.Sc. thesis examining committee
	M.Sc thesis oral examination
	review of thesis/project by the examining committee
	establishment of the Ph. D selection committee
	review of student's suitability for Ph.D. studies
	advisor's assessment of Ph. D student's progress
	documenting and implementing the program of studies
	establishment of the Ph. D advisory committee
	annual review of the Ph.D. student's progress
	conducting the Ph.D. Candidacy Examination
	conducting the Ph.D. Oral Examination
FINAL INSPECTION OF GRADUATE STUDENTS	Graduation
RECEIVING, IN PROCESS AND FINAL INSPECTION OF A RESEARCH PROJECT	Activities specified in the research project plan

TABLE 5.6: Inspection Processes and Activities (Continued)

5.2.2.11 Control of Inspection, Measuring and Testing Equipment

The objectives are: proper control of the methods and equipment used for measuring and testing of student knowledge, experience and skills, control of the methods used to ensure that the faculty's (department's) programs conform to the specified requirements, as well as control, calibration and maintenance of the inspection, measuring and test equipment used in research. The following processes are included:

- design of tests, quizzes, assignments, project requirements, exams
- designing, applying, reviewing, changing and improving the marking and grading schemes
- review of inspection and testing methods for student knowledge, experience and skills

• control, calibration and maintenance of equipment used for inspection, measuring and testing at the course level, such as instant scoring machines, standardized and computerized tests

• control, calibration, maintenance, handling and safeguarding of inspection, measuring and test equipment used in research activities

• control, maintenance and review of methods used for inspection and measurement of the degree to which an undergraduate or a graduate program meets specified requirements

5.2.2.12 Inspection and Test Status

The objective is to ensure that student knowledge, experience and skills, programs/courses, as well as research projects, are properly identified with regard to inspection and testing activities performed upon them, and that the inspection and test status indicates whether these are conforming or nonconforming to specified requirements. For example, a class list with grades for specific components of the course indicates a student's inspection and test status in a course. Another example is the student academic status, determined after evaluation by the board of examiners.

The following processes apply:

• undergraduate student's inspection and test status at the course level, including the receiving inspection and test status, in-process inspection and test status, regarding the term work, and the final inspection and test status, regarding the final exam

• inspection and test status of undergraduate students at the program level, including the admission status, student academic standing and the graduation status

• inspection and test status of graduate students, including the admission status, status with regard to course-work and thesis related work and the graduation status

• inspection and test status of a research project.

5.2.2.13 Control of Nonconforming Product

Nonconforming products are students who do not meet specified requirements in a course or program, courses/programs that failed to achieve stated objectives, as well as research projects that did not meet specified contract requirements. This element requires the identification, evaluation, documentation and segregation of such students, courses/programs or research projects. In terms of undergraduate students, control of nonconformancies related to term-work and final exams, as well as control of students under academic suspension is required. Control of graduate students who do not meet course or thesis requirements, as well as nonconforming contracted research must be addressed, as well.

5.2.2.14 Corrective and Preventive Action

The objective is to ensure the identification and elimination of existing or potential nonconformities of considerable magnitude. This is done by planning, designing, implementing and reviewing adequate corrective actions to prevent existing nonconformities of occurring again, and adequate actions to prevent the occurrence of potential nonconformities. Corrective and preventive actions taken at all stages of planning, design and delivery of programs, courses and research in the faculty (department) are included. Existing and potential nonconformancies are identified by means of internal quality audits (see section 5.2.2.17), statistical techniques (see section 5.2.20), inspection and tests or personal observations.

5.2.2.15 Handling, Storage, Packaging, Preservation and Delivery

The objective is to provide methods of handling, storage, preservation and delivery of material and equipment that prevent damage or deterioration, as well as methods to ensure a safe and healthy environment. In case that any damage or deterioration occurs, the objective is to ensure detecting and assessing such occurrences, and implementing corrective and preventive actions to eliminate causes of further damage and/or deterioration (see 5.2.14).

This element of the quality system covers the handling, storage, preservation and delivery of teaching, learning and research equipment and materials, as well as identifying and safekeeping the teaching, learning and research environment. The equipment and material include lecture rooms, research laboratories, computer laboratories, overhead projectors, electronic displays, chalk boards, textbooks, software, solution manuals, materials used in tests and experiments, research project reports, and research papers. Provision of a healthy and safe environment includes proper conduct of faculty, staff and students, personal safety and health, as well as parking and traffic regulations, sports services, housing and student life.

5.2.2.16 Control of Quality Records

The objective of quality records is to provide evidence that adequate quality assurance activities are being carried out. This element applies to the identification, collection, indexing, access, filing, storage, maintenance and disposition of quality records. A Master List of quality records should be kept.

5.2.2.17 Internal Quality Audit

The objective is to verify that the quality system complies with planned arrangements, such as the ISO 9001 International Standard, and to verify whether these arrangements are implemented effectively and are suitable to achieve quality objectives. Internal quality audits serve to improve the quality system from the perspective of individual faculty and staff members, since they raise official attention to shortcomings and problems within the system. An effective internal quality audit system should be established on the basis of ISO 10011 Guidelines for Quality Audit.

5.2.2.18 Training

The faculty (department) must identify the training needs of its faculty and staff, including the teaching and research assistants, and provide the adequate training. Also, student counselling needs should be identified and proper counselling services supplied. Thus, the following processes should be addressed:

- Development and training of faculty,
- Development and training of teaching and research assistants
- Development and training of administrative staff and technicians
- Student curriculum and personal counselling
- Research staff development and training, including sabbatical leaves

- Faculty promotion and tenure

5.2.2.19 Servicing

This element of the quality system covers the servicing of programs and courses. Students are provided with information on new developments in the field of expertise, career counselling, provision of the list of engineering graduates to prospective employers and alumni organization's services. This element also includes servicing in the domain of research projects, when such activities are required by the contract.

5.2.2.20 Statistical Techniques

The objective is to ensure that the need for statistical techniques required for quality assurance of student learning, course teaching and research is established, and that the identified techniques are implemented and controlled. Statistical techniques may include statistical process control (control charts), the seven quality tools, analysis of variance, hypothesis testing, and so on.

5.3 ISO 9001 VERSUS ACCREDITATION SCHEMES

5.3.1 Overview

Engineering faculties in Canada and the United States have already encountered certain assurance schemes in the accreditation of their undergraduate programs. The Canadian Engineering Accreditation Board (CEAB) evaluates undergraduate degree programs offered at Canadian universities and accredits those which meet minimum standards. The same mandate in the United States is given to the Accreditation Board of Engineering Technology (ABET). These two accreditation schemes have been discussed in detail in Chapter 2. The objective of this section is to compare the proposed quality assurance scheme, i.e. ISO 9001 to the current engineering accreditation schemes. In the comparison, the interpretation of the ISO 9001 standard as given in section 5.2 is used. The CEAB scheme is evaluated on the basis of the questionnaire the board sends to interested departments and the documentation developed for the '93 accreditation of the

Faculty of Engineering at the University of Manitoba. ABET vision and criteria available on the board's web page (http://www.abet.ba.md.us) have been used for the illustration of this scheme. In the following sections, similarities and differences between ISO 9001 and accreditation schemes are given, followed by the cross-reference comparison of their elements.

5.3.2 Similarities

Several similarities of the current accreditation schemes and ISO 9001 are evident. They are the following:

- Accreditation schemes and ISO 9000 are both designed to assess, verify and make results visible to the public.
- The list of institutions accredited by CEAB or ABET, and registered to ISO 9000 is readily available.
- Accreditation schemes and ISO 9000 are voluntary.
- Substantial documentation and records are required
- Accreditation/Registration starts with sending a document to a registration or accreditation body. In ISO 9001, this document is the quality manual, in CEAB/ABET it is a questionnaire.
- If a questionnaire/quality manual is assessed as appropriate, a site-visit follows.
- The site visit is conducted by an ABET/CEAB team, or by an ISO 9000 registrar.
- Compliance with minimum standards is required.
- If it appears that a program/institution is not in compliance with the accreditation/ISO 9000 criteria, a non-compliance report will be issued, and a follow-up audit performed.
- Accreditation/registration is granted for a limited time period.

5.3.3 Differences

The following are perceived differences between the CEAB and ABET accreditation schemes, on one side, and the ISO 9001 system, on the other.

• CEAB and ABET are institutions providing *accreditation* directly to interested universities, whereas ISO 9000 registrars provide *registration*. The difference is that ISO 9000 registrars are *accredited* by a body called the Registrar Accreditation Board

• CEAB and ABET accredit engineering *programs*, whereas ISO 9000 registration is provided to a *facility* or an institution. This means that an industrial engineering undergraduate program can be ABET accredited, but an industrial engineering department can be ISO 9001 registered.

• Accreditation schemes are limited to engineering programs only, whereas ISO 90001registration is open to any faculty or department.

• Accreditation schemes are designed for undergraduate programs only. ISO 9001 registration can cover graduate programs, as well.

• ABET scheme provides accreditation at either the basic or advanced levels. There are no levels in ISO 9000 registration or the CEAB accreditation.

• ABET will grant initial accreditation only if students have graduated from a program prior to the on-site visit. There is no such restriction in ISO 9001, i.e. a totally new department can become ISO 9001 registered.

• A quality Manual can take any shape, form or content, as long as it describes the quality system of an organization and is in compliance with the standard. However, accreditation schemes require a pre-designed questionnaire to be simply filled in with required information about an institution, and/or its program.

• ISO 9001 is an international standard, whereas CEAB/ABET schemes are set at a national level.

These three schemes can also be viewed through the three-dimensional model of university products and processes presented in Chapter 4. While the current CEAB and ABET accreditation schemes mainly focus on programs and courses, i.e. the teaching process, ABET 2000 criteria emphasize measurable learning outcomes (Figure 5.1). Neither scheme addresses research activities directly. On the other hand, ISO 9001 focuses on all three dimensions of the product.

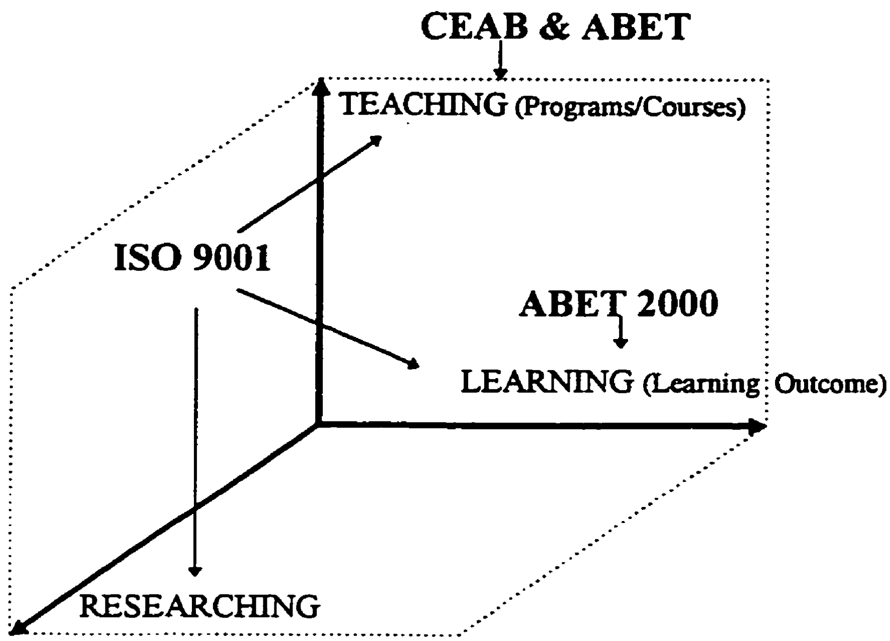


FIGURE 5.1: Assurance Schemes Compared on the Basis of the US Model

5.3.4 Cross-Reference

In order to further compare the three schemes, the elements of ISO 9001-94 have been cross-referenced with the elements of the CEAB questionnaire from 1993. (Table 5.7), as well as with the elements of ABET criteria from 1996. (Table 5.8). Since ABET criteria also provide procedures for assessing engineering programs, these criteria have been cross-referenced with the ISO 10011-1 (1994) Guidelines for Auditing Quality Systems (Table 5.9).

It can be concluded that ABET and CEAB accreditation schemes emphasize program design, but do not address how the program is actually executed. In other words, the schemes provide assurance that appropriate courses are designed, that facilities are in place, and that faculty is qualified. But they do not address course delivery, maintenance and proper operation of equipment and facilities, and faculty's involvement in assessing student knowledge and skills. The schemes also depict management and faculty responsibilities, as well as provide for proper training of faculty, through sabbatical and research leaves, conferences and so on. In general, current ABET and CEAB place little emphasis on explicit quality assurance, i.e. the question: 'How does the faculty of engineering assure their various interested and involved parties of the adequate quality of services rendered?' is neither posed nor indirectly answered. ISO 9001, however, addresses this valid question.

	ISO 9001-94 (SECTIONS 4.X)																			
CEAB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1A.1-1A.3	√																			
1A.4	√															√				
1A.5		√																		
1A.6-1A.7											√							√		
1B.1-1B.2	√																			
1B.3		√																		
1B4.-1B.5	√																			
1B.6				√																
1B.8	√										√					√		√		
1B.9	√																			
1B.10									√							√				
1B.11			√			√			√											
1B.12				√																
1B.13								√	√	√		√	√			√				
1B.14		√							√											
1B.15-16				√					√											
1B.17									√											
1B.18-1B.20	√			√					√											
1B.21	√																			
1C.1-1C.3	√															√				
1C.4	√																			
1C.5						√		√												
1C.7																√				
1D.1				√					√							√				
1E.1																√		√		
2A.1-2A.4	√			√																
2A.5-2A.9				√					√											
2A.10	√								√		√									
2A.11				√					√											
2A.12-2A.13	√								√		√									
2A.14-2A.16				√					√											
2A.17									√							√				
2A.18	√								√											
2A.19																√				
2A.20	√			√																
2A.21	√																			
2B.1-2B.5																√				
2C.1-2C.3	√			√												√				
2D.1		√		√												√				
2E.1																√		√		

TABLE 5.7: ISO 9001-94 Vs. CEAB-93 Cross-Reference

ABET	ISO 9001-94 (SECTIONS 4.X)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
IV.A				√																
IV.B.1				√																
IV.B.2		√		√														√		
IV.C.1	√	√				√			√									√		
IV.C.2		√		√																
IV.C.3.a-c				√																
IV.C.3.d			√	√																
IV.C.3.e-j				√					√											
IV.C.4.a						√				√										
IV.C.4.b						√				√										
IV.C.4.c																√				
IV.C.4.d																			√	
IV.C.5	√																			
IV.C.6		√				√														
IV.C.7	√																			
IV.D.1			√			√														
IV.D.2			√	√		√										√				
IV.D.3	√																			
IV.E.1	√																	√		
IV.E.2			√	√						√										
IV.E.3				√																
V.C.2														√						

TABLE 5.8: ABET-96 Vs. ISO 9001-94 Cross-Reference

ABET	ISO 10011-1 (1994)																	
	1	2	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	4.1	4.2	5.1	5.2	5.3	5.4	6	7
I.A	√																	
I.B												√						
I.C											√							
I.D	√																	
I.E		√																
II.A.1			√															
II.A.2-11	√	√	√	√	√	√	√											
II.B										√								√
II.C																	√	
II.D						√						√						
V.A													√					
V.B													√	√				
V.C													√	√	√	√		
V.D																	√	√
V.E									√								√	√
V.F																		√

TABLE 5.9: ABET-96 Vs. ISO 10011-1 (1994) Cross-Reference

CHAPTER SIX

QUALITY SYSTEM IMPLEMENTATION

This chapter addresses the implementation of a quality system in a university environment, and presents examples from a case study of establishing an ISO 9001 system in an engineering department of a Canadian university. First, a project plan for the design, documentation, implementation, and maintenance of the quality system in an engineering department is presented, followed by the description of the project phases and steps. Subsequently, examples of required documentation are provided, including the department's quality manual, quality system procedures, work instructions and records. One of the requirements of the ISO 9001 quality system is the establishment of an internal quality audit system. The development of a quality audit system, considering the ISO 10011 audit guidelines, concludes the chapter.

6.0 PROJECT PLAN

In the following fourteen sections, steps toward the implementation and maintenance of an ISO 9001 quality system in a university are suggested. An illustration of these steps with a timeline is provided in Figure 6.1. It is assumed that a university, department, faculty and/or institute establishes the system independently, using existing human, material and information resources (i.e. without hiring external consultants or other forms of external help). The registration of the quality system by an accredited registrar is one of the goals of the ISO 9001 project.

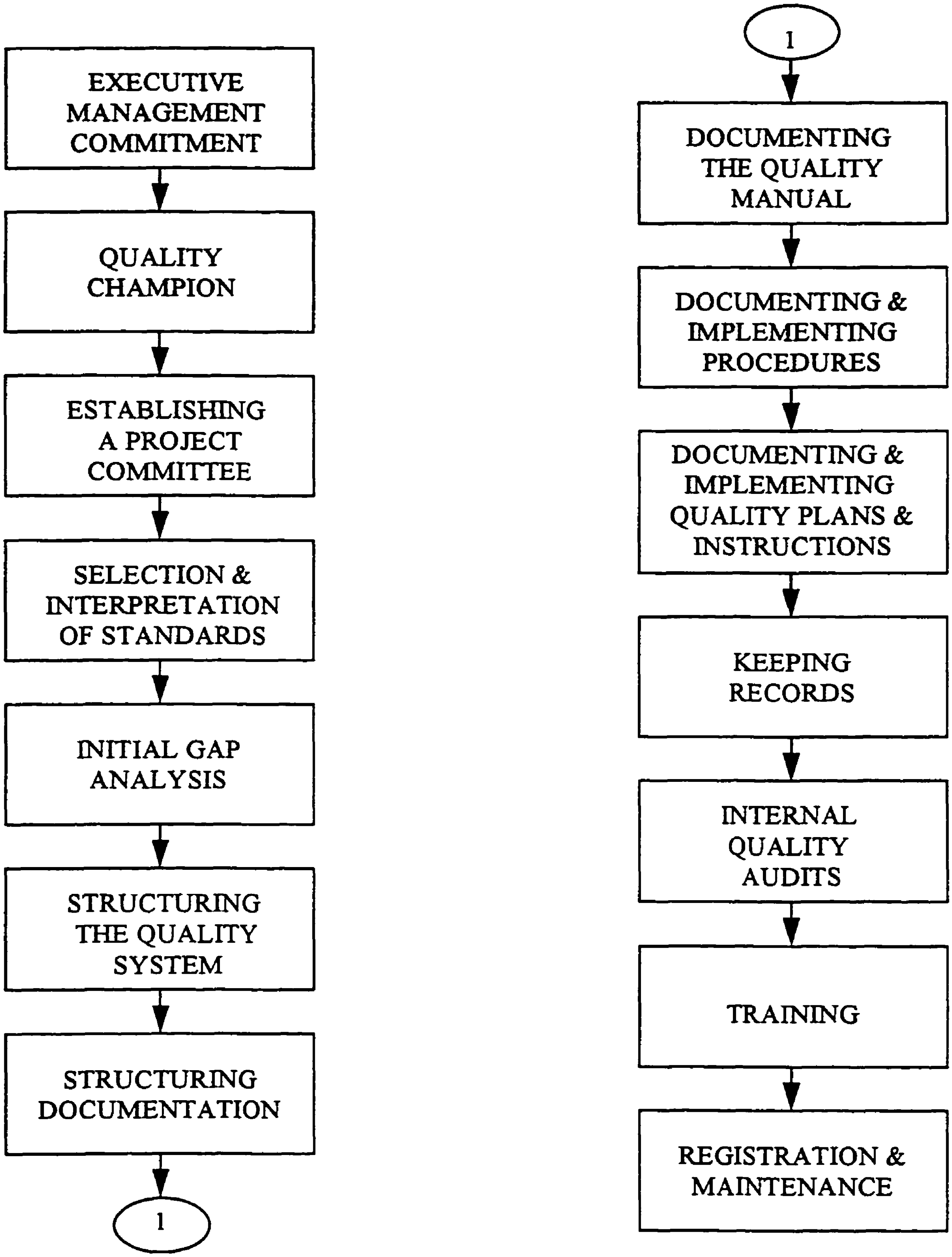


FIGURE 6.1: ISO 9001 Project Plan for a University

6.1 EXECUTIVE MANAGEMENT COMMITMENT

Universities are publicly accountable for their work in education and research, and therefore most of them already have some kind of a quality assurance system in place. As it was pointed out in Chapter 5, engineering and management schools, for example, are accredited by national accreditation boards, and have documentation available to illustrate the performance according to accreditation criteria. Thus, the establishment of a formalized ISO 9001 quality system will not have to be started from scratch. However, before any progress is made, the executive management of a university department, faculty or institute must be totally committed to the quality system implementation. The commitment of the dean, associate deans, department heads and directors is certainly a necessary, but of course not the sufficient condition, for successful documentation and implementation. This condition is emphasized in most of the available literature on the topic (Walker, 1997; Pfeiffer and Wunderlich, 1997; Gelders et al, 1995). To gain such commitment, benefits of an ISO 9000 quality system in a university for individual faculty and staff members, as well as for students and other stakeholders of the university, should be put forth. As the number of university institutions which are applying quality assurance systems is rapidly increasing, their experiences can be used in ensuring the executive management commitment. Universities that already implemented ISO 9000 systems are reporting that benefits greatly outweigh concerns (for example, see Doherty, 1995; Tannock and Burge, 1994; Lindström, 1994; Gelders et al, 1995; Pfeifer and Wunderlich, 1997; Harris and Owen, 1994; Hulshoff and Ori, 1994).

6.2 QUALITY CHAMPION

Once such a commitment is assured, a Quality Champion should be selected. The Quality Champion is a person with a genuine and passionate commitment to quality of education and research, knowledge of university's processes and procedures, strong leadership and communication abilities. Because ISO 9000 quality system includes teaching, learning, research processes, and administration, it is advised that the Quality Champion be a faculty member with some experience in administrative functions. This person should also be familiar with quality assurance standards, such as ISO 9000, and/or environmental management standards, such as ISO 14000. Because ISO 9000 and ISO 14000 are very similar (and will be integrated in the future), the lack of knowledge of quality assurance with familiarity in environment/health and safety management should not be an obstacle for the Quality Champion, providing that he/she is totally committed to quality improvement. The knowledge of and/or experience with accreditation schemes and processes will provide a great asset.

In the case that the Quality Champion is not familiar with the quality standards, principles of establishing a quality system, and/or quality auditing, ample training opportunities are available through national standardization bodies or societies for quality, such as the American Society for Quality (ASQ).

6.3 ESTABLISHMENT OF THE PROJECT COMMITTEE

The next necessary step toward ISO 9001 registration and maintenance is to organize a project (or 'steering' committee). The committee, headed by the Quality Champion, will ensure that the quality message is spread throughout the faculty/department and 'steer' the ISO 9000 effort. In regular meetings, the project committee will plan and organize standard interpretation, documentation, implementation, registration and maintenance activities, address problems arising during the project, and manage human and financial resources associated with the project. Membership of the committee should include, but is not limited to: the dean, associate deans and department heads, representatives from administrative and support staff, as well as the Quality Champion.

6.4 SELECTION AND INTERPRETATION OF STANDARDS

As was mentioned in Chapter 5, ISO 9000 standards are generic in nature, however they require an interpretation for use in higher education. Such interpretation was provided in section 5.2.2 of this thesis, for application associated with the University System and teaching, learning and researching processes. This interpretation can be used to develop a comprehensive quality system in a university environment. However, some universities may want to interpret the standards independently, or use other models of quality systems, for instance the EPC model of Tannock and Burge (1994), or combined ISO 9000 and TQM models of Ho and Wearn (1995) and Lo and Sculli (1996). Also, the possibility to develop a quality system according to the ISO 9002 standard will still exist in the next couple of years, before only ISO 9001 is available. The decisions on which quality system model to select and whether special interpretation is required should be made by the Project Committee, upon the recommendation of the Quality Champion. If an interpretation is required, it can be performed by the Quality Champion.

At this time, the scope of the quality system should be well defined and documented. For example, faculty members may feel that a quality system should not be established to include their research activities, and that the scope should be limited to teaching and learning in undergraduate programs only. The opposite situation is possible, where research activities are covered, but not teaching and learning (e.g. Pfeiffer and Wunderlich, 1997; Walker, 1997). Also, some departments within a faculty or a university may take a 'wait and see' attitude, arguing that the establishment of a quality system is not a pressing issue and can be dealt with later. Therefore, a precise definition of the participating departments and their educational, research and administration activities covered by the quality system should be provided in the scope. As a note, one department within a faculty or university could establish and register its quality system as a prototype for other departments to follow. This approach may prove to be very useful since:

- experience and expertise in developing a quality system will emerge
- documentation will have many similar, if not totally identical features
- ISO 9001 registered department's faculty members can serve as auditors in an another department

6.5 INITIAL GAP ANALYSIS

The next step is to perform an initial gap analysis against the selected quality system standard. Although the gap analysis has some features of an internal audit, it is important to recognize the difference between the two. While a gap analysis merely verifies the compliance with the quality system standard, a quality audit includes the examination and verification of the compliance, as well as the effectiveness and suitability of the quality system to achieve set objectives. Experiences and skills gained in gap analyses, however, are very useful in establishing an internal quality audit system, which is one of the requirements of ISO 9001 (section 4.17).

In a faculty which has experiences with accreditation of programs, such as engineering, management or medicine, the gap analysis should start with an examination of the documents and processes that are available and could be used as a foundation for a quality system. For example, any Canadian engineering faculty that is CEAB accredited will find that most of the documentation required for the ISO 9001 quality system already exists. The best-covered areas, as the comparison analysis from Chapter 5 indicated, are:

- Design control (section 4.4 of ISO 9001)
- Process control (4.9 of ISO 9001)
- Purchasing (4.6)
- Inspection and testing (4.10, 4.11, 4.12)
- Training (4.18)

Even the development of some ISO 9001 requirements that do not appear to be covered in the CEAB documents, such as 4.17 Internal Quality Auditing and 4.20 Statistical Techniques, can be based on existing processes. For example, the faculty/department's executive management regularly performs management reviews of the education, research and administrative processes, together with faculty or department councils. These review meetings can be used for overseeing the internal quality audit system that needs to be developed. Also, most faculty members already apply or are familiar with statistical techniques in teaching, learning and research, and only a systematic use of these techniques in quality improvement stands in the way to meeting this particular requirement of ISO 9001.

The gap analysis is performed by the Quality Champion, with assistance from the members of the Project Committee. It is useful to classify all existing documents according to the twenty requirements of ISO 9001, e.g. all documentation that pertains to 4.9

Process Control should be classified as such. In the case study, a folder with twenty separators, one for each requirement of ISO 9001, was created, and copies of existing procedures and records were catalogued accordingly. This approach proved to be very helpful in the quality system documentation phase, because these documents were referenced in quality system procedures and were readily available.

In order to gain experience in planning and conducting internal quality audits, the gap analysis can be executed as an audit and according to ISO 10011 Quality Audit Guidelines. For example, the Quality Champion would:

- prepare the gap analysis plan;
- identify the standard against which the analysis is conducted;
- identify and inform the people who will be interviewed to provide information
- prepare working documents, including, checklists, interview and observation forms
- conduct an opening meeting with the Project Committee and interviewees
- perform the analysis, including collecting evidence, documentation and information
- conduct a closing meeting with the Project Committee and inform them of main results
- draft a gap analysis report

The result of the gap analysis should be a statement of the degree of compliance of the current system with the selected quality system standard. The gaps in each ISO 9001 requirement should be identified, and areas requiring the most work emphasized.

6.6 STRUCTURING THE QUALITY SYSTEM

As was emphasized in Chapter 3, a quality system is a set of interdependent processes that function harmoniously, using various resources to achieve objectives related to quality. One of the resources of the quality system is its documentation, which provides objective evidence that the system is indeed achieving quality objectives. However, before the quality system is documented, it needs to be properly conceptualized and structured. Armed with a conceptual model of the quality system (presented in section 3.1.3 of the thesis), the structure of a university-based quality system can be illustrated (Figure 6.2).

A quality system consists of complex processes and elements with different levels of complexity and scope. Typically, a university department performs its educational and research activities through undergraduate and graduate programs, as well as faculty-based research projects. Each of these processes has specific quality specifications, or the desired level of quality (denoted as 'Q_D' in Figure 6.2), and produces a certain actual level of quality (denoted as 'Q_A' in Figure 6.2). The system is performing according to specifications, if actual quality equals desired quality. Looking into the structure of these programs as complex elements of the quality system, we realize that undergraduate/graduate and research programs pass through the planning, materialization, maintenance and improvement phases. Each phase has quality specifications ('Q_D') and produces actual quality ('Q_A'). For instance, an objective of the materialization phase of an undergraduate program can be to graduate 300 students every year, with at least 75% of new graduates employed in the first year after graduation. If only 200 students graduated from this program, with 100 being employed, then the actual level of quality has not reached its specifications.

Following the structure of the quality system in the direction from more to less complex elements, we find that each phase consists of a number of smaller elements (let us call them 'stages'). In undergraduate education, stages are represented by the courses a student is required to take throughout the studies, while in research projects stages can be a literature review, acquisition of resources, reporting research findings, and so on. Again, each stage has quality requirements and achieved levels of quality. For instance, quality requirements for a course are usually given in a General Calendar of a university, while the actual level is examined using peer and student evaluation. The process flowchart in Figure 6.3 illustrates this element of a quality system. Being consistent with industrial engineering terminology, the next element in this hierarchy is an 'operation', and is represented by the lecture, laboratory or tutorial, i.e. constituents of a course. Again, each operation is inspected for fulfillment of quality requirements (for an approach to quality control and improvement of these operations, please refer to Chapter 8). Finally, operation as a process transforms input knowledge into output knowledge, experience and skills (Figure 6.2).

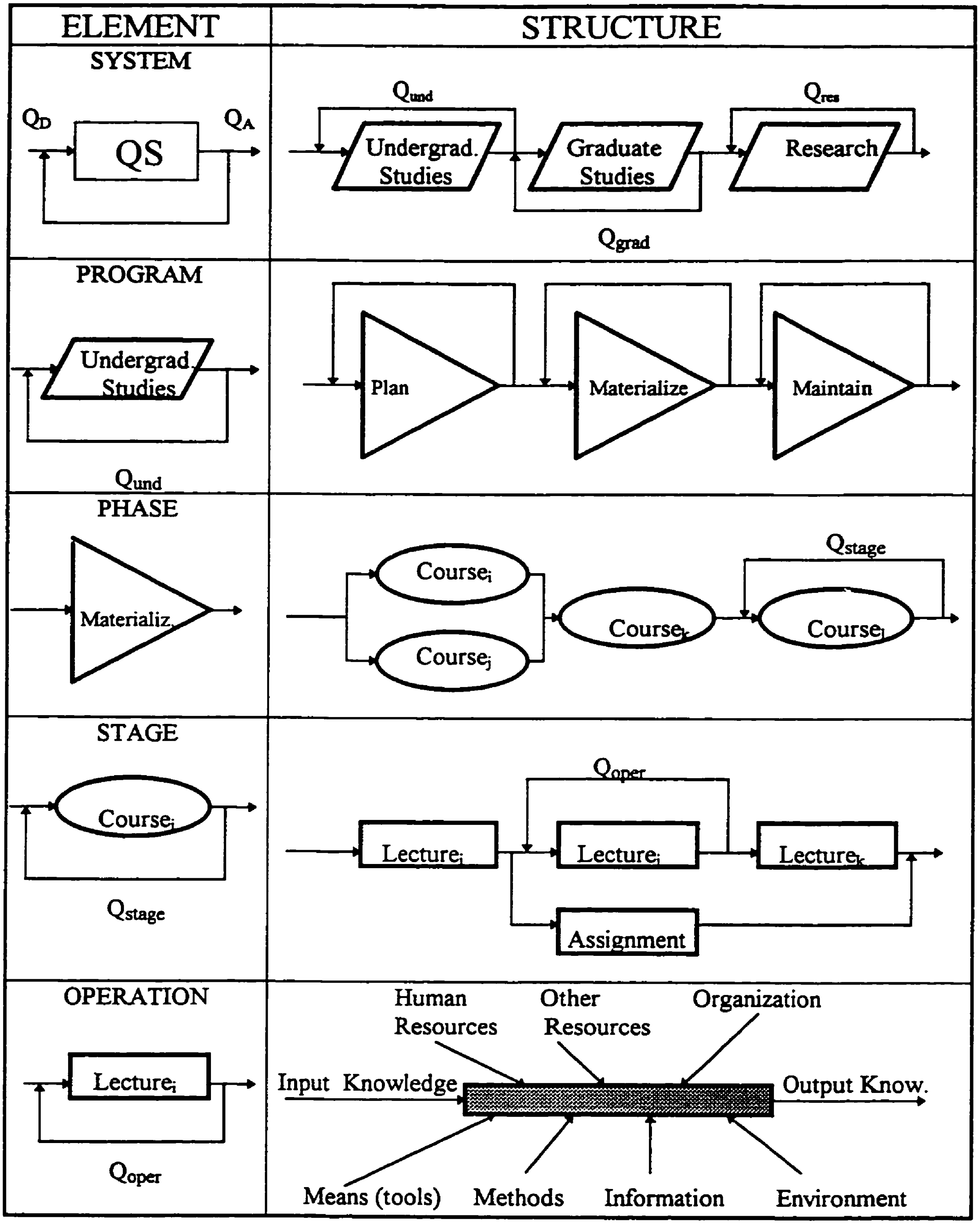


FIGURE 6.2: University-Based Quality System Structure

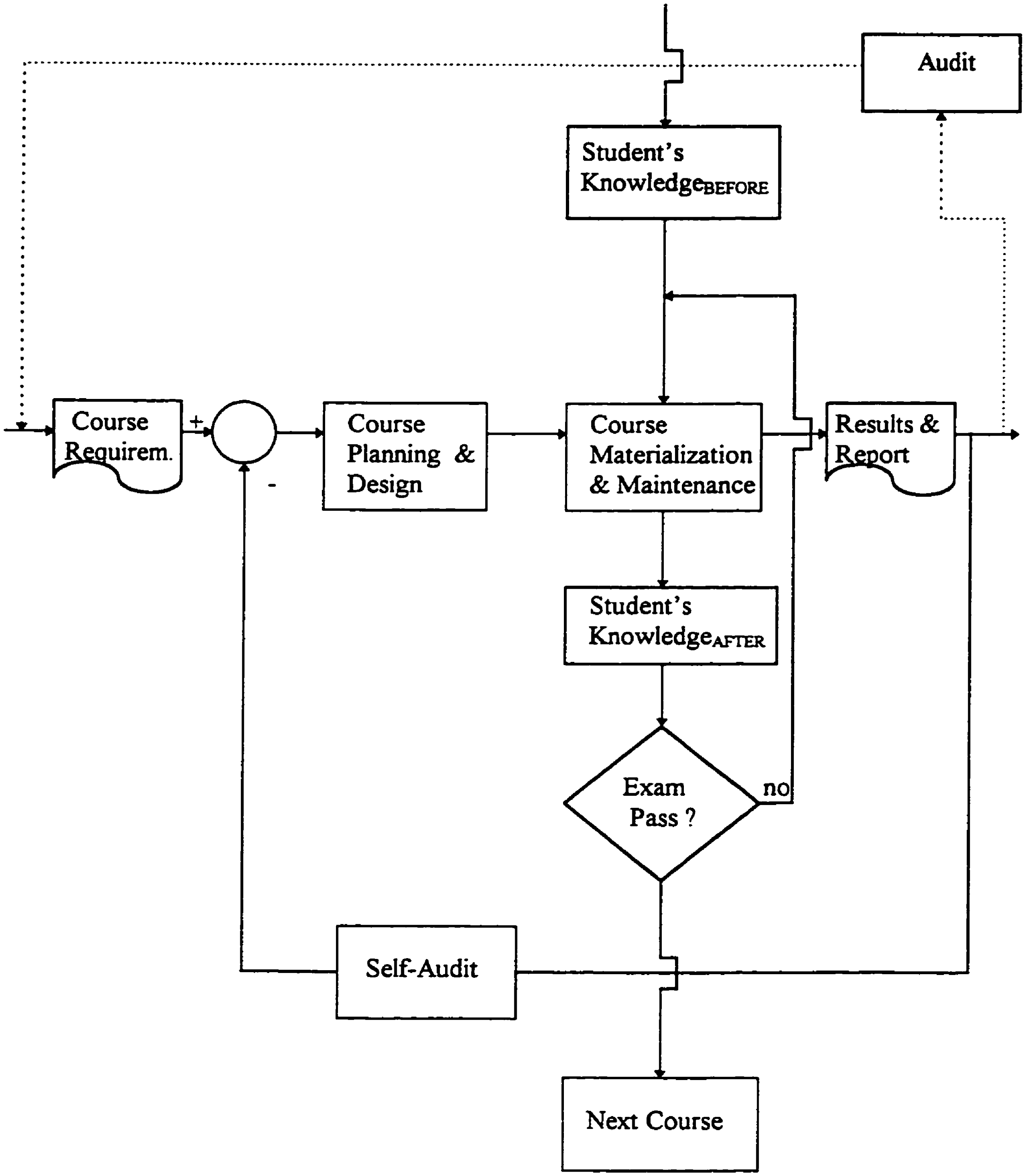


FIGURE 6.3: Course Level Process Flowchart

This structural model of the university-based quality system will assist us in designing appropriate documentation resources in the next step.

6.7 STRUCTURING DOCUMENTATION

A quality system requires documentation to support the achievement of objectives related to quality. In a multi-tiered system, it is common to have a multi-tiered documentation. It is important to recognize that quality system documentation does not necessarily imply paper documents. On-line documentation, using HTML and Java is particularly useful for ISO 9000 management (Clarkin and Dow, 1997). Manufacturing-oriented companies which have established ISO 9000 quality systems usually structure their documentation in four levels: a Quality Manual, Procedures, Work Instructions and Records. However, a university-based quality system, structured in the preceding section should have the following documentation available (Figure 6.4):

- *Faculty quality manual*, describing the quality system and referring to procedures and plans at the faculty level. This document should also contain the faculty's quality policy, illustrating the main quality objectives. For example, a Faculty of Engineering would draft its quality manual. As a note, depending on the size and organization of a particular university, this document could become a university quality manual, and department manuals could describe quality systems of specific departments and faculties.
- *Departmental quality manual*, describing the quality system and referring to procedures and plans at the departmental level. For example, a Department of Mechanical and Industrial Engineering would draft its departmental quality manual. Faculty and departmental manuals could be very similar, with the departmental manual addressing specific issues, elements, programs and procedures within a particular department.
- *Quality system procedures* specify ways to perform quality-related activities in a department. For example, each of the twenty elements of the ISO 9001 quality system can be addressed with individual procedures.
- *Course and research project quality plans*, setting out the specific quality practices, resources and sequence of activities relevant to a particular course or research project.

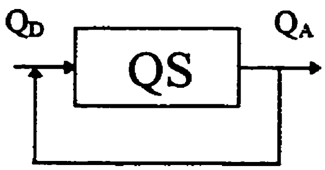
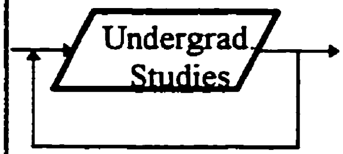
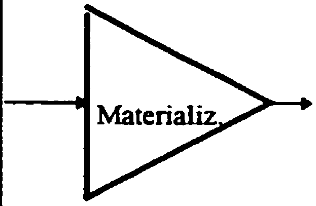
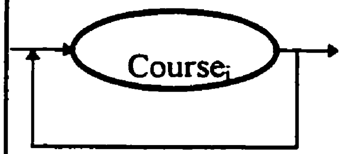
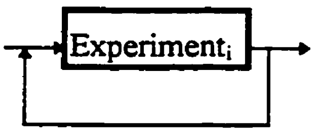
ELEMENT	DOCUMENT DESCRIBING THE ELEMENT	REQUIREMENTS (Q_D) STATED IN
SYSTEM 	FACULTY QUALITY MANUAL	QUALITY POLICY
PROGRAM 	DEPARTMENTAL QUALITY MANUAL	MISSION STATEMENTS
PHASE 	QUALITY SYSTEM PROCEDURES	OBJECTIVES/ STRATEGIES
STAGE 	COURSE QUALITY PLANS	COURSE REQUIREMENTS
THE OPERATION 	INSTRUCTIONS	COURSE SYLLABUS

FIGURE 6.4: Quality System Documentation

♦ *Instructions*, detailing how specific operations in research, teaching, and learning are performed, as well as who is responsible and authorized to perform them.

♦ *Records*, providing objective evidence of compliance with the quality system standard, and information for maintenance and improvement of the quality system.

The following sections explain the design and implementation of quality system documentation.

6.8 DOCUMENTING THE QUALITY MANUAL

The Quality Manual is a document which states the quality policy and describes the structure and content of the quality system in a department or faculty. The scope of the manual depends on the stated scope of the quality system, and relates to the totality of processes and resources aimed toward achieving objectives stated in the quality policy. The manual can be drafted by the Quality Champion, and may include the following three parts:

♦ *Foreword*

♦ *Introduction*

♦ *Quality System Structure*

In the foreword, written by the dean or department head, innovative character of the quality system in academia may be referred to, a statement of the assistance and support of the executive management is provided, and the relation of the quality system with the department's or faculty's mission is stated.

An introduction should include the table of contents, a statement of what 'quality system' and 'quality assurance' mean to the people in the department/faculty, as well as the main objectives related to customer satisfaction. Benefits of a well documented and implemented quality system in the department should be clearly drawn. Also, a brief overview of the standard to which the quality system complies to (e.g. ISO 9001) is helpful for the readers and users of the manual. The manual should reflect the operations and terminology used by educational institutions (Lo and Sculli, 1996). Therefore, an interpretation of terms and concepts used in the manual and the quality system in whole should be illustrated, followed by an overview of the quality system documentation. Quality policy is then stated, and the organizational structure of the department / faculty demonstrated. Finally, for document control purposes, the quality manual should incorporate an amendment records sheet, as well as the controlled distribution list, indicating the custodians of controlled copies of the manual.

In the third part of the manual, the structure and content of the quality system is illustrated. This part can be organized according to the department's own needs and purposes. However, to provide for a better understanding of the quality system by all persons involved, it is suggested that each requirement of the quality system standard is addressed separately. Therefore, the third part of the ISO 9001 quality manual would contain twenty elements, one for each requirement of ISO 9001. These elements have the same layout, incorporating:

♦ *Objectives* pertaining to the specific element of the quality system. For example, for contract review, the objective is to provide the department with a clear understanding of customers' requirements, specifications and needs, to evaluate if these requirements and specifications can be achieved, and to provide the customers with a clear understanding of the manner in which the department shall meet them.

♦ *Scope*, defining the processes to which the element applies to. For example, the contract review element in a department of mechanical engineering applies to:

- defining and documenting the industry and society requirements with respect to undergraduate and graduate programs offered, and the assessment of the departments ability to meet the requirements

- contract review with the employers participating in the cooperative undergraduate industrial engineering program

- ensuring and reviewing that the students understand the admission requirements, program content and context, graduation requirements, and their responsibilities and authorities

- review of industry and NSERC -sponsored research contracts

♦ *Responsibility, authority* and interrelationships of persons involved

♦ *Application*, illustrating the mode of use of specific guidelines in the quality system standard. For example, each section of the ISO 9001, element 4.3 Contract Review, can be addressed separately. This would include the identification of procedures used to manage contract review, illustration of how amendments to a contract are managed, and a statement of quality records pertaining to contract review.

♦ *Reference documents*, cross-referencing procedures and quality plans applying therein.

To illustrate the design of a quality manual in academia, Appendix I contains Parts 1 and 2 of the Quality Manual for the Department of Mechanical and Industrial Engineering at the University of Manitoba, as well as two elements from Part 3, namely Design Control and Process Control.

6.9 DOCUMENTING AND IMPLEMENTING PROCEDURES

The next step in documenting a quality system in academia is drafting operational procedures. As suggested in section 6.7, each requirement of the quality system standard can be covered with one procedure. For example, requirement 4.7 Control of Customer-Supplied Products is covered by an appropriate procedure. The following procedure headings are suggested:

♦ *Purpose*, defining the reasons why a particular element of the quality system is needed, and its main objective. For example, the purpose of the training procedure is to ensure that the training needs of faculty, teaching and research staff are identified, adequate training and development arranged, as well as to ensure that students' counselling needs are identified and adequate counselling services provided. The objective is to ensure that all faculty and staff are qualified and competent, and to provide adequate counselling to students.

♦ *Scope*, determining the array of processes the procedure applies to. It is useful to assign a unique code to each process depicted. For instance, the code could consist of the section number from ISO 9001 (18 for Training), a three-letter abbreviation for the type of product (STU - for students' education, PRG - for programs and courses, and RES - for research), and an ordinal number of the process. Accordingly, the training procedure of the Department of Mechanical and Industrial Engineering at the University of Manitoba applies to:

- (18PRG1) Development and training of faculty, including:
    - a) assessing and reviewing the need for hiring new faculty and staff
    - b) hiring new faculty and staff
    - c) training and development of new faculty and staff in terms of teaching
- (18PRG2) Development and training of teaching assistants
- (18PRG3) Development and training of administrative staff and technicians
- (18STU1) Student curriculum and personal counselling, including:
    - a) first year engineering students counselling
    - b) review of individual student progress in the first and subsequent years of studies
    - c) appointment of First Year Engineering Faculty Advisors to students
    - d) individual counselling provided by the faculty's student affairs office
    - e) individual counselling provided by the university's counsellors
    - f) appointment of second, third and fourth year Faculty Advisors
    - g) establishment of the Undergraduate Student Counselling Committee
    - h) selection of technical electives
    - i) career counselling
- (18RES1) Research staff development and training
- (18PRG/RES1)Faculty promotion and tenure

♦ *Definitions* required for better understanding of the procedure

♦ *Procedure* itself, defining the steps for performing the process, as well as decision points in the process. This part is divided into the following (Figure 6.5):

- <u>input elements</u>, information and material resources, such as records, procedures and forms that are provided to the process by some other process (supplier source)
- <u>flowchart</u>, illustrating specific steps, as well as information and material used in the process
- <u>responsibility matrix</u>, depicting responsibility and authority of persons involved in the process

- <u>output elements</u>, information and material resources, such as records, procedures and forms that are provided by the process to some other process (customer)

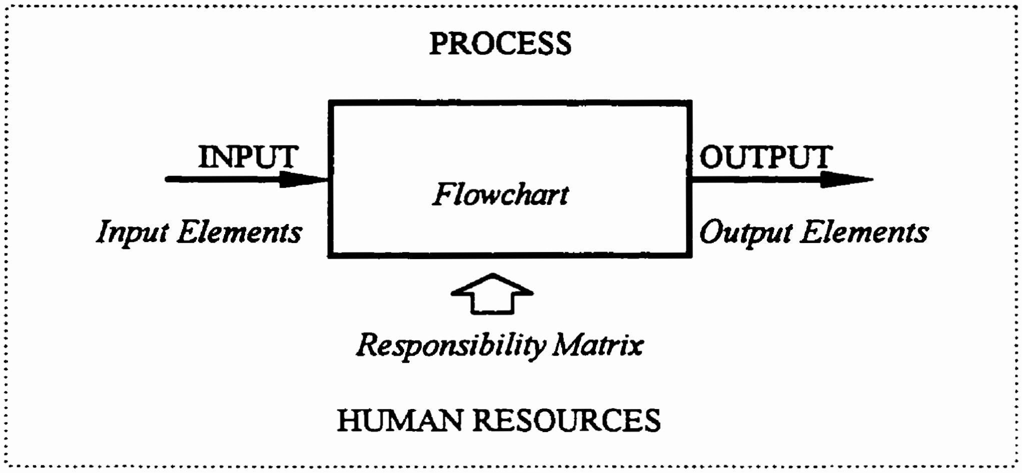


FIGURE 6.5: Procedure Documenting a Process

◆ *Reference documents*, pertaining to records, instructions and other procedures

An example of a purchasing procedure is provided in Appendix 2.

6.10 IMPLEMENTING QUALITY PLANS AND INSTRUCTIONS

As was stated in section 3.1.3 of this thesis, each course, program and contracted research project should have a separate quality plan, standing alone or as a part of the course or research project plan. Quality plans can be drafted according to the ISO 9000 Guidelines for Quality Plans (ISO 9004-1994, Part 5). The content of a typical course quality plan was illustrated in section 3.1.3, and an example of the plan for a fourth-year engineering operations research course is presented in Appendix III.

A research project quality plan should include:

◆ a statement of research project objectives

◆ a list of persons participating in the project, including research assistants and technicians, as well as their authorities and responsibilities

- a list of equipment required for the project, including books, papers, material, computers, machines and tools
- schedule of major phases in the project
- a statement of methods used to inspect, test and verify research progress
- quality records to be kept for quality system assurance and improvement
- laboratory instructions, Material Safety Data Sheets (MSDS), instructions for research assistants and technicians
- a statement of criteria for evaluating the success of the research project

A work instruction specifies the way of performing activities related to operational aspects of a quality system (Lo and Sculli, 1996). Instructions can include flowcharts, layout of the workplace, statement of responsibilities and authorities of the person(s) performing an activity depicted in the instruction, and specific steps to perform the activity. Work instructions should refer to quality system records and cross-reference procedures to which they apply. For example, work instructions can include laboratory activities of technicians, research and teaching assistants, administrative activities such as filing an NSERC research proposal or purchasing equipment for teaching purposes. To demonstrate this level of quality system documentation, two instructions are provided in Appendix IV: teaching assistant's instructions for a mechanical engineering laboratory, and instructions on managing students' timetable clashes.

6.11 KEEPING RECORDS

Quality records are an integral part of the quality system documentation. The department or faculty should identify, collect, index, file, store, maintain and properly dispose all records resulting from quality system activities. It is very important to properly manage quality records because:

- they represent objective evidence for demonstrating conformance to specified requirements of the quality system standard. A registrar's auditor would certainly request access to specific quality records to evaluate compliance and suitability of the system;
- they are used for continuous quality control and improvement.

Examples of the scope of quality records for specific quality system requirements can be found in Appendix II (Procedure for Purchasing). Appendix V provides a quality control record from a thermodynamics course.

6.12 INTERNAL QUALITY AUDITS

A quality audit can be defined as 'a systematic, unbiased, objective, and comprehensive examination and comparison of quality related activities and their results with specified requirements, and the determination whether these are suitable and effective to meet objectives' (Willborn, 1997). Internal quality audits, or first party audits, are conducted internally in an organization with an established quality system, i.e. the client is usually the executive management, and auditee is a part of an organization being audited. In a higher education institution, internal quality audits are established mainly with the following three-fold purpose:

- verifying compliance with selected quality system standards, such as ISO 9001
- assessing the suitability and effectiveness of the quality system in achieving objectives related to quality
- providing the possibility for improvement of the quality system and its elements

Internal quality audits in a university can be developed using international quality audit guidelines ISO 10011, parts 1, 2 and 3. The current issue of the guidelines is from 1991. However, a project of review and improvement is currently under way at an international level, within the subcommittee #3, Technical Committee 176 of the International Organization for Standardization. Depending on the scope of the ISO 9001 project, internal quality auditors can be recruited from the faculty, as well as the administrative and support staff. Auditor training is readily available through national standardization bodies, such as CSA, as well as through the American Society for Quality (ASQ). It is suggested that prospective internal quality auditors attend one or more training courses provided by these institutions, and, if possible, obtain an ASQ certification as Certified Quality Auditors (CQA).

Within the ISO 9001 project, auditors can be trained to verify compliance of the established quality system with ISO 9001, and subsequently to assess the suitability of the system to meet objectives set in the quality policy. The ISO 9001 compliance in a university can be assessed using a comprehensive checklist provided in Appendix VI. Finally, after the certification is obtained, internal quality audits are also useful in preparing the department or faculty for upcoming surveillance audits by the registrar (section 6.14).

6.13 TRAINING

In order to maintain an established quality system, on-going quality education and training should be provided. This can be accomplished through the development of a continuous training program for faculty and staff in internal quality auditing, statistical techniques for quality improvement, as well as methods such as Quality Function Deployment, Design of Experiments, and Taguchi techniques. Training needs of all faculty and staff should be identified, and adequate training in quality provided. A useful approach would be to establish a program of undergraduate and/or graduate studies in quality assurance. Also, the experience gained in the development of a quality system may be beneficial for establishing a registrar specializing in certifying higher education institutions.

6.14 REGISTRATION AND MAINTENANCE

An established quality system can be registered to the ISO 9001 standard by an accredited registrar. Some time before the anticipated completion of the ISO 9001 project (minimum several months), the Quality Champion should contact a registrar and inquire about the possibility for registration. Unfortunately, at the time of writing this thesis, not a single university-level department or institution in North America has obtained ISO 9000 registration. Therefore, nationally-accredited registrars lack the experience of auditing universities. However, the solution may be found in contacting registrars with experience in certifying community colleges or other training institutions, or even contacting a European-based registrar. National standardization bodies, such as the Canadian

Standards Association and its Quality Management Institute may be able to provide assistance, as well.

After a registrar has been selected, it will evaluate the Quality Manual first, and if the manual is considered suitable and compliant with the ISO 9001 standard, a site-visit will follow. This site visit is actually an external party quality audit, where a registrar assesses the compliance of the established quality system with the standard. In the case that the compliance is established, the department or the faculty will obtain an ISO 9001 certificate. However, the ISO project does not stop there. In order to fully use the benefits of quality assurance, the quality system must be maintained and continuously improved. On-going quality training, statistical quality improvement techniques and internal audits are the tools of choice. Also, an established quality system can be used as a foundation for developing other assurance systems, such as environmental management according to ISO 14000 standards, health and safety management and so on. It is also important to note that registrars perform surveillance audits every 6-12 months, and in the case that a quality system is not compliant with the standard, the ISO 9001 certificate is revoked.

CHAPTER SEVEN

QUALITY SYSTEM OBJECTIVE: ZERO-DEFECT STUDENTS

In this chapter, an objective for creating zero-defect students is set and explained. The knowledge and competence of a zero-defect student satisfies all customer requirements. The processes of determining the customer of a university and identifying customer requirements are focused next. Translating requirements into technical specifications for programs and courses is accomplished using Quality Function Deployment (QFD). A case study of the application of QFD in an undergraduate quality assurance course is presented. Subsequently, the delivery of courses, programs and research that will ensure the zero-defect output, together with benchmarking for continuous quality improvement are addressed.

7.1 SETTING THE ZERO-DEFECT OBJECTIVE

7.1.1 Some Quality System Objectives

In chapter 3, a quality system was defined as the 'set of interdependent processes, that function harmoniously, using various resources, to achieve objectives related to quality'. One objective related to quality is to provide confidence to customers that the requirements for the quality of a product are met. This objective is accomplished by developing a quality assurance system, ISO 9001 being a worldwide-accepted example. However, an organization can set other objectives for its quality system to accomplish. Motorola, a North American communications company is now famous for its '6σ quality' objective. Instead of concentrating on ±3σ control limits like all other manufacturing companies, Motorola figured that the possibility of 3 defects per 1000 products was too high for sensitive electronic equipment. Thus, they decided to embark on the 6σ limit program, which allows defects in the 1 parts per million order of magnitude. Needless to say, Motorola succeeded in accomplishing this objective.

Another goal some manufacturing organizations have set is the 'zero-defect product'. The term was coined by quality pioneer Philip Crosby to illustrate a product virtually free of defects. Since the thrust of this thesis is the idea that universities are not that different from manufacturing organizations, an interesting question emerges: 'Can universities, like manufacturing organizations, set and achieve the zero-defect goal?'. This chapter will show that the answer to this questions is undoubtedly 'Yes'. Creating zero-defect students, as one of the products of the University Production System is addressed.

7.1.2 What are 'Zero-Defect' Students ?

'Quality' in general is defined as 'the ability of a *product* to satisfy stated or implied *requirements*'. Naturally, the requirements for the product are set by the customer. In some cases, the customer may provide detailed specifications for a product, such as the torque, speed, type of gear shift mechanism, interior and exterior dimensions when buying a car. In other cases, the manufacturer will set internal specifications, on the basis of customer needs and requirements.

The virtue of the product to have no defects implies that all requirements and specifications are met. 1 ppm means that one part in every million does not meet one or more specifications. The other 999,999 parts meet virtually all specifications. On the other hand, the term 'zero-defect' has a different meaning in different industries. In electronic industry, the goal may be 1 part per million (ppm) defective, at most. A carpenter will be satisfied with 1 defected chair in a thousand. It was shown in previous chapters that a university produces three distinct products, the quality of which is certainly measurable and comparable to set requirements and specifications. Therefore, the universities should be able to say to their customers: 'If you want our students to know how to use a manometer to measure relative pressure, we can assure you that 999 students out of a thousand will know how". Or "At the most, one in every million students will not be familiar with the name of the first president of the United States". Or "All our courses and programs meet all specifications and requirements".

Like zero-defect products, zero-defect students are not 'perfect', in the sense that they know everything. They just satisfy all the requirements. Also, not all quality characteristics are critical, i.e. in case of not meeting the requirements, these characteristics would render the product unusable. The ability of the car to run is its critical quality characteristic. The ability of a medical doctor to diagnose illnesses is his/her critical characteristic. A structural engineer who does not know the principles of the strength of materials fails to meet a critical requirement, and should not be allowed to practice. This is where all organizations, including universities, should strive to achieve the "zero-defect" goal first : what the customer deems important. The critical quality characteristics must be met by 100% of students. Surpassing customer needs only comes after meeting these goals. At a university, "zero-defect" goals can be set at different levels. For example, a professor may set a list of topics and/or skills all students in his/her course must master before they pass the course. Or, a department can set zero-defect objectives at an undergraduate or graduate program level.

How can a university provide confidence to its customers that the students will have the required knowledge after graduation? In other words, how can this zero-defect goal be achieved? The answer may seem simple: by ensuring that student's knowledge meets customer specifications. This implies that both the customers and specifications are known.

7.2 DETERMINING CUSTOMER REQUIREMENTS

The first step in determining customer requirements is to define who the customers of the university, faculty or department really are. A survey of students, their families and alumni can be helpful. The following are some questions that can be useful. What do students want from our university / faculty / department? Why did they choose to study here? When they graduate, where do they go? Do most of them continue studies at a postgraduate level? What has been the experience of our alumni with employers? Necessary information can be collected through questionnaires, feedback forms, alumni gatherings and so on. At this time, certain policy issues should also be clarified with the faculty and staff. What do we want? Is research our strength, or is it curriculum, strong emphasis on teaching and leading edge courses? What is our market? Should we attract students from our province/state/country, or should we focus more on international students? A number of universities and departments have gained excellent reputations by focusing on their strengths and defining their market niche. For example, one Canadian university is a leader in biosystems engineering, although it does not even have other engineering departments.

The second step is to define what customers really want. Universities should have a system in place for collecting and analyzing data from the prospective student employers, alumni, government, graduate schools and the community. The requirements of governmental and professional institutions should be defined, as well. For instance, ABET provides specifications for the knowledge of engineering fundamentals. In the specification for the mechanical engineering program, it is stated that 'the program must include in-depth instruction of thermal and mechanical systems, including the design and realization of such systems' (ABET, 1997C).

After the determination of customer requirements and specifications, they should be translated into a program and course design. A detailed explanation of a technique that can be used to accomplish this is provided in the following section.

7.3 QUALITY FUNCTION DEPLOYMENT

7.3.1 Overview

Defined customer requirements for student knowledge and skills should determine the program and course design (see chapter 4, Figure 4.3). Quality Function Deployment (QFD) is a technique that can be applied for translating customer needs and requirements into a set of course/program specifications, as well as proper internal requirements for student knowledge, including appropriate examination techniques. For example, consider the following situation. A mechanical engineering professor is developing a thermodynamics course. Among other inputs, he/she has the above-mentioned ABET requirement for mechanical engineering and a survey of prospective student employers, mainly in the manufacturing sector. The results indicate that the employers require a thorough knowledge and ability to apply the thermodynamics basic concepts, such as engine and refrigeration cycles, entropy, laws, gas properties, as well as sufficient laboratory experience and use of computer software applied in thermal sciences. They consider the knowledge of concepts and laboratory experience equally important, each being twice more important than the use of computers. Using QFD, the professor decides on the number of laboratory and lecture hours, types of laboratory experiments used and assignments requiring computers for computations. The former are "technical characteristics" that will meet, to a certain extent, the "customer requirements". For example, a laboratory experiment with the purpose of determining the heating value of natural gas has a very strong relationship with the requirements for laboratory experience and applying the knowledge of gas properties. It has a weak relationship with the requirement for knowledge of thermodynamics laws, and no relationship with the use of computer software. The professor then constructs the 'house of quality', and effectively manages to distribute available resources into a course that will meet customers expectations. QFD can also be used to design an effective examination scheme. For example, the professor can assess the ability of different examination methods to adequately illustrate student knowledge. A multiple choice test may be adequate to test the knowledge of fundamental principles of thermodynamics, or the workings of the Carnot engine. However, it may not be the best choice to illustrate the ability of the student to apply these principles in real-life problems. Here, a numerical problem may have a stronger relationship with the requirement.

At the program level, translating customer requirements into design specifications can also be accomplished using QFD. Here, the problem involves the selection of required and elective courses, requirements for work experience during studies (perhaps in the form of co-operative education). It is feasible that arts and sciences faculties may benefit in this case more than engineering and medicine, because they are not bound as much by regulations of governmental institutions and national accreditation boards.

In the following section, an illustrative example of translating requirements into technical specifications using QFD for an undergraduate quality assurance course is provided.

7.3.2 QFD For an Undergraduate Course

Quality Function Deployment is a concept that provides means of translating customer requirements, specifications and needs into appropriate technical requirements for each stage of product development and production. It is often stated that QFD brings the 'voice of the customer' into an organization (Sullivan, 1986). The phrase 'Quality Function' does not relate to the quality department, but rather to all activities needed to assure that quality is achieved. QFD is based on a sequence of four key documents (called matrices):

1. Customer Requirement *Planning Matrix*
2. Product Characteristic (Part) *Deployment Matrix*
3. *Process Plan Matrix*
4. *Quality Control Matrix*.

These matrices gradually translate customer requirements into product characteristics and quality control activities. For example, the planning matrix translates customer requirements into final product characteristics, and the deployment matrix translates final product characteristics into component (part) characteristics (Figure 7.1).

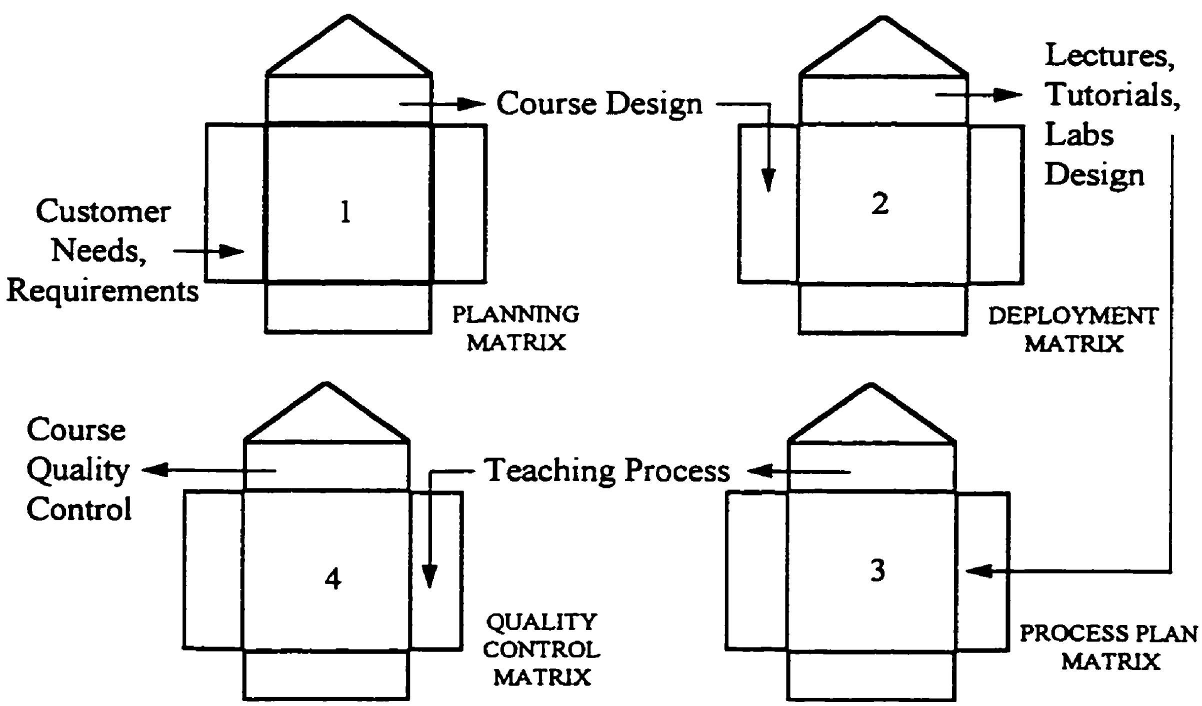


FIGURE 7.1: Quality Function Deployment for a Course

Figure 7.1 also depicts how quality function deployment matrices can be used to translate customer requirements for a university course into specific lectures, laboratories and tutorials, as well as provide adequate methods of quality control of learning outcomes.

A demonstration of the application of QFD to plan an undergraduate quality assurance course follows. As presented in Chapter 4, customer requirements for a particular undergraduate course may include specifications from national engineering accreditation boards (CEAB in Canada), course specifications stated in the General Calendar of the University, as well as industry and society (market driven) quality characteristics. For instance, course specifications for an engineering quality assurance course at the University of Manitoba are stated as follows (General Calendar, 1997/98): " *Modern applications of quality assurance/control techniques for industrial engineers: organization, sampling, reliability, corporate product responsibility; examples from local industry* ". Interestingly, the Society of Manufacturing Engineers, which is also a customer of an engineering faculty, recently published a report outlining the engineering competency gaps of recent university graduates (SME, 1998). In terms of quality, the skills and knowledge are lacking in issues related to *ISO 9000 compliance and statistics*. As was emphasized in the previous section, customer requirements can also be obtained through employer surveys and contacts with industry and governmental agencies. In this example, a survey of manufacturing, service and small business companies conducted by Dr. James Evans (1996) from the University of Cincinnati will be used as a representative sample of the market needs for a quality assurance course. The participants in the survey were companies that received the prestigious Malcolm Baldridge National Quality Award, and therefore are not only knowledgeable about quality, but are at the very cutting edge of quality management. The participants rated sixty quality assurance and management concepts or skills they thought should be developed in students. For the purpose of this thesis, these sixty concepts have been classified into twelve general. The general concept rating has been obtained as the sum of individual concepts' rating in the survey. For instance, the general concept of "teamwork" included original survey concepts of "cross-functional teamwork", "team process and team member effectiveness", "team-building skills", and "team facilitation skills". These four concepts respectively obtained ratings of

4.35, 4.14, 3.8 and 3.54, for a composite rating for "teamwork" of 16. The general concepts or skills to be developed in quality assurance students then include: *problem solving, teamwork, interpersonal skills* (consensus development, meeting dynamics), *customer focus, internal/external customers, statistical methods* (SPC, seven quality tools, process control, variation, process capability, basic statistics), *process/systems concepts, continuous improvement, general quality concepts, engineering concepts* (mistake-proofing, re-engineering, concurrent engineering), *total quality management, and DOE/QFD/Taguchi methods*. Together with these concepts, the economics of quality, quality standards and organization for quality complete the list of customer requirements, or the "voice of the customer". The latter three received the average importance rating of the former twelve specifications, i.e. 18.

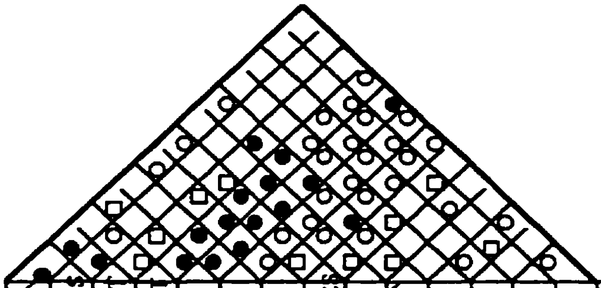
Subsequently, these requirements are translated into specific course design characteristics, i.e. general topics that should be taught to students, such as communication theory and practice, group dynamics, human resources management, quality planning and assurance, organization for quality, statistical process control, acceptance sampling, Total Quality Management, and so on. The inter-relationships between the customers' voice and course design characteristics are then estimated using a three-level estimation of the relationship's strength: weak, strong and very strong (Figure 7.2). For instance, "quality standards" as a customer requirement has a very strong relationship with the course topics of quality concepts, quality planning and assurance, and system concepts, but has a weak relationship with quality management philosophies. Importance ratings for each of the customer's requirements are included in the Planning Matrix (Figure 7.2), along with the evaluation of competitors with respect to each requirement and design characteristics, using a 1-10 scale. Two immediate competitors have been chosen: the "Management of Quality and Reliability" course from the Faculty of Management at the University of Manitoba (competitor A), and the quality control course from the Faculty of Engineering at the University of Regina (competitor B). Information about the latter course was presented at the Tenth Canadian Conference on Engineering Education in Kingston, Ontario, and is available in the proceedings

LEGEND:

● VERY STRONG

○ STRONG

□ WEAK



			COMMUNICATION	GROUP DYNAMICS	HR MANAGEMENT	SYSTEM CONCEPT	Q CONCEPTS	Q PLANNING	Q ASSURANCE	QM PHILOSOPHIES	Q COSTS	Q ORGANIZATION	SPC	ACC. SAMPLING	DOE/ TAGUCHI	ENGINEERING	MARKET EVALUATION	COMPETITOR A	COMPETITOR B	SELLING POINTS
INDUSTRY	SKILLS	PROBLEM SOLVING	○	○	□	●	○	○	○	●	□	□	□		●	●	4	5	9	*
INDUSTRY	SKILLS	TEAMWORK	●	●	○		□			□		●					16	9	9	*
INDUSTRY	SKILLS	INTERPERSONAL	●	○	○												15	5	3	
INDUSTRY	KNOWLEDGE / COMPREHENSION	CUSTOMER FOCUS					●	○	●	●		○					29	4	5	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	INTERNAL CUSTOMERS						□	●	●							10	4	5	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	STATISTICAL METHODS							○	□	□		●	○		□	37	1	7	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	SYSTEMS CONCEPT		□	□	●	●	●	●	○	●	●	○	□		□	28	1	2	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	CONTINUOUS IMPROVEMENT					●		□	●		●	○		●	●	16	5	8	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	QUALITY CONCEPTS					●	○	○	○	○						30	4	4	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	ENGINEERING CONCEPTS					○	○	○				□		○	●	13	1	1	*
INDUSTRY	KNOWLEDGE / COMPREHENSION	TQM	○	□	○					●		○					11	8	6	
INDUSTRY	KNOWLEDGE / COMPREHENSION	DOE / TAGUCHI / QFD							○		□				●	□	7	2	2	*
CEAB	KNOWLEDGE / COMPREHENSION	QUALITY ECONOMICS					□				●						18*	1	5	
CEAB	KNOWLEDGE / COMPREHENSION	QUALITY STANDARDS				●	●	●	●	□							18*	1	9	*
CEAB	KNOWLEDGE / COMPREHENSION	QUALITY ORGANIZATION	□	□	□	□				○	○	●					18*	5	4	
		COMPETITOR A	3	7	7	1	3	4	1	7	5	1	1	1	2	1				
		COMPETITOR B	5	5	3	2	5	8	8	7	1	5	7	6	2	1				

FIGURE 7.2: Course Planning Matrix

(Vandenberghe, 1996). For example, competitor A emphasizes groupwork and human resources management, thereby receiving an "8" and "7", respectively. On the other hand, acceptance sampling methods are not taught at all, receiving a the lowest rating of "1". The selling points for the QFD-designed course have been subsequently identified, where the strengths of the engineering faculty are paired with competitors' weaknesses. For instance, emphasizing the systems and engineering concepts in teaching the course should provide an edge over immediate competitors.

Next, course design characteristics and topics are translated into specific components of the course: lectures, laboratories and tutorials [Figure 7.3: Product Characteristic (Part) Deployment Matrix].

	LECTURE BLOC 1	LECTURE BLOC 2	LECTURE BLOC 3	LECTURE BLOC 4	LECTURE BLOC 5	LECTURE BLOC 6	LECTURE BLOC 7	LECTURE BLOC 8	LECTURE BLOC 9	LECTURE BLOC 10	LECTURE BLOC 11	LECTURE BLOC 12	LECTURE BLOC 13	LAB BLOCK 1	LAB BLOCK 2	LAB BLOCK 3	TUTORIALS
COMMUNICATION	○	○	□			□	□										
GROUP DYNAMICS	○	○	□			□	□			□							
HR MANAGEMENT		○	□	□		□	□										
SYSTEM CONCEPT	●	○	□	□		○	○							□			○
Q CONCEPTS	□	●	□	□										□			○
Q PLANNING				●										○			○
Q ASSURANCE					●	●								●			○
QM PHILOSOPHIES			○														
Q COSTS								○									
Q ORGANIZATION							●							□			
SPC								○	●	●	●				●		●
ACC. SAMPLING								●							□		●
DOE/ TAGUCHI											●	●	●			●	●
ENGINEERING												○	●			●	●

FIGURE 7.3: Product Characteristic (Part) Deployment Matrix

For instance, quality assurance concepts, including the ISO 9000 standards, are deployed in the eighth and ninth week of lectures, as well as in the first laboratory. The focus of the first week of lectures is placed on the systems and quality concepts, and should include working in groups or class simulations to provide for illustration of communication and group dynamics theories. One such class simulation can be planned as follows. Students are divided into several groups, each representing a function in a manufacturing organization: marketing, design, purchasing, production, and sales. One group is assigned the role of a customer, and is given an already built model of a car or any other product. The model can be built using plastic/metal model kits or "LEGO" squares. Another group will be "suppliers", who will be given the unassembled parts of the car, together with parts from other unrelated models. The simulation starts when the marketing function tries to provide car specifications, including the color, size and physical appearance of the car, without actually seeing it (even the "customers" group of students can only see the assembled car for a short time). Then, using marketing specification, the design group tries to design a car, and specify which particular parts (standard LEGO squares) the purchasing department should get from the supplier. After assembling the car and selling it to the customer, the manufactured and pre-assembled cars are compared. It is very likely that the two will not appear to resemble each other. Several concepts can be taught from this simulation: group dynamics, communication, internal and external customers, customer-supplier chain, concurrent engineering, quality loop, and so on.

The next QFD step involves a further development of each component of the course, i.e. lectures, laboratories and tutorials, and the identification of critical knowledge and skills that should be developed in students. The knowledge and skills can be demonstrated using the Bloom's taxonomy of six levels of cognition: knowledge, comprehension, application, analysis, synthesis and evaluation (Figure 7.4). All six levels should be attained by students in order to fully accomplish set course goals, and approach the ultimate objective of zero-defects. Take a case of the lecture block 10, where attribute control charts are taught (from Figure 7.3). In this vein, the student should recall specific facts about the attribute charts (knowledge), be able to draw them (comprehension),

COMPONENT	CHARACTERISTIC	CRITICAL COMPONENT CHARACTERISTIC
LECTURE BLOCK 9		
LECTURE BLOCK 10	KNOWLEDGE	RECALLING SPECIFIC FACTS ABOUT ATTRIBUTE CONTROL CHARTS
	COMPREHENSION	ABILITY TO DRAW AN ATTRIBUTE CONTROL CHART
	APPLICATION	SOLVING NUMERICAL PROBLEMS WITH CHARTS
		DRAWING A CHART FOR A REAL-LIFE APPLICATION
	ANALYSIS	ABILITY TO ANALYZE RESULTS OF THE CONTROL CHART APPLICATION
		ABILITY TO FIND ASSIGNABLE CAUSES OF VARIATION
	SYNTHESIS	ABILITY TO EFFECTIVELY COMMUNICATE THE RESULTS OF THE PROBLEM TO OTHERS
		SELECTION OF THE APPROPRIATE CONTROL CHART FOR A REAL-LIFE PROBLEM
	EVALUATION	MAKING JUDGMENTS ABOUT THE VALUE OF ATTRIBUTE CHARTS
		RECOGNIZING DISADVANTAGES AND AREAS OF PROPER USE
LECTURE BLOCK 11		

FIGURE 7.4: Component (Part) Deployment Chart

be able to solve numerical problems and draft a chart for a real-life manufacturing or service situation (application). The student should also have the ability to analyze results and find assignable and common causes of variation (analysis), effectively communicate the results of the analysis to his/her peers and/or professor (synthesis), and to be able to evaluate the value of attribute charts, recognize their advantages and disadvantages and proper usage (evaluation). All of these characteristics are deemed essential and should be monitored, controlled and improved upon.

The critical lecture / laboratory / tutorial characteristics are then developed using teaching / learning processes. The professor can plan specific teaching strategies, such as lecturing in a one-way communication manner, using interactive computer teaching, demonstrating a laboratory or allowing the students to perform experiments on their own. For such purposes, the process plan matrix is helpful (Figure 7.5). Relationships between specific strategies and developed critical characteristics are established. For example, a laboratory demonstration in attribute control charts can be expected to have a very strong impact perhaps only on student's recollection of facts, but certainly not on his/her ability to effectively communicate the results of the analysis to others. Here, specific control points of student knowledge can be identified, as well as the frequency of control. In this vein, knowledge and comprehension is effectively tested using a modified Background Knowledge Probe for the "before" and "after" knowledge.

Finally, a quality control plan for a particular lecture, laboratory and/or tutorial is developed in a Quality Control Matrix (Figure 7.6). The next chapter provides a detailed approach to quality control and improvement of course teaching and learning outcomes.

PROCESS	CRITICAL COMPONENT PART CHARACTERISTICS: RECALLING SPECIFIC FACTS ABOUT ATTRIBUTE CONTROL CHARTS	ABILITY TO DRAW AN ATTRIBUTE CONTROL CHART	SOLVING NUMERICAL PROBLEMS WITH CHARTS	DRAWING A CHART FOR A REAL-LIFE APPLICATION	ABILITY TO FIND ASSIGNABLE CAUSES OF VARIATION	ABILITY TO ANALYZE RESULTS OF THE CONTROL CHART APPLICATION	SELECTION OF THE APPROPRIATE CONTROL CHART FOR A REAL-LIFE PROBLEM	ABILITY TO EFFECTIVELY COMMUNICATE THE RESULTS OF THE PROBLEM TO OTHERS	MAKING JUDGMENTS ABOUT THE VALUE OF ATTRIBUTE CHARTS	RECOGNIZING DISADVANTAGES AND AREAS OF PROPER USE	CONTROL POINTS	METHOD	FREQUENCY
LECTURE EX-CATEDRA (ONE-WAY)	●	○	●	○	○	●	●		○	●	Before After	BKP + Control Chart	Once per lecture hour
COMPUTER ASSISTED (INTERACTIVE)	○	○	●				●				As per computer software	Computer Assisted Test	As per computer software
LABORATORY (DEMONSTRATION)	●				○	○			○	○	Before After	BKP + Control Chart	Once per demo
LABORATORY (HANDS-ON)		●	●	●	●			○	●	●	Before After	Muddy Point	Once per lab
GROUP LEARNING				○	○			●		○	Before After	BKP + Control Chart	Once per lecture hour

FIGURE 7.5: Process Plan Matrix

PROCESS PLAN	CONTROL POINT	CONTROL METHOD	SAMPLE SIZE	FREQUENCY
INPUT KNOWLEDGE	BEFORE EVERY LECTURE & LABORATORY	BACKGROUND KNOWLEDGE PROBE (BKP)	100%	ONCE PER LECTURE HOUR
LECTURE EX-CATEDRA (ONE-WAY)	AFTER THE LECTURE	MODIFIED BKP SHEWHART CONTROL CHART+EWMA	100%	ONCE PER LECTURE HOUR
COMPUTER ASSISTED (INTERACTIVE)	DURING THE LECTURE	MULTIPLE CHOICE COMPUTER ASSISTED	100%	AS PER COMPUTER SOFTWARE
LABORATORY (DEMONSTRATION)	AFTER THE LAB	MODIFIED BKP SHEWHART CONTROL CHART+EWMA	100%	ONCE PER DEMO
LABORATORY (HANDS-ON)	AFTER THE LAB	MODIFIED BKP SHEWHART CONTROL CHART+EWMA	100%	ONCE PER LABORATORY
GROUP LEARNING	AFTER THE LECTURE	MODIFIED BKP X-R CONTROL CHART	RANDOM CHOICE THREE GROUPS	ONCE PER LECTURE HOUR
OUTPUT KNOWLEDGE	EVERY WEEK	QUIZ	100%	ONCE PER LECTURE BLOC
	AFTER 3 WEEKS	TEST	100%	ONCE PER 3 LECTURE BLOCS

FIGURE 7.6: Control Chart Matrix

7.4 PROGRAM/COURSE DELIVERY AND BENCHMARKING

After designing the program and courses to meet customer requirements, the next step in reaching the zero-defect goal is to deliver these programs and courses in such a manner that all students receive enough knowledge to meet specifications. Most importantly, what the students have learnt must be useful in the real world. A course for a university is the same as a sanding paper for the carpenter. Both are used to manufacture a product. However, without the carpenter's skill to apply good finish, or without the professor's interesting and intriguing lecture, chairs have less chance to be bought, and students will be less eager to learn. Also, there are many ways to make a chair, and an abundance of furniture manufacturers in the market. There is not just one university producing mechanical engineers. There are hundreds, and they provide learning opportunities in thousands of different programs, courses and facilities. A university can use this fact to it's advantage, by benchmarking against other universities and schools (Weller, 1996).

Benchmarking provides a plenitude of ideas that can be used to improve teaching and learning processes, and ultimately the quality of student knowledge. It does not necessarily require comparisons with the universities considered to be 'the best", and it is not limited to technical schools either. What has not worked at another university, may work pretty well somewhere else, under different circumstances. Or, if a classroom simulation approach to teaching managerial psychology yielded excellent results in one university, why not use it in another? The objective is to know the market and competitors well enough to cut the leading edge and always satisfy the customers.

In course/program delivery, a university should have a teaching/learning process control system in place in order to consistently yield zero-defect knowledge. Statistical process control (SPC), the seven quality control tools, analysis of variance are just some of the techniques that can be used. Together with the quality function deployment, these techniques have been used to approach the zero-defect goal.

CHAPTER EIGHT

QUALITY CONTROL AND IMPROVEMENT

This chapter presents an approach to monitoring, controlling and improving the teaching process and learning outcomes in an academic quality system. The approach focuses on teaching and learning, rather than research processes, and is based on statistical quality control techniques. Quality control of the common constituents of a university course: lectures, laboratories and tutorials is addressed, followed by a description of the tools for quality improvement. Finally, illustrative case studies of quality control and improvement in three mechanical and industrial engineering courses are presented.

8.1 QUALITY CONTROL AND IMPROVEMENT

Quality control and improvement techniques have been used in the manufacturing environment for decades. Nevertheless, if there is an environment where inspection, testing and quality control is firmly embedded, it is the school and the university. Students are continuously tested through term tests, assignments, projects, quizzes and exams. It seems, however, that the quality control (QC) techniques used in education today are at the level of manufacturing QC in the twenties. Term-tests and exams resemble the 'go-no go' gauges: if the student performs above the cut-off level, he/she passes the test and is allowed to proceed. Costly 100% inspection is performed every time, sometimes without an apparent reason. This is particularly evident in the example of a final exam. While the purpose of the final inspection in manufacturing is to evaluate whether the product meets established specifications, and as such is a 'go-no go' issue, students are graded to a greater or lesser extent according to their performance on the final exam. It would be hard to imagine an automobile company advertising its cars as: 'This car received an A in our final inspection. This one, however, barely passed it and is rated as a D-car'. And not only are the students graded according to their performance in the final inspection, but the grades they receive are often falsely assumed to be normally distributed. This grading scheme, referred to as the 'bell-curve marking', compares a student's performance with the performance of his/her peers, and assigns grades according to the belief that most students are mediocre, some perform very well and some not so well. If all students, say, perform poorly on an exam, with no student receiving more than 60%, bell-curve marking may still fail no one. However, in the environment where zero-defect students are created, this scheme may not work at all. Rather than comparing a student's knowledge and competence with the performance of his/her class peers, it should be compared against an established standard. No medical doctor should practice if he/she is not capable of diagnosing illnesses. No structural engineer should be an engineer if he/she does not know the principles of the strength of materials. Instead of measuring the length of a table using a refrigerator, two chairs and three coffee cups as references, use a ruler.

Quality knowledge and competence must be built into students, and not just inspected at the end of a course or program. When a student reaches the final exam, nothing can be done to enhance his/her knowledge: there are no lectures or labs pending and hence no new material taught or learned. Therefore, if there is any inspection and testing to be done, it should be done continuously before and after every lecture, laboratory and tutorial, much like in the Toyota production system where a product is continuously inspected after each operation and before every consecutive operation. The final exam should then only verify whether the student has acquired sufficient knowledge and competence to be considered competent in the matter taught in the course, and for that matter could be a pass/fail inspection only. This would be similar to ASQ certification exams or engineering professional exams, where a person either receives or doesn't receive certification.

Techniques such as Statistical Process Control (SPC), Analysis of Process Capability, Acceptance Sampling, or the 'Seven Quality Control Tools', together with established classroom assessment techniques, can be used to build in quality on a continuous basis. These techniques are often ignored in the analysis of the teaching and learning processes (Vazzana, Bachmann, and Elfrink, 1997), 'which has led to the situation where the professors and teachers 'cannot readily disprove a claim that their instructional systems are the cause of poor student performance, nor can they claim credit when student performance is exceptional' (Ensby and Mahmoodi, 1997). In order to be able to prove or disprove such claims, the teaching and learning processes must be continuously monitored, controlled and improved in the classroom. A good way to go about this is to obtain instant feedback from students about what they've learned in the classroom during a particular lecture. The following three sections illustrate an approach to quality control in three common constituents of a university course: lectures, laboratories and tutorials.

8.2 QUALITY CONTROL IN LECTURES

8.2.1 Approach

As was discussed in Chapter 4 of this thesis, lectures add new dimensions to student knowledge and abilities much like a milling or drilling operations add new surfaces or shapes to a manufactured product. In manufacturing, a quality characteristic created in these value-adding operations, such as the depth of a hole or a shaft diameter, is monitored and controlled using control charts. In education, with each lecture, a student should learn something new about the matter taught. Thus, a control chart should monitor and control what the student has learned. However, measuring the amount learned is undoubtedly not as easy as using a simple ruler to measure a diameter of a shaft. Over the years, hundreds of Classroom Assessment Techniques (CATs) have been developed to assist us in this task. A compendium of fifty different CATs is provided in Angelo and Cross's book 'CATs: Handbook for College Teachers" (Angelo and Cross, 1993). Combining CATs with control charts provides the possibility to control learning outcomes and the teaching process.

It is suggested that a modified Background Knowledge Probe (BKP) be used to measure the learned material, together with plotting a control chart of results as a statistic. A BKP requires students to write short answers and/or circle the correct responses to multiple choice questions, and provides feedback on students' prior learning (Angelo and Cross, 1993). A modified BKP for a lecture would ask the students about their prior knowledge on the matter to be taught at the beginning of a lecture, but would also ask the same questions at the end of a lecture. This technique provides multiple benefits:

• information on incoming variation in student 'baseline' knowledge is provided

• information on how much and how well the students have learned the material is provided

• 'before' and 'after' knowledge can be compared to roughly estimate the value-added outcome

• 'unnatural' effects, such as when a student knew the answer before but not after can be examined

• students are focused on the most important issues in a lecture (assuming that the probe reflects these)

An example of the modified BKP for a lecture about Pareto and Ishikawa diagrams in a quality assurance (industrial engineering) course is given in Figure 8.1. The probe consists of five questions, each with six possible answers. One answer is always 'I don't know', to allow the students to express unfamiliarity with a concept, rather than guessing the right answer. For each question, the statistics should be collected to provide information on the number of students circling each of the answers before and after the lecture, the number of correct answers before and after, as well as information on how many students answered the question correctly both times, answered incorrectly both times, were wrong or did not know the answer before and were correct after, and were correct before and wrong after (Figure 8.1). For example, the first question was answered correctly by 19 out of 48 students before the lecture and 46 after the lecture, with 28 students who learned the answer during the lecture. On average for the lecture, 90.4% were correct after, with 52.5% whose learning can be attributed solely to the lecture.

Distribution of answers should be analyzed for an insight into the reasons for most common errors. The total number of correct answers a-priori indicates the magnitude of familiarity with the topic, and a-posteriori correctness indicates the proportion of students who can be considered to have mastered the subject. Situations where the students were wrong both times or have 'unlearned' the subject should be examined further. These may indicate that further clarification or even the repetition of a part or the whole lecture is required. It may also indicate the lack of attention of certain students, fatigue and a number of other effects. Thus, it is important not to assign a special cause of variation

LECTURE QUESTIONS (SET #8)

(1) First step in constructing a cause-and-effect diagram is to:
- (a) clearly define the cause of the problem
- (b) clearly define the effect or symptom for which the causes must be identified
- (c) plot a control chart for possible causes
- (d) draw a histogram of causes
- (e) none of the above
- (f) I don't know

ANSWER: BEFORE: ________ AFTER: ________

(2) Another name for cause-and-effect diagram is:
- (a) Checksheet
- (b) Pareto
- (c) Histogram
- (d) Deming
- (e) Fishbone
- (f) I don't know

ANSWER: BEFORE: ________ AFTER: ________

(3) The purpose of the Pareto analysis is to:
- (a) identify special (assignable) causes
- (b) brainstorm all possible causes of errors
- (c) calculate correlation factor and covariance
- (d) identify the "vital few" causes from the "useful many"
- (e) none of the above
- (f) I don't know

ANSWER: BEFORE: ________ AFTER: ________

(4) The difference between the Pareto diagram and the histogram is:
- (a) Pareto diagram has a cumulative percent axis, histogram does not
- (b) Histogram has a cumulative percent axis, Pareto does not
- (c) You can estimate the type of distribution from the Pareto diagram, not from the histogram
- (d) a & c
- (e) none of the above
- (f) I don't know

ANSWER: BEFORE: ________ AFTER: ________

(5) Which of the following statements are true:
- (a) the "vital few" causes cause most problems
- (b) cause-and-effect diagram is not a substitute for data
- (c) the "awkward zone" exists in the cause-and-effect diagram
- (d) a & b
- (e) none of the above
- (f) I don't know

ANSWER: BEFORE: ________ AFTER: ________

<table>
<tr><th>Question (Answers)</th><th>Before</th><th>After</th><th colspan="2">Correct Before</th><th colspan="2">Correct After</th></tr>
<tr><td>2a</td><td>3</td><td>0</td><td colspan="2">16</td><td colspan="2">48</td></tr>
<tr><td>2b</td><td>7</td><td>0</td><td>Same Correct</td><td>Same Wrong</td><td>(⊥∨∅)⇒ T</td><td>(T∨∅) ⇒ ⊥</td></tr>
<tr><td>2c</td><td>1</td><td>0</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>2d</td><td>4</td><td>0</td></tr>
<tr><td>2e</td><td>16</td><td>48</td></tr>
<tr><td>2f</td><td>17</td><td>0</td><td>16</td><td>0</td><td>32</td><td>0</td></tr>
</table>

FIGURE 8.1: Modified Background Knowledge Probe for a Course

right away and act upon it, but to use a control chart to distinguish between special and common causes.

To monitor and control the teaching process and learning outcomes, these modified BKPs should be administered in each lecture during a course. This will enable the professor to identify and eliminate special causes of variation in student knowledge and abilities, as well as in his/her own performance. Moreover, the documentation of results and SPC analysis will provide assurances of quality to students and customers. The controlled variables include the proportion of students who knew the answer after the lecture (p_C), or the proportion of students who were wrong or did not know the answer before and were correct after (p_L). While the first one measures the learning outcome, the latter clearly indicates the professor's impact on the student knowledge created, i.e. the quality of the teaching process. Since it is also possible that some students were correct before and wrong after, the difference between the number of correct answers before and after the lecture can also be used as an indicator of the knowledge acquired. These variables can then be monitored using a number of control charts, depending on the choice of statistics and subgroups (Figure 8.2). For example, if a professor wishes to observe the performance on each individual question, an attribute 'p' chart can be used with the p_C and/or p_L statistics directly plotted for each question. This chart can also be used in the examination of performance from lecture to lecture. In situations with a small number of subgroups, such as after only a few lectures, short-run charts can be applied. Other modified charts, such as the Q chart (Quesenberry, 1991) can also be used. However, due care should be given to rational subgrouping and the choice of control charts. For instance, since the p_L and p_C statistics are proportions by nature, the use of the p-control chart is advised, rather than the Shewhart's chart for averages and ranges. Also, p-charts are applied when the proportion of defective units is monitored. Of course, the proportion of students who knew the correct answers is certainly not viewed as a proportion defective, but quite the opposite, as proportion conforming. Therefore, ($1-p_C$) statistic or even the proportion of incorrect answers can be plotted. An implementation procedure for a p-chart is suggested in the next section.

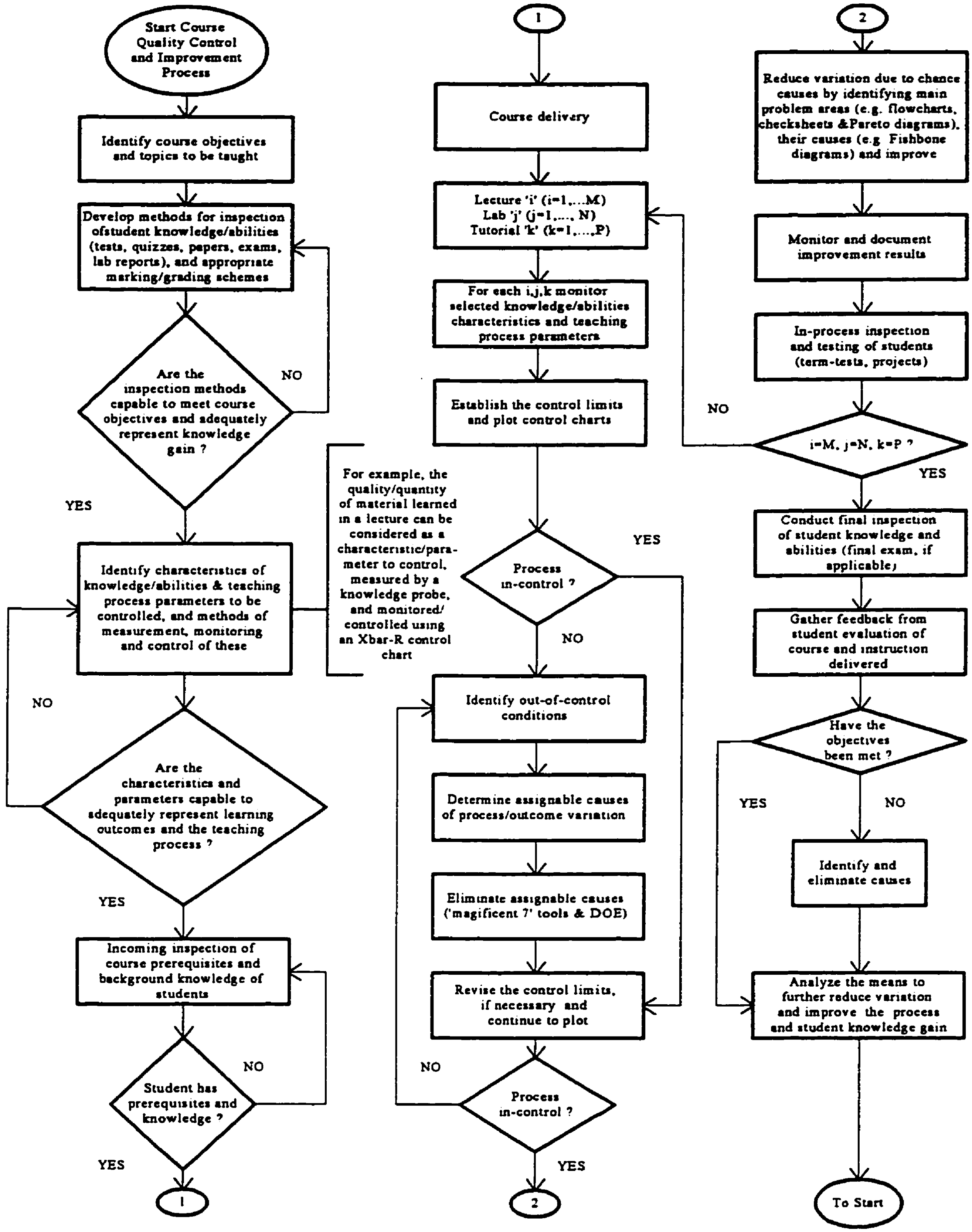


FIGURE 8.2: Course Quality Control and Improvement Process

8.2.2 Implementation Procedure for a P-chart

Step 1: For each question in BKP, record the number of students who were wrong or did not know the answer before and were correct after (L_i), as well as the total number of students (n_i).

Step 2: Treat each question as a subgroup (sample), and the number of students who answered each question as the size of the subgroup (n_i). For instance, if 25 students answered the first question and 24 answered the second one, then n_1=25 and n_2=24. Evidently, subgroup size may change from question to question and will most certainly change from lecture to lecture, depending on the number of students attending. The number of questions given represents the number of subgroups (g).

Step 3: If we assume that there is an equal probability of each student being wrong before and correct after, that the students are independent of each other, and a sample of n students is taken, then the statistic p_L should be binomialy distributed. Thus, a p-chart with the following central line: CL = $\underline{p}$, where $\underline{p}=(\Sigma L_i)/(\Sigma n_i)$, i=1,2,...,g, and control limits: $\underline{p} \pm 3 (\underline{p}(1-\underline{p})/n_i)^{0.5}$ is plotted. These limits can be established after about 25 subgroups, i.e. 25 questions. For example, if each BKP contains 5 questions, a p-chart can be plotted after five lectures.

Step 4: Plot the proportions $p_{Li} = L_i / n_i$ on the chart.

Step 5: Identify assignable causes of variation. Empirical rules for indicating out-of-control conditions can be found in [11, 12, 15]. Also, the next section on the Xbar-R chart will provide some interpretations of out-of-control conditions that can be applied here, as well.

Step 6: Eliminate points for which assignable causes of variation have been found. Re-compute the control limits and continue monitoring the teaching/learning process.

8.2.3 Case Study

The above-mentioned approach has been used to monitor and control classroom lectures in an industrial engineering course. A modified BKP with five questions (n=5) has been applied in nine (g=9) lectures. Classroom attendance has been in the 35-50 range. A p-chart drafted for the p_c statistic (Figure 8.3) shows three points, corresponding to questions #10, 32 and 37 well below the lower control limits, indicating out-of-control conditions. The analysis illustrates that all three questions were numerical in nature, requiring the students to apply the knowledge of several theoretical concepts to solve the

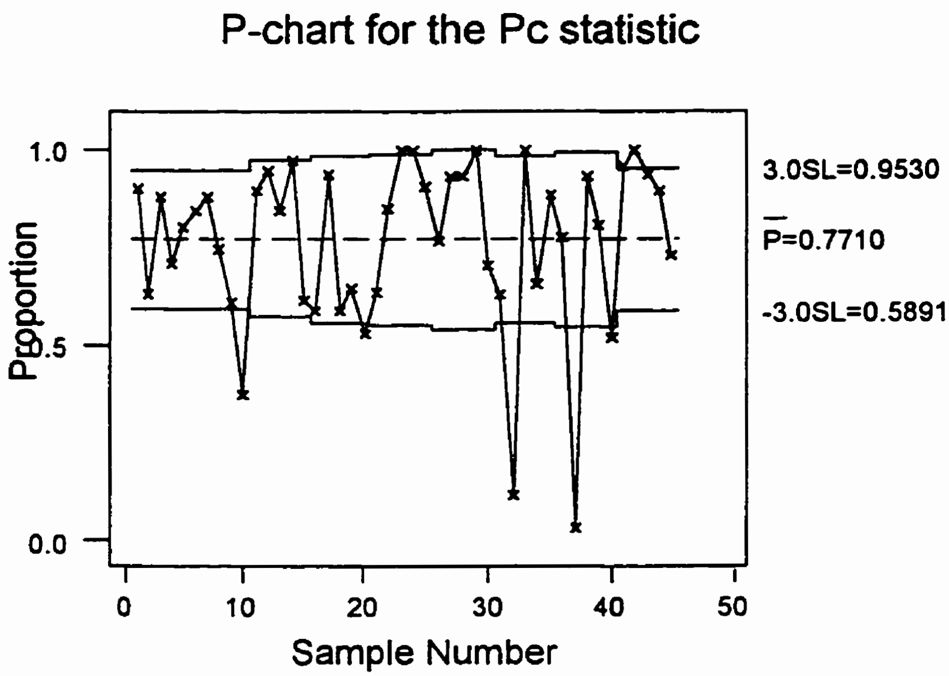


FIGURE 8.3: p-Chart for p_C in Lectures

problem. Low output may indicate that students did not have the time or motivation to solve these problems (it did not count for marks), but also that more emphasis should be given to practical applications of theory.

8.3 QUALITY CONTROL IN LABORATORIES

8.3.1 Approach

Laboratory experiments in engineering education differ from classroom lectures in that a class is usually divided into smaller groups of students. Also, contrary to lectures, which present new material with each new lecture, laboratory experiments are repetitive in the sense that each group of students is required to perform essentially the same experiment. Nevertheless, the approach to quality control in laboratories is similar to the one for classroom lectures.

A modified BKP is administered with each group of students performing the experiment. However, only one BKP is needed for a particular experiment. For example, the BKP for a thermodynamics laboratory can have seven questions, a number of which can be numerical. The questionnaires used for the laboratory case study are presented in Appendix 8. Similarly to lectures, laboratory sessions with a certain number of students can be thought of as 'subgroups'. The rationale for this type of subgrouping is the following. In a laboratory, the learning opportunity is provided a selected group of students attending the session, and not to the whole class. The next session provides the learning opportunity on the same topic, but to a different group of students, and is subject to a whole new set of disturbances and factors. For instance, the professor, the teaching assistant or the students might be more or less tired, and environmental conditions might change. The chance of variation between laboratory sessions is maximized, and those sessions therefore represent subgroups. We can then monitor:

(a) the total number of incorrect answers after the laboratory session for all students in a group. For instance, if there were two students in the eighth group, and the first student's BKP had two incorrect answers, and the second student's BKP had one, then the number of 'defects' was three.

(b) the total number of questions which had incorrect answers before and correct answers after the laboratory session for all students in the group. This statistic is analog to the p_L statistic used in the quality control of lectures, however instead of the proportion we have a count.

Since the measured parameters are counts, and the number of students in each laboratory session can vary, a u-chart for defects per session is suggested. First, the average number of defects (say incorrect answers after the session) for each laboratory session $u_j = (\Sigma c_i)/n_j$ is calculated. Here, $i=1,2,\ldots,n_j$ denotes an individual student in the j-th group; c_i is the count of either the incorrect answers for each student or the number of questions with an incorrect answer before and a correct answer after for each student; n_j is the number of students in each session; and $j=1,2,\ldots,g$ is the number of laboratory sessions. For example, using the example presented for the parameter (a) above, $c_1 = 2$, $c_2 = 1$, $n_g = 2$, $u_g = (2+1)/2 = 1.5$. After these calculations, the center line is established as $u^* = (\Sigma u_j)/g$, control limits as $u^* \pm (u^*/n_j)^{1/2}$, and control charts plotted and analyzed. The analysis of out-of-control conditions is similar to the classroom lecture case. For example, an upward trend on the u-chart may indicate a deterioration in the teaching assistant's presentation of the material, while a point below the lower limit may indicate that the students did not understand explanations or did not pay attention. In the case where each student performs his/her own experiment (i.e. the subgroup size n=1), a p- chart is suggested. Then, the fraction of nonconforming answers is calculated and plotted on the control chart.

8.3.2 Case Study

The approach for quality control in a laboratory setting was studied using a second year mechanical engineering (thermodynamics) course. Students were divided into 16 groups of 7 students in average, each group performing a 1.5 hour-long experiment on a different day. The students were required to attend the laboratory session, take appropriate measurements, perform the necessary calculations and write individual reports on the experiment. At the beginning of the session, a teaching assistant explained the apparatus and measurement methods in detail, together with the necessary theoretical principles. The BKP was applied at the beginning and end of each session. Groups of students performing the experiment on a particular day were treated as subgroups (g=16), with a variable subgroup size, due to the fact that some students were not able to participate on a scheduled date. Thus, 'n' varied from 4 to 9.

A u-chart was drafted for the statistic (Figure 8.4). The control chart indicates in-control conditions, with a downward trend on the chart for the first seven groups. The professor might have emphasized the necessity of adequate preparation for labs (e.g. reading lab notes in advance) in the first part of the course, causing the students to attend the lab prepared and know the answers on the BKP before the session. However, as the course approached the end of the term and the work load increased, the students might not have had enough time to read lab notes before the session, causing the statistic to fluctuate at a higher level.

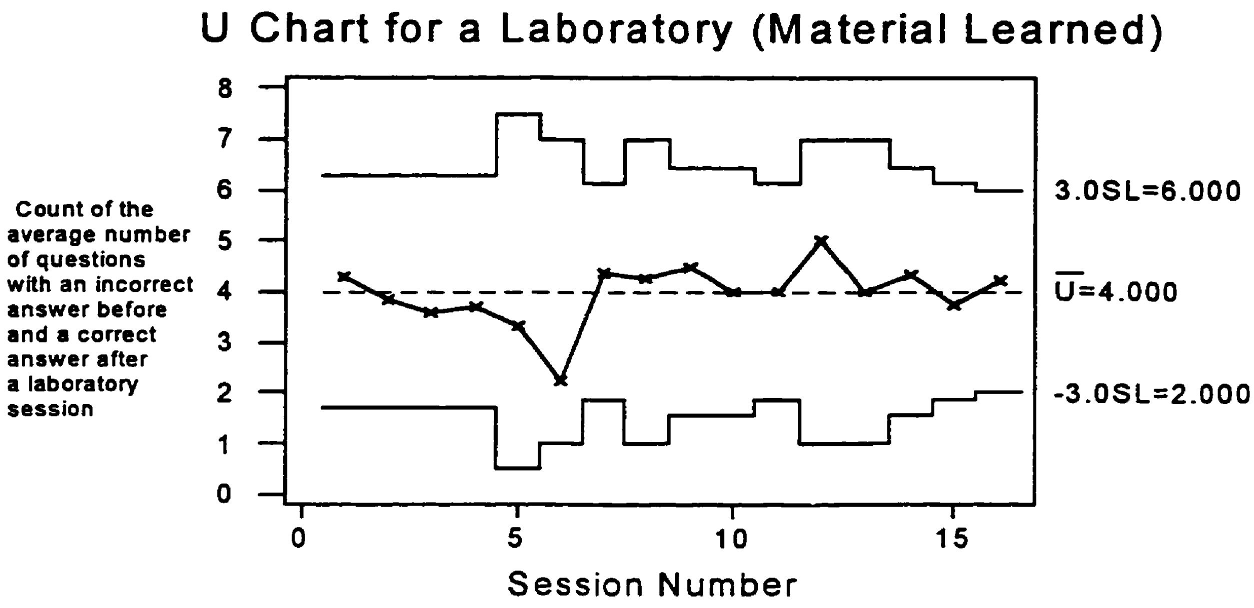


FIGURE 8.4: U-Chart for a Laboratory

8.4. QUALITY CONTROL IN TUTORIALS

8.4.1 Approach

When a tutorial consists of a professor or a teaching assistant (TA) solving numerical problems, the same approach that is used for a lecture can be applied, with perhaps the BKPs emphasizing numerical questions or analytical abilities. However, when an assignment to be handed in at the end of a tutorial is given to students, the professor (TA) can use a different approach. Instead of using a knowledge probe, errors in the assignments can be recorded and monitored. A total number of errors for each assignment or the occurrence of a particular error can be traced. This can be done with a 'u' chart, which monitors the average number of nonconformities per unit. If, for instance, n_i=50 students made a total of c_i=100 errors in assignment 'i', the average number of errors is $u_i = c_i / n_i = 100/50 = 2$. Statistic u_i is plotted on a chart with $u^* = (\Sigma u_i)/g$ as a central line (g is the number of assignments or problems), and $u^* \pm 3\times (u^*/n)^{1/2}$ as control limits. The u-chart allows for changes in the subgroup size, i.e. the number of students attending each tutorial. Also, if the number of students attending the tutorial is extremely large (say over 50), and recording the number of errors not economical, then random samples of n students' assignments can be drawn from the population and analyzed using a simple Xbar-R chart, with 'n' as a subgroup size.

8.4.2 Case Study

A tutorial in a first year core engineering course has been used. The tutorial is planned as a 1.5 hour session with the professor assisting students individually in solving numerical problems. Subsequently, each student is required to solve a given problem (the same problem for all students) and submit the solution to the teaching assistant (TA), who then makes corrections and marks the solutions. The total number of errors the students made for each such assignment was recorded, and the results plotted on an u-chart (Figure 8.5). For example, in assignment #2, 13 students did not make appropriate assumptions, 25 students missed appropriate units for properties, and 36 students used a wrong table to find a property. Thus, a total of 74 errors were recorded from 92 students, yielding u=74/92=0.804. As a note, each student can make multiple errors, and thus a 'u' chart is used. The u-chart in Figure 8 indicates 5 points outside control limits. Assignments # 6 and 10 had a high number of errors concerning missed statement and/or assumptions, and students making an argument that they did not know they were supposed to identify these assumptions. Assignments #12 and 13 were not difficult, with only a few calculations required, and thus had very few errors. Finally, assignment #16 simulated a problem that could be given on a final exam, required a large number of calculations and was worth three times more in terms of marks than that of all other assignments.

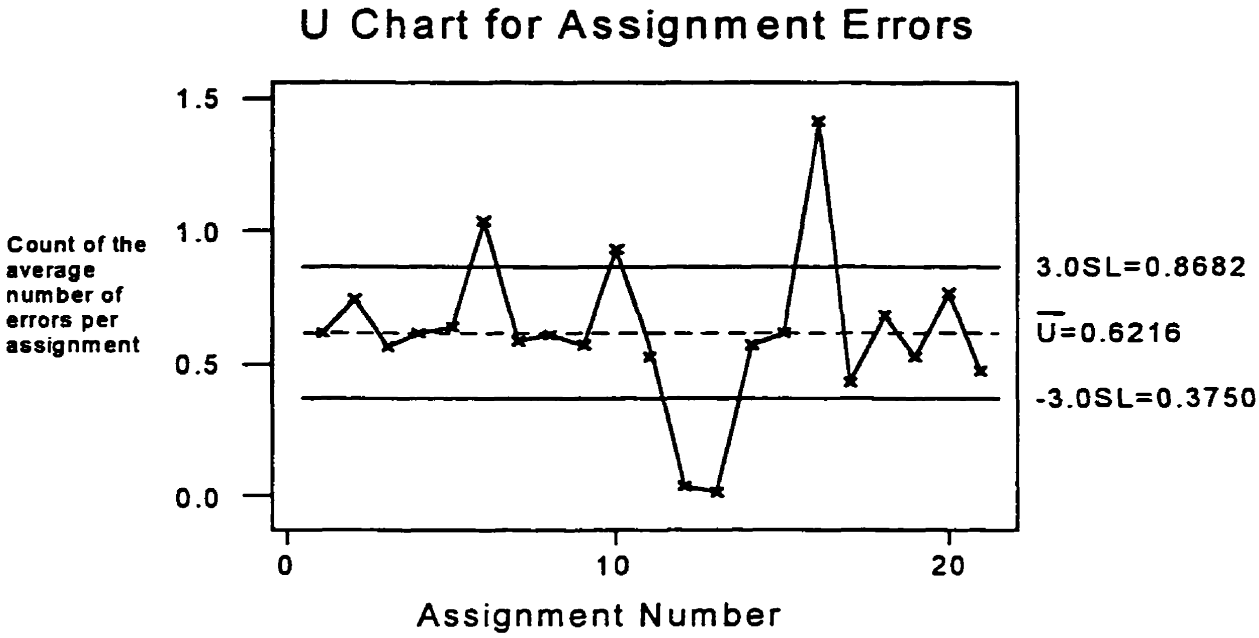


FIGURE 8.5: U-Chart for the Number of Errors in Tutorial Assignments

8.5 QUALITY IMPROVEMENT WITH THE 'SEVEN QC' TOOLS

8.5.1 Approach

Apart from a control chart, six other tools are widely acknowledged to be extremely helpful in quality improvement. They are the flowchart, histogram, checksheet, Pareto, Ishikawa and scatter diagrams. These tools are easy to learn and have a broad area of application. Assuming that these tools are reasonably well known, the description of the tools and applications is limited to Table 8.1, which uses the 5W technique (Why, What, When, Where, Who and How) to illustrate their possible impact in engineering education. The next section presents a case study of the application of these tools in a mechanical engineering course and corresponding improvement results.

TOOL	WHY	WHAT	WHEN/WHERE	WHO	HOW (Key Notes)
Flowchart	♦ To understand how the process works and where decisions are made ♦ To illustrate the flow of information, processes and material in an unambiguous way	Processes: ♦ laboratory/classroom/tutorial preparation and execution ♦ student follow-up ♦ repairing equipment ♦ literature search ♦ calculation of parameters	♦ At the beginning of quality improvement efforts ♦ At anytime when a problem is perceived or anticipated in: the laboratory, general office, class, the library, computer facility, machine shop	Participating: ♦ Faculty (professors) ♦ Technicians ♦ Teaching Assistants ♦ Administration Coordinating: ♦ Faculty (professors)	♦ Learn the necessary flowcharting symbols (e.g. [11]) ♦ Find out who is responsible or most knowledgeable about the process to be flowcharted. Interview him/her/them. ♦ Ask questions
Control Charts	♦ To identify if any special causes of variation exist ♦ To recognize when these causes occurred	Causes of variation of: ♦ teaching process ♦ learning outcomes ♦ administrative processes	♦ Classroom, ♦ Laboratory, ♦ Tutorial ♦ General Office/Library	♦ Professors ♦ Teaching Assistants ♦ Research Assistants	♦ Refer to the body of this article ♦ Lliterature: [11, 12, 14]
Histogram	♦ To identify the type of distribution (normal, uniform) ♦ To classify individuals according to specification limits	♦ Student grades	Evaluating students performance after: tests, laboratory reports, exams, quizzes	♦ Professors ♦ Teaching Assistants	♦ Make sure that samples are representative (more than 100 units) ♦ For smaller sample sizes, use stem and leaf displays or box-plots (see [11])
Checksheet	♦ To record the frequencies of occurrence ♦ To record the locations of occurrence	Frequencies: ♦ typical student mistakes Location: ♦ Equipment breakages	♦ Laboratory reports ♦ Tests, quizzes, exams ♦ Assignments	♦ Faculty (professors) ♦ Teaching Assistants ♦ Research Assistants	♦ Identify typical errors (e.g. missing SI units) ♦ Put a tally each time the error has occurred ♦ Location check-sheets are useful in experiments
Pareto Diagram	♦ To identify the 'vital few' causes from the trivial many'	♦ Common mistakes	♦ Laboratory reports ♦ Tests, quizzes, exams ♦ Assignments	♦ Faculty (professors) ♦ Teaching Assistants	♦ Concentrate first on solving the 'vital few' problems
Ishikawa Diagram	♦ To identify root causes of variation and possible malperformance ♦ To illustrate causal interrelationships	Malperformance of: ♦ individual students ♦ groups of students ♦ professors ♦ teaching assistant Variation of: ♦ Marks	♦ Experiments (e.g. the causes of low grades in the Steam Turbine Thermodynamics Experiment) ♦ Tests, quizzes, exams (e.g. why so many students have failed the Thermodynamics term test)	Participating: ♦ Faculty (professors) ♦ Technicians ♦ Teaching Assistants ♦ Staff ♦ Administration ♦ Students	♦ Organize a brainstorming session with the professor, teaching assistant(s), technician(s), staff and students ♦ Ask questions to generate ideas
Scatter Diagram	♦ To tentatively evaluate possible relationships between different factors	Factors: ♦ two teaching assistants ♦ two student groups ♦ two technicians ♦ student course and laboratory marks	♦ Laboratory reports ♦ Tests, quizzes, exams	♦ Department Head ♦ Faculty (professors) ♦ Teaching Assistants	♦ The degree of correlation can be evaluated

TABLE 8.1: The Seven QC Tools in Engineering Education: Suggestions for Use

8.5.2 Case Study

8.5.2.1 Overview

In order to illustrate how quality of the learning outcomes can be improved to approach the zero-defect objective (Chapter 7), a case study from a thermodynamics laboratory in a second year engineering course is presented. The students are required to attend and write reports on four thermodynamics experiments during a semester. The students' performance in one of these experiments, namely the Sargent Gas Calorimeter Experiment, has been focused on during the fall semesters of 1995, 1996 and 1997. The objectives of the first part of the analysis, conducted in the fall semester of 1995, were to understand the laboratory process, in terms of required activities such as scheduling and conducting the laboratory session, writing and marking reports, etc., as well as to determine the areas where students typically make errors and the causes of these errors. The objectives of the second part of the analysis were to determine critical knowledge characteristics for the laboratory, i.e. what the student should know and where he/she should not make mistakes, to improve the laboratory teaching process on the basis of the first year's analysis, and to monitor the results of the changes on the critical characteristics. The following sections present the results.

8.5.2.2 Part One: Understanding the Process and Determining Causes of Errors

To understand the laboratory process, a flowchart was drafted (Figure 8.6). The flowchart includes activities from scheduling the laboratory sessions, through conducting the session and marking students' reports, to the submission of the final teaching assistant's report to the professor. Possible improvements in the process can be made in terms of gathering student reports. The reports are collected at the end of the day by an administrative assistant. The assistant then places the reports in an envelope, and leaves the envelope in the designated teaching assistant's (TA) mailbox. The TA collects the envelope at his/her earliest convenience. It is evident that this procedure requires an unnecessary effort from the general office staff, and is time consuming. An improvement can be made through by-passing the general office.

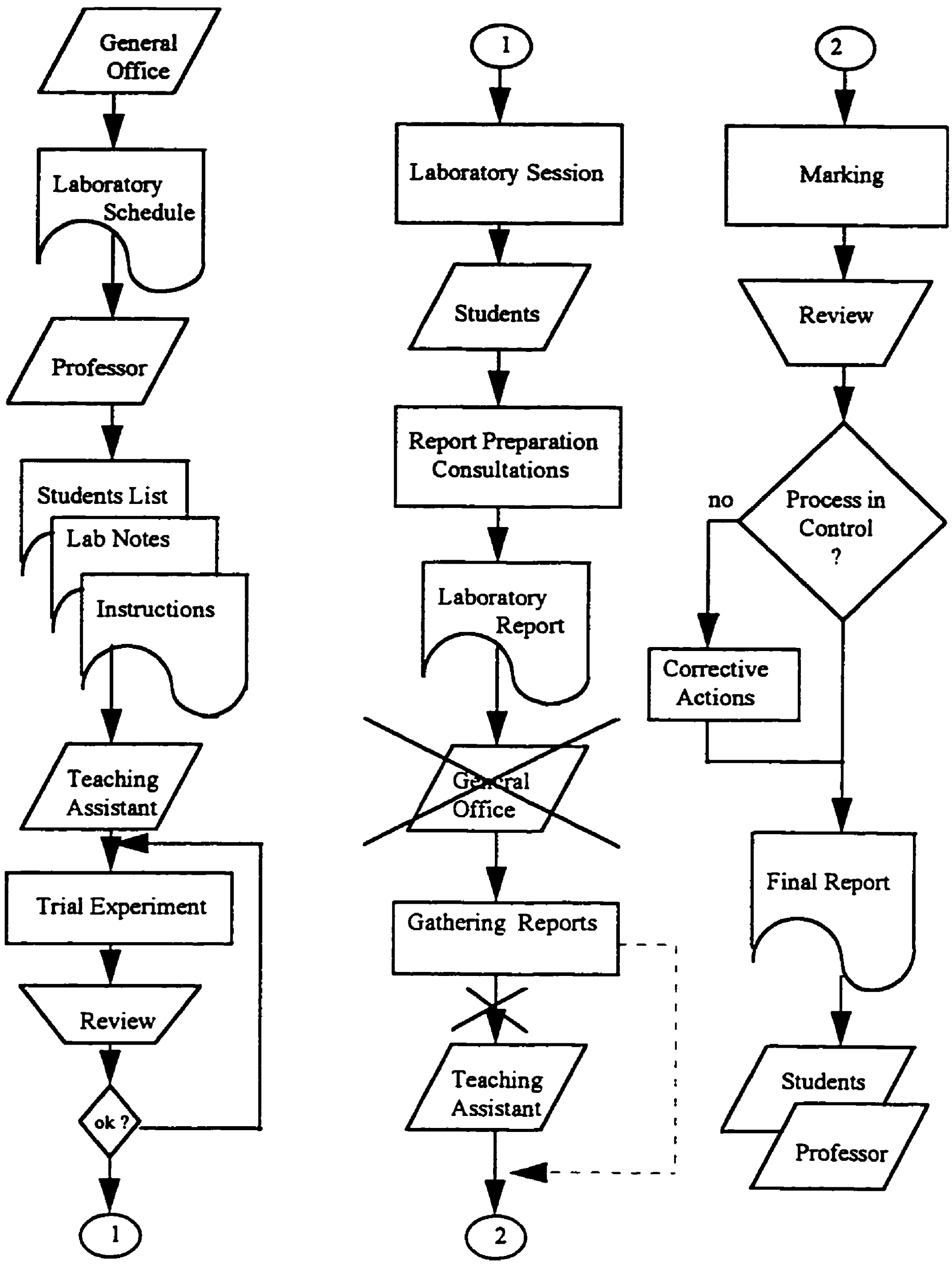


FIGURE 8.6: Laboratory Process Flowchart

Students can place the reports directly in the TA's mailbox, and he/she can take them any time in the day, possibly marking them sooner. Although it is conceivable that this change may not directly affect the improvement of student knowledge, it provides additional time that can be used for re-submitting the report after initial marking takes place.

A checksheet (Figure 8.7) has been developed from observing common mistakes the students had made in calculating the heating value, which is the objective of the experiment. Each student may make several mistakes in one report. A tally was placed on a type of calculation error each time a student makes the error. A sample of 30 from the population of 88 students has shown that 60% (18 students) made a mistake with regard to the calculation of relative pressure. Another common error with a large percentage of occurrence is the missing component of pressure, namely the pressure of water vapour formed in the course of experiment. The other common errors included using the wrong table to find the enthalpy, incorrect gas volume used, as well as missing identification of the apparatus. To underline the most common errors, a Pareto diagram (Figure 8.8) has been used. As we can observe, 23.7% of all errors were caused by the wrong pressure calculation. Relative pressure (measured with a manometer), has been calculated using the density of natural gas, instead of the density of the manometer fluid.

The causes of the relative pressure calculation error, which occurred with the largest frequency, were identified using a cause-and-effect diagram (Figure 8.9). The possible causes of this error include unclear laboratory notes, and thus it is suggested that the notes be revised to provide a clear procedure for calculations. However, it is also suggested that the explanation of how a manometer works should be emphasized more in the laboratory session, since this is a very important and widely used instrument in the engineering practice.

Calculation Error	Tally
Pressure Corrections not Included	𝍸 𝍷𝍷
Conversion of Units of Pressure	𝍷𝍷
Pressure of Water Vapour Not Included	𝍸 𝍸 𝍸 𝍷
Relative Pressure Calculation Wrong	𝍸 𝍸 𝍸 𝍷𝍷𝍷
Relative Pressure Not Included	𝍸
Wrong Temperature for Enthalpies	𝍷𝍷𝍷𝍷
Wrong Table Used for Enthalpies	𝍸 𝍷𝍷
Temperature Conversions	𝍷𝍷
Gas Flow Volume not Appropriate	𝍸 𝍷𝍷
Air Volume not Appropriate	𝍷
Missed Units After Numbers	𝍷𝍷
Figure Marked Inappropriately	𝍸 𝍷𝍷
TOTAL STUDENTS	30

FIGURE 8.7: Breakdown of Calculation Errors

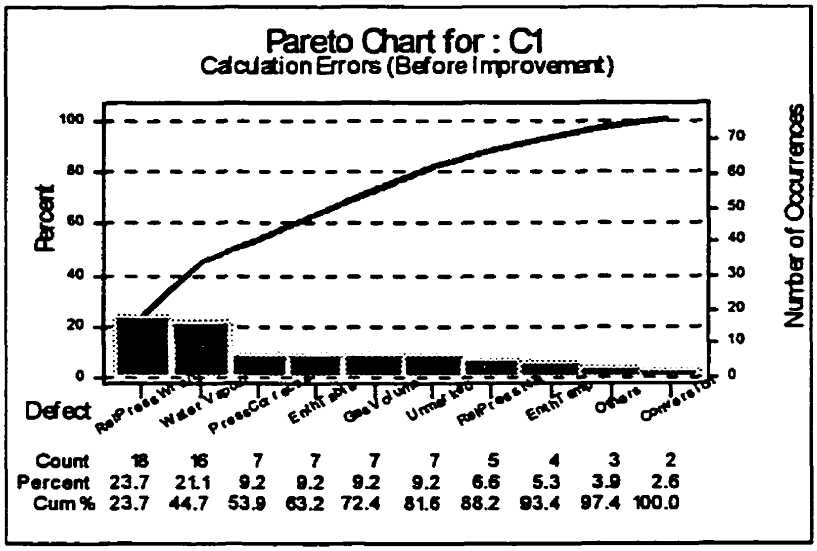


FIGURE 8.8: Pareto Diagram for Errors

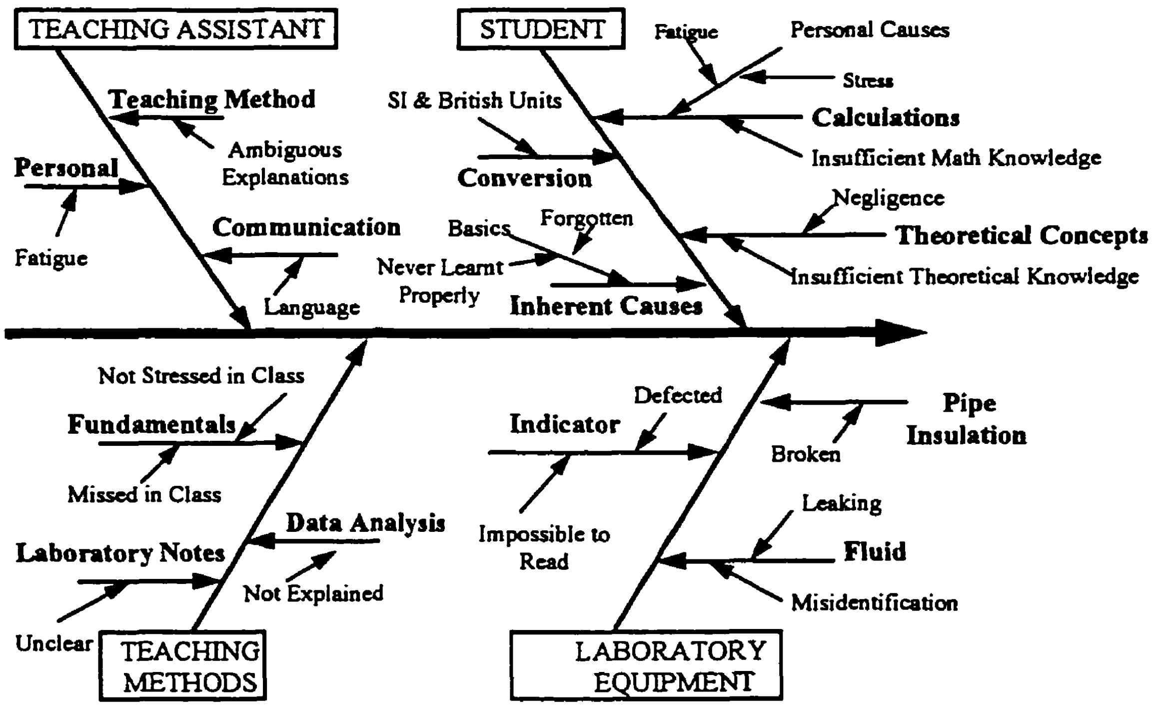


FIGURE 8.9: Cause-and-Effect Diagram for the Relative Pressure Error

8.5.2.3 Part Two: Quality Improvement and Approaching the Zero-Defect Goal

In an improvement effort in 1996., critical quality characteristics for student knowledge gained from the experiment were defined. Students should master the concepts of the heating value, lower, higher and the observed heating values, heating value units, calculation of the heating value and relative pressure, the concept of the reduction factor, as well as be familiar with the apparatus and the calorimeter method used in the experiment.

To facilitate improvement, laboratory notes were clarified with respect to the calculation of the heating values, relative pressure and the pressure of water vapour. The workings of a manometer were explained in detail, and a new figure of the elements of the apparatus was drafted. Report requirements and student responsibilities were also clarified. It was decided that the teaching assistant should focus on explaining the principles of measuring relative and water vapour pressure, as well as other critical characteristics. In terms of the report results, only 2% of students' reports contained an error in calculation of relative pressure. This represents a major improvement from 60% the previous year. Other major errors have sharply decreased as well (Figures 8.10 Checksheet and 8.11 Pareto Diagram). For example, the water vapour pressure error has fallen from 53 to 4%, and wrong enthalpy table from 23 to 6%. One error, namely missed units, has significantly increased in percentage (from 6.7% in the first year to 46% in the following year).

The results indicate significant improvement in critical quality characteristics of student knowledge, and a sharp decrease in the total number of report errors (from 2.5 errors per student in average to about 1 error per student). It was noted at the time that the list of critical quality characteristics should be expanded in 1997. with the knowledge of dimensional analysis, which was expected to cut the number of errors related to units.

In the third year of the improvement project (1997), laboratory notes were again improved, with an additional report requirement for the numerical calculation of errors, as well as remarks not to miss units after numbers and suggestions to perform dimensional analysis. This year also included a new teaching assistant, who conducted the laboratory for the first time.

Error Type	# Occurred (Year 2)	# Occurred (Year 3)
Pressure Corrections not Included	0	15
Conversion of Units of Pressure	6	0
Pressure of Water Vapour Not Included	4	2
Relative Pressure Calculation Wrong	2	0
Relative Pressure Not Included	1	0
Wrong Temperature for Enthalpies	4	16
Wrong Table Used for Enthalpies	2	4
Temperature Conversions	3	39
Gas Flow Volume not Appropriate	2	0
Air Volume not Appropriate	3	0
Missed Units After Numbers	42	32
Figure Marked Inappropriately	2	1
Adding Properties With Different Units	14	13
Conversion of Mass and Volume	2	0
Wrong Specific Heat	3	0
Pressure Correction Wrong	6	0
Wrong Units for Properties	8	0
Wrong Chart Reading	1	0
Source Missing	N/A	38
Wrong Interpolation	N/A	5
TOTAL STUDENTS	98	77

FIGURE 8.10: Checksheet of Errors (After Improvement, 1996.)

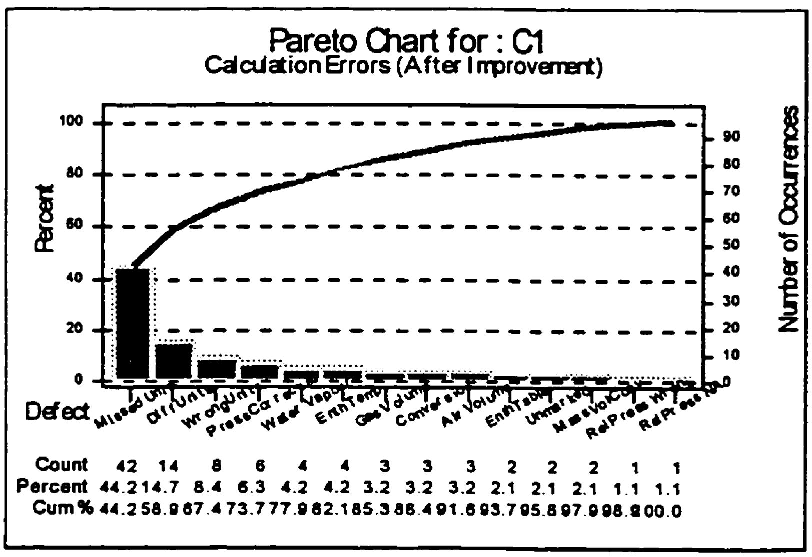
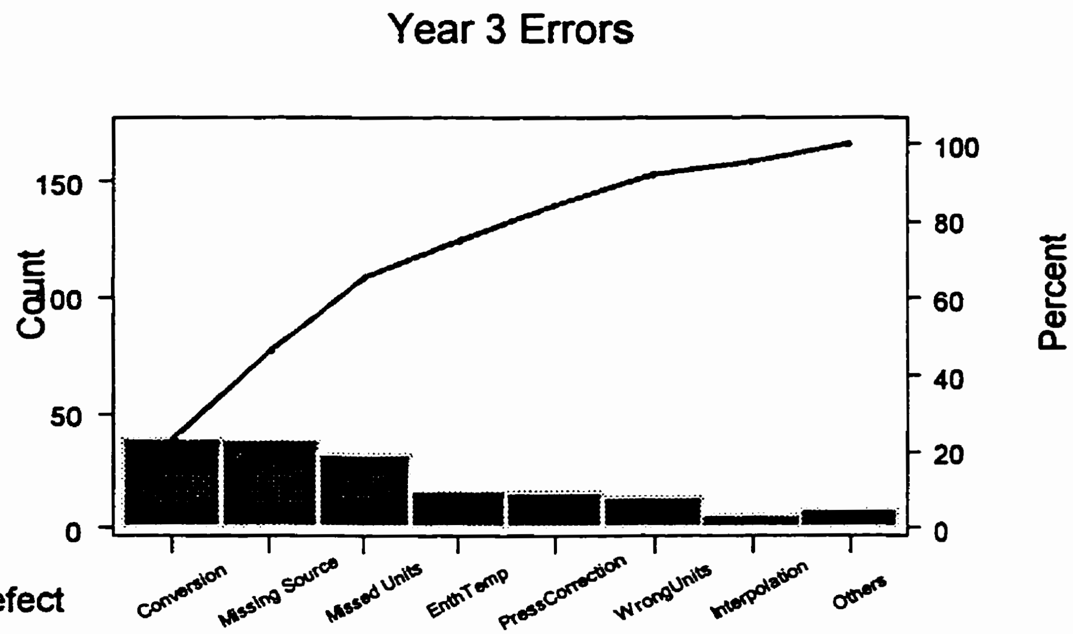


FIGURE 8.11: Pareto Diagram for Report Errors (After Improvement, 1996.)

Again, the number of errors in reports which occurred the most was tallied, with the final results represented in Figure 8.10, third column. The Pareto diagram is given in Figure 8.12. The identified critical quality characteristics, such as the correct calculations of the relative and water vapour pressure show a remarkable improvement from the first year. Virtually no such errors were made, i.e. with respect to the critical quality characteristics, the zero-defect goal has been achieved. However, errors related to units, such as the missing units, wrong units for properties, or unit conversions have not decreased, and some of them actually increased. One error that was not major in previous years, namely a missing source for properties (i.e. table, figure, calculation from which the property is derived is not mentioned) has also occurred a large number of times. From these facts we can draw a conclusion that *quality improvement efforts indeed work within the span of control of the course in which they were implemented*. However, they may not be successful for learning outcomes outside of the intended span of control. For instance, operations with units are taught in high-school, and therefore should be known by students before they even start engineering studies. In this case, unless some time is actually spent in the first year on emphasizing the importance of dimensional analysis and units, it is outside of the span of control of the engineering faculty. The overall improvement project is illustrated in a storyboard format in Figure 8.13.



Defect	Conversion	Missing Source	Missed Units	EnthTemp	PressCorrection	WrongUnits	Interpolation	Others
Count	39	38	32	16	15	13	5	8
Percent	23.5	22.9	19.3	9.6	9.0	7.8	3.0	4.8
Cum %	23.5	46.4	65.7	75.3	84.3	92.2	95.2	100.0

FIGURE 8.12: Pareto Diagram for Quality Improvement in 1997.

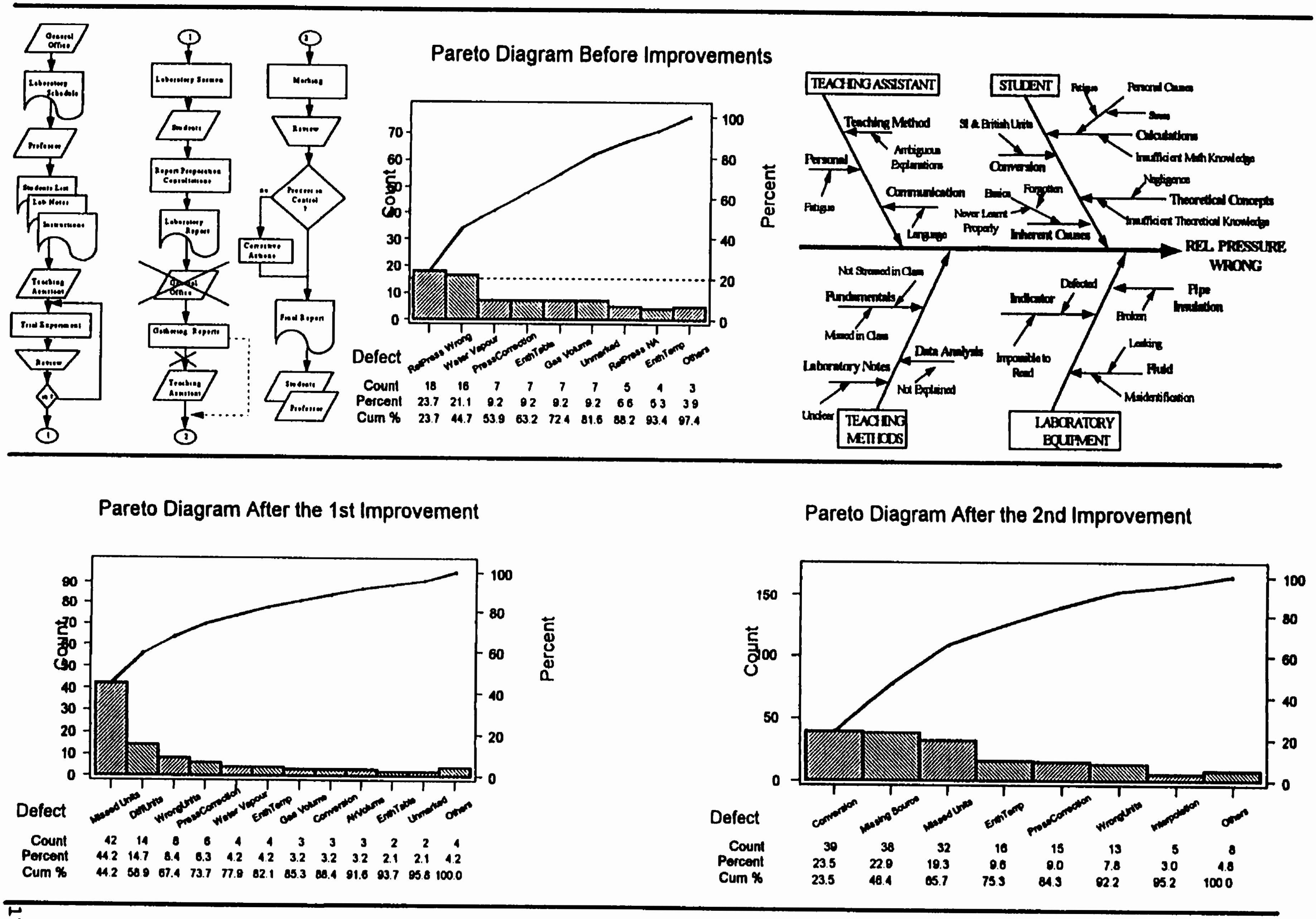


FIGURE 8.13: Quality Improvement in a Laboratory Course

CHAPTER NINE

QUALITY CHARACTERISTICS

A university's products have certain quality characteristics that satisfy the needs and requirements of the university's customers. Naturally, different universities and the various people working in them have differing views on what these characteristics should be, and how much weight should be given to each of them when designing and implementing teaching, learning and research activities. Therefore, this chapter will examine quality characteristics of three university's products: student's education, courses and research, as perceived by members of an engineering faculty in a Canadian university. A hierarchy of product quality characteristics is designed using an operations research technique called the Analytic Hierarchy Process (AHP). The widely used AHP procedure was, however, modified before application, in order to avoid an illogical test for consistency required from decision makers. Therefore, the chapter begins with the illustration of some paradoxes that occur when the current AHP procedure is applied, followed by the description and proof of the suggested consistency test. Subsequently, a hierarchy of the university's product quality characteristics is developed using this approach. Seven engineering professors were involved in the decision making, and the results of their decision are presented. The chapter is concluded with a suggested hierarchy of quality characteristics and its applications.

9.1 PARADOXES OF THE AHP CONSISTENCY TEST

9.1.1 Consistency Test

The Analytic Hierarchy Process was developed by Dr. Thomas Saaty in the early 1980's. It is a deterministic decision making technique that can be used when there are multiple decision criteria and multiple alternatives. The procedure, as explained in section 2.7 of the thesis, involves a multi-level hierarchy of decision criteria. The weights for criteria are determined by comparing them in pairs, using a 1/9-9 scale. In the case that there are n criteria, each pairwise comparison is stored in an $n \times n$ matrix A. The (i, j) entry (for $i < j$) of the matrix, $a_{i,j}$, measures how much more important criterion 'i' is than criterion 'j'. For example, if there are two criteria: A and B, and the decision maker (DM) considers A absolutely more important then B, he/she would assign number 9 to this particular pairwise comparison ($a_{12}=9$). The pairwise comparison matrix A is symmetrical about its principal diagonal, i.e. $a_{j,i} = 1/a_{i,j}$ and $a_{i,i} = 1$ for all i and j. Because a DM is making comparisons of each and every pair of criteria, he/she is making a certain number of judgments that are redundant, i.e. can be derived from other judgments. For example, if A over B is a "3", and B over C is a "2", then for perfect consistency, the judgment A over C can be calculated as 3*2=6. However, a DM can decide that A over C is not exactly a "6", but can be a "5" or "7". Therefore, if a decision maker was perfectly consistent then $a_{i,k} = a_{i,j}\, a_{j,k}$ for all i, j, and k.

The current AHP procedure suggests a consistency test performed on every pairwise comparison matrix A. The test uses the right principal eigenvalue λ of A. If the matrix A is perfectly consistent ($a_{i,k} = a_{i,j}\, a_{j,k}$) the eigenvalue λ would equal n. If the matrix A is not perfectly consistent, λ will be greater than n. The so-called 'consistency index' (CI), defined as $(\lambda - n) / (n-1)$, is the negative average of the other roots of the polynomial of A. The CI is then 'compared with the same index obtained as an average over a large number of reciprocal matrices of the same order whose entries are random' (Saaty, 1992). If the resulting ratio (called the 'consistency ratio' or CR) is smaller than 0.1 (number arbitrarily chosen by Saaty), then the estimate of weight from A is accepted. Otherwise, it is suggested that the DM should re-evaluate and change entered judgments to satisfy consistency.

Saaty's consistency test has a few shortcomings, however. Three are listed:

- When the consistency index is calculated using the random index, the latter was obtained through a simulation of 500 randomly filled matrices of each size in range from 2-10 (Lane and Verdini, 1989; Wind and Saaty, 1980; Saaty and Mariano, 1979). Although the sample size appears to be sufficiently large, there is no guarantee that another simulation would yield identical random index (mean random inconsistency). It is also not clear why computer simulation is used, when all other parameters in AHP (λ, CI, n) are mathematically correct.

◆ The 0.1 limit for the consistency ratio was arbitrarily chosen, i.e it is completely empirical. Such a limit does not take into account the fact that larger matrices (say n=5) may naturally have larger inconsistencies, because of the increasing number of pairwise comparisons. Therefore, Lane and Verdini (1989) suggest stricter limits for n=3 and n=4.

◆ The consistency test is testing a wrong hypothesis. According to Lane and Verdini (1992) the following is tested:

H_0: The $a_{i,j}$'s ($i<j$) are randomly and uniformly selected from the 17 value scale {1/9 - 9}

versus

H_1: The $a_{i,j}$'s ($i<j$) are not randomly and uniformly selected from the scale {1/9-9}

Such hypotheses are not consistent with the purpose of the test itself, being to prevent illogical judgments or inadvert mistakes in pairwise comparisons. An example of a mistake is entering a 1/3 instead of a 3 in position (i,j) if the decision maker believed attribute i was very strongly more important than attribute j. However, making a mistake and/or being illogical are not synonymous with being random. The result is that pairwise comparisons that are reasonable can fail the consistency test because we cannot reject the null hypothesis. The next section presents three examples of such paradoxes (from Karapetrovic and Rosenbloom, 1998).

9.1.2 Paradoxes

The following examples present paradoxes which occur when Saaty's consistency test is used. The first paradox actually occurred during the evaluation of an engineering faculty's program decision (Karapetrovic et al, 1998C).

Paradox 1: A decision maker compares three quality characteristics: A, B and C. He/she believes that A is weakly more important ('3') than B, and A is weakly more important ('3') than C. When comparing B and C, the decision maker views B weakly more important ('3'). Has the decision maker made a mistake in judgment? No. Has the decision maker been unreasonable? No. However, the resulting pairwise comparison matrix is:

$$A = \begin{pmatrix} 1 & 3 & 3 \\ 1/3 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{pmatrix}$$

The matrix has a principal eigenvalue of 3.136, the consistency index is .068, and the random index is .58 (because n=3). Therefore, the consistency ratio is 0.117, which is larger than 0.1, and H_0 cannot be rejected. The matrix fails the consistency test. However, the pairwise comparisons are not random. If we did use these judgments, the resulting weights (w_a =.584; w_b =.281; w_c =.135) are quite reasonable and consistent.

Paradox 2: Consider a game called 'Rock, Paper and Scissors". Two players simultaneously display a hand signal for a rock, a paper or scissors. A fist indicates a rock, an open hand indicates paper, while two fingers (index and middle) indicate scissors. The rules of the game are that paper always beats rock, scissors always beats paper, and rock always beats scissors. If both players have the same hand signal it is a tie. Suppose a player believes his opponent will randomly and uniformly make his or her choice. Suppose our player decides to use AHP to rank the choices. In doing a pairwise comparison, since paper always beats rock, a reasonable decision maker would rank paper an 'a' (where a ≥ 1) over rock. If the decision maker was logical, he or she would also rank scissors an 'a' over paper and rock an 'a' over scissors. The resulting pairwise comparison matrix would be

$$A = \begin{pmatrix} 1 & a & 1/a \\ 1/a & 1 & a \\ a & 1/a & 1 \end{pmatrix}.$$

If $1 \leq a \leq 1.4$, the matrix A will pass the consistency test. If $1.4 < a \leq 9$, the matrix A will not pass the consistency test. It is certainly not a mistake or an unreasonable judgment to choose an $a > 1.4$ when doing these pairwise comparisons. The resulting weights would be $w_{rock} = 1/3$, $w_{paper} = 1/3$ and $w_{scissors} = 1/3$ which are reasonable and correct.

Paradox 3: Consider the following dice game. Two players each have 4 dice. The sides of the dice have the following numbers:

Die A: 0-0-4-4-4-4

Die B: 3-3-3-3-3-3

Die C: 2-2-2-2-7-7

Die D: 1-1-1-5-5-5

Each player chooses one die and rolls. The player with the higher roll wins. It can be proven that die A beats die B 2/3 of the time, die C 4/9 of the time, and die D 1/3 of the time. Die B beats die C 2/3 of the time and die D 1/2 of the time. Die C beats die D 2/3 of the time. If a player decides to use AHP to rank the dice a reasonable pairwise comparison matrix would be:

$$\begin{pmatrix} 1 & 2 & 4/5 & 1/2 \\ 1/2 & 1 & 2 & 1 \\ 5/4 & 1/2 & 1 & 2 \\ 2 & 1 & 1/2 & 1 \end{pmatrix}$$

The pairwise comparisons are reasonable, logical, and certainly non-random. The resulting relative weights are $w_A = .239$, $w_B = .253$, $w_C = .262$, and $w_D = .246$. These are reasonable based on the information in the problem. However, with a principal eigenvalue of 4.507, a consistency index of .169, and a random index of .90, the pairwise comparison fails the consistency test because $CR = 0.187 > 0.1$.

9.2 A QUALITY CONTROL APPROACH

The previous section shows that the consistency test should check for mistakes and consistency, rather than for non-randomness. Rather than test:

H_0: The decision maker's choices are *random*

versus

H_1: The decision makers choices are not *random*

it is suggested that the following hypotheses are tested:

H_0: There are *no mistakes* in the pairwise comparisons

versus

H_1: There *are mistakes* in the pairwise comparisons.

To perform this test, a statistical quality control approach is advised. For the purpose of providing information on the consistency of performance, statistical quality control techniques have been successfully used in manufacturing for decades. The Shewhart control chart is probably the best known and most widely used example. The idea of the control chart is to monitor and control process performance. No production process will produce items that are exactly alike. Some variability due to chance causes, such as environmental or input fluctuations, is inevitable (Grant and Leavenworth, 1996). If only chance causes of variation are present, the process will consistently perform within it's natural variation limits, it is "in-control" and should be left alone. However, if non-chance events occur, such as an operator's mistake or a worn tool, the process will exceed it's natural variation limits, and it is "out-of-control". To put the process back in control, these "special" or non-chance causes must be eliminated. The control chart suggests when and sometimes where to look for these special causes of variation. In instances where natural variability of products is not understood, operators might try to produce "perfect" products, and correct a process that appears not to make consistent products. For example, after a quality characteristic such as the diameter of a shaft turned out to be higher than expected, an operator adjusts the process to get a lower diameter, not understanding the principle of regression towards mean. Such action, however, may actually be a special cause of variation itself (Grant and Leavenworth, 1988).

It is suggested that control charts be used to determine whether a decision maker is consistent in making pairwise comparisons in AHP, i.e. to accept or reject the hypothesis that there are mistakes in the decision maker's pairwise comparisons. There is an analogy between production and decision-making processes (Figure 9.1). Decision-making can be viewed as a production process that transforms input information into decisions.

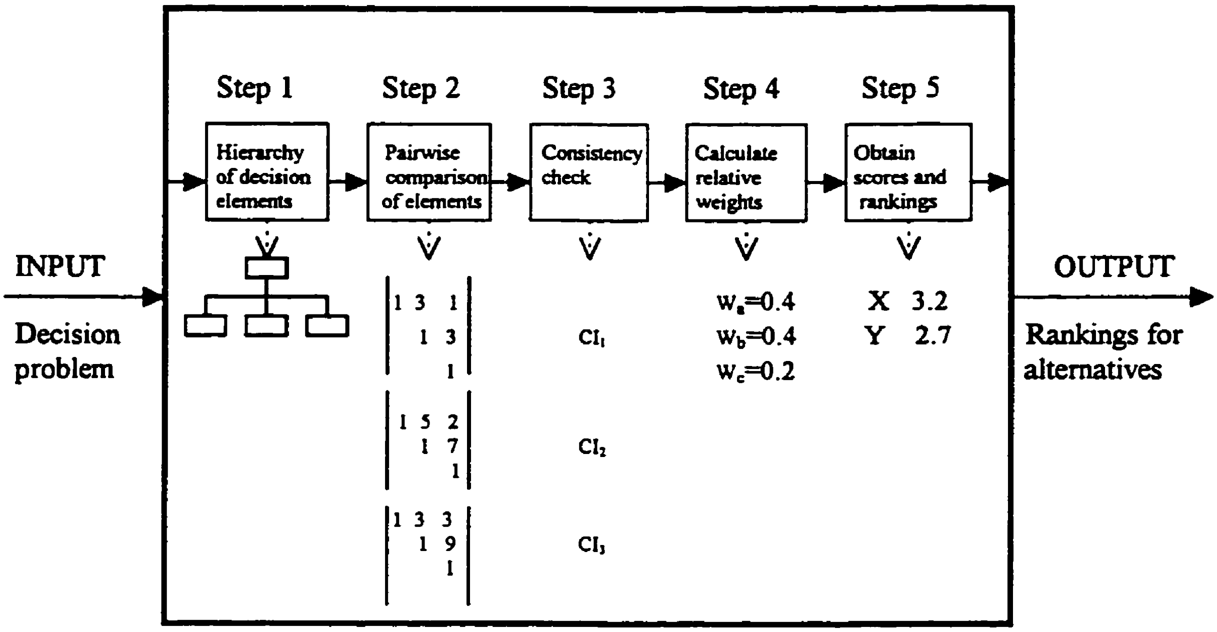


FIGURE 9.1: The AHP Decision Making Process

Let us assume that the decision maker compares three attributes: **a**, **b**, and **c** using AHP. The decision maker possesses certain information about these attributes, and on the basis of available information, the decision maker makes three judgments on their relative importance. The decision maker considers **a** weakly more important than **b** ('3'), **b** weakly more important than **c** ('3'), and **a** also weakly more important than **c** ('3'). Subsequently, the decision maker fills out a pairwise comparison matrix, which in fact is the product of his/her decision making process.

Before moving on to another pairwise comparison matrix, the standard AHP procedure suggests a consistency check using a consistency ratio (CR) for the matrix. As our paradox examples show, the matrix may fail the consistency check, and the decision maker is forced to correct his/her decision making process, by changing certain judgments. For example, the decision maker might change a over c to a '7' instead of '3', to satisfy consistency. Every time a matrix fails the consistency check, the decision maker is forced to adjust his/her decisions to meet the CR $\leq$ 0.1 criterion. The question is: can we determine whether a decision maker is consistent by observing one matrix at a time and adjusting the decision making process after each 'inconsistent' matrix, or are we simply repeating the mistake of the manufacturing operator, not taking into account the natural variability of decision making? The latter is the logical answer.

Thus, rather than looking at one pairwise matrix at the time for consistency, a control chart method that will monitor and control the consistency of the entire decision making process is proposed. In Sections 9.2.1 and 9.2.2 approaches for a single decision maker, and for multiple decision makers are suggested, respectively.

9.2.1 Single Decision Maker

For a single decision maker, a quality control method using the moving average and range control charts for consistency checks is proposed. For a particular decision problem and corresponding hierarchy of decision elements, a single decision maker makes pairwise comparisons of attributes and alternatives, and fills, say N pairwise matrices in a particular order. Using Saaty's consistency check procedure, it is possible to calculate the principal eigenvalue $\lambda_{max, i}$ for each matrix A_i (i = 1, 2, 3, ..., N). The inconsistency throughout each matrix can be captured by $\lambda_{max, i} - n_i$, where n_i is the dimension of the matrix A_i. This number represents the deviation of the judgments from a perfect consistency, in which case $\lambda_{max, i} = n_i$. To correct for the size of the matrix, the deviation is divided by n-1, and a consistency index $CI_i = (\lambda_{max, i} - n_i)/(n_i-1)$ is obtained.

Instead of dividing each CI_i by the "random index", plotting a moving average and moving range control charts using consistency indices as individual observations of consistency is proposed. For example, consistency indices for the first three matrices, CI_1, CI_2 and CI_3 , can be used as the first sample of individual observations. The average $CI_{a,1} = (CI_1+CI_2+CI_3)/3$ is plotted on the moving average control chart, and the range R_1 = maximum $\{CI_1, CI_2, CI_3\}$ - minimum $\{CI_1, CI_2, CI_3\}$ is plotted on the moving range control chart. For the second sample, CI_1 is dropped, and CI_4 is introduced. The second sample average becomes $CI_{a,2} = (CI_2+CI_3+CI_4)/3$, the range is R_2 = maximum $\{CI_2, CI_3, CI_4\}$ - minimum $\{CI_2, CI_3, CI_4\}$, and these points are plotted on the corresponding control charts. This process continues until all consistency indices are included in the chart. Therefore. this chart will have N-2 points. Subsequently, the average of sample averages is calculated: $\underline{CI} = \Sigma CI_{a,j} / (N-2)$, j=1, 2, ...N-2, as well as the average of sample ranges: $\underline{R} = \Sigma R_k / (N-2)$. Control limits for the moving average control chart are estimated at: $\underline{CI} \pm 3\sigma_{CIa}$, where σ_{CIa} is the average of sample standard deviations. These control limits can also be calculated using sample ranges as: $\underline{CI} \pm 3A_2\underline{R}$, where A_2 is a factor which depends on the sample size. For the sample size of 3, $A_2 = 1.02$. Control limits for the moving range control chart are estimated as factors D_3 and D_4 for the lower and upper control limit, respectively. Factors D_3 and D_4 also depend on the sample size, and together with the factor A_2 can be found in any quality control textbook (Grant and Leavenworth, 1996; Montgomery, 1996; Besterfield, 1996).

Once the control charts are plotted, we can look for any special causes of variation in consistency of the particular decision maker. These special causes are visible on the charts as points outside control limits, upward and downward trends, or a large number of consecutive points above or below the central line. For example, a point above the control limit on the moving average control chart may indicate that the decision maker has made a mistake in entering a judgment. Instead of a "3" the decision maker placed a "1/3", which contributed to the larger consistency index for that particular matrix, and ultimately raised the average for samples in which this CI was included. An upward trend on the chart may indicate fatigue of the decision maker, since consistency indices increase as time passes by. A downward trend may show the intent of the decision maker to be perfectly consistent. In this case, the decision maker makes judgments using the transitivity rule, i.e. A/B is 3, B/C is 2, so A/B must be 6, and as time passes, the decision maker is getting better and better in applying the rule. A special cause of variation may occur in the following scenario, as well. At the beginning of the decision making process, the decision maker who is unfamiliar with AHP procedures, makes a number of judgments, which will be used in several pairwise comparison matrices. The interviewer, who facilitates the AHP technique, notices that the decision maker has been 'inconsistent', and warns the decision maker of the transitivity rule. Till the end, the decision maker makes judgments strictly according to the rule. The result of such a scenario will likely be a number of points below the central line on the moving average control chart, and an erratic pattern on the moving range chart.

It must be noted, however, that the interpretation of several points outside control limits and trends on the moving average/range chart differs slightly from the Shewhart Xbar-R chart, because successive points on the former chart are not independent of one another (Grant and Leavenworth, 1996). An extreme value of the consistency index will thus have a greater effect on a moving average/range chart, since its used more than once in calculations. The aforementioned examples illustrate the necessity of plotting points consecutively, i.e. the first matrix to be filled is first to be plotted, then the second, and so on. This type of subgrouping used for process control allows for the minimum chance of variation within a subgroup and a maximum chance for variation between subgroups (Grant and Leavenworth, 1996).

The statistical quality control approach to AHP consistency checks is by no means limited to the use of the afore-mentioned moving average and range charts. For example, if judgments are spaced some time apart, such as in the case where a decision maker fills in matrices over couple of days, it may be useful to plot individual values of consistency indices CI_i on an individuals (I) chart, combined with a moving range (MR) chart. In this case, 3σ limits on the I chart are obtained as $\underline{X} \pm 3\sigma$, where $\underline{X}$ is the average of individual values, and σ is estimated from the moving range (Grant and Levenworth, 1988). Also, in the cases where a decision analyst is interested in detecting small shifts in the mean of consistency indices, and/or the decision hierarchy has relatively few attributes and alternatives yielding a smaller number of matrices, the exponentially-weighted moving average (EWMA) chart is particularly useful. The EWMA chart is typically used with individual observations (Montgomery, 1996), which provides the opportunity to use it in a single decision maker case, however it can also be applied to multiple decision makers (section 9.2.2). Using the EWMA chart for a single decision maker, the value $z_i = wCI_i + (1 - w)\, z_{i-1}$ is plotted, where $w \in [0,1]$ is the weight (constant) and z_0 (starting value) can be set as the process target (say CI=0) or calculated as the average of available data. The EWMA control limits are set at $\mu \pm L\sigma \{w[1-(1-w)^{2I}]/(2-w)\}^{1/2}$, where L is the width of control limits. An excellent outline of the EWMA chart is provided in Montgomery (1996).

To summarize, the following is the proposed procedure for quality control of consistency in the case of a single decision maker:

Step 1: The decision maker provides his or her input to the N pairwise comparison matrices A_1., A_2, ... A_N in the decision hierarchy where the ordering of the pairwise comparison matrices corresponds to the order of data input.

Step 2: The moving average and moving range control charts are constructed.

Step 3: Using standard quality control methodology, a determination is made on whether the process is out of control or not. If the process is out of control, the pairwise comparisons are deemed inconsistent and the pairwise comparison matrices should be re-examined. If the process is in control the Analytic Hierarchy Process can continue.

9.2.1.1 Example

This section presents an example to illustrate the single decision maker procedure. Step 1 of the procedure involves calculating λ_{max} for each pairwise comparison matrix. Comparing the attributes A, B and C, a decision maker considers A to be weakly more important than B ('3'), B to be weakly more important than C ('3'), and A again weakly more important than C ('3'). The following pairwise comparison matrix (matrix #2) was obtained:

$$A_2 = \begin{pmatrix} 1 & 3 & 3 \\ 1/3 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{pmatrix}$$

Note that this matrix is identical to the matrix from the first paradox example. The weight for attribute A is 0.584, B is 0.281, and C is 0.135. $\lambda_{max} = 3.136$ with a consistency index of .0677. Next, consistency indices for all twenty-five matrices with 3×3 or more elements are calculated, obtaining the results presented in Table 9.1.

Matrix Number	Consistency Index
1	0.0000
2	0.0677
3	0.0516
4	0.0515
5	0.0516
6	0.0515
7	0.0515
8	0.0000
9	0.0878
10	0.0514
11	0.0514
12	0.0514
13	0.1773
14	0.0515
15	0.0878
16	0.0000
17	0.0515
18	0.0000
19	0.0603
20	0.0878
21	0.0000
22	0.0000
23	0.1042
24	0.0856
25	0.0517

TABLE 9.1: Consistency Indices for a Single Decision Maker

Moving average and moving range charts are then plotted (Figures 9.2 and 9.3). For example, the point corresponding to sample #3 on the moving average control chart is obtained as: $(CI_1 + CI_2 + CI_3)/3 = (0+.0677+0.0516)/3 = 0.03976$. The moving range for this particular sample is 0.0677. As we can observe from Figure 9.2, subgroup #15 on the moving average chart is almost on the upper control limit line, with subgroup #13 close to the upper control limit on the moving range chart, which may indicate a special cause of variation, i.e. a mistake in pairwise judgments.

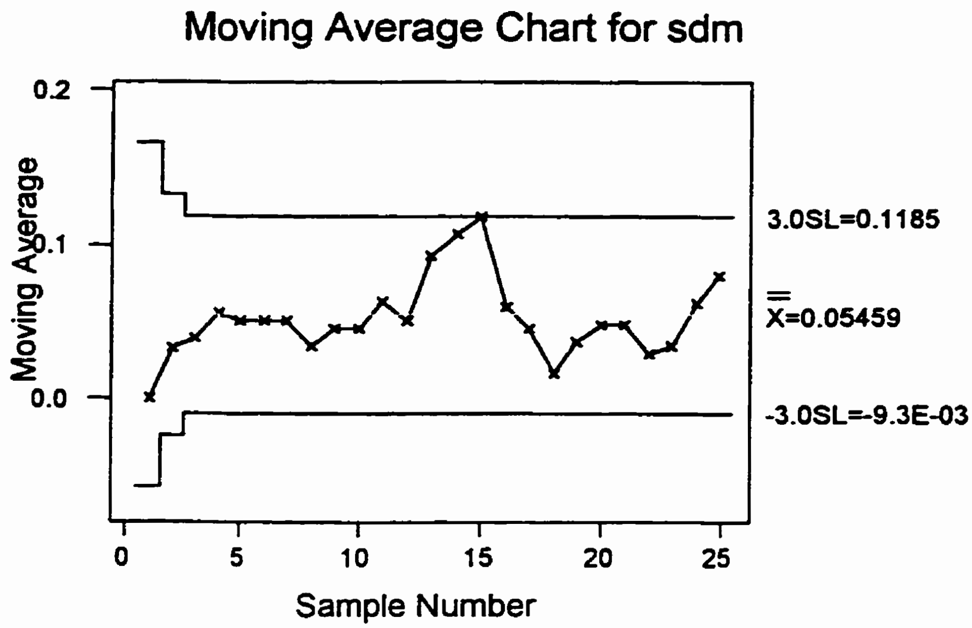


FIGURE 9.2: Moving Average Control Chart for a Single Decision Maker (Example)

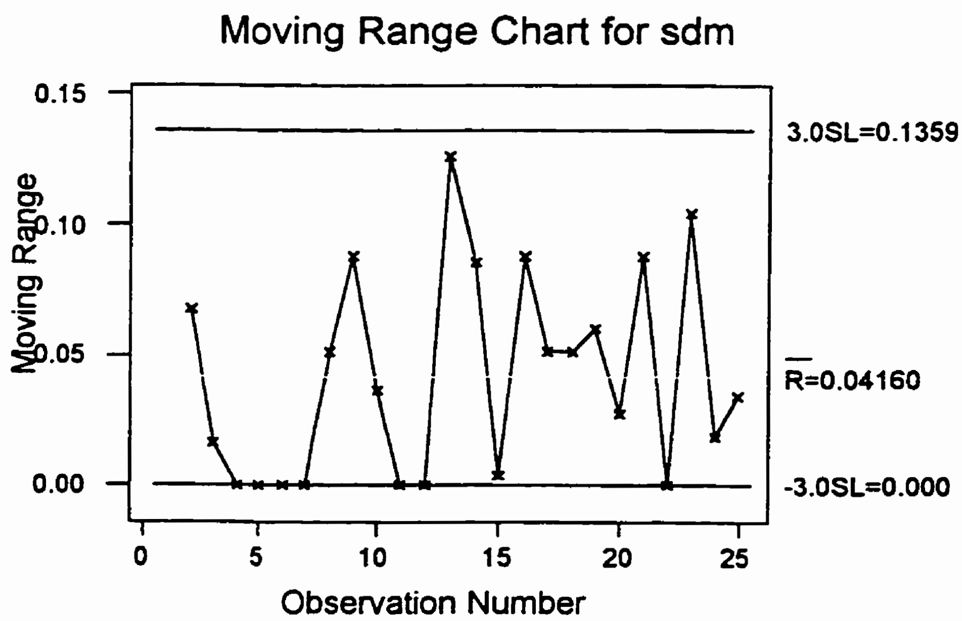


FIGURE 9.3: Moving Range Control Chart for a Single Decision Maker (Example)

In particular, matrix #13 with the CI of 0.1773 should be questioned. The matrix is:

$$\begin{pmatrix} 1 & 1/3 & 3 & 3 \\ 3 & 1 & 3 & 3 \\ 1/3 & 1/3 & 1 & 1 \\ 3 & 1 & 1 & 1 \end{pmatrix} = A_{13}$$

A closer look at the matrix reveals that the decision maker has probably made a mistake, most likely in judgment a_{13}. It is obvious that alternative B is preferred to all other alternatives, and that alternatives C and D are considered equal. Judgment a_{14} points out that alternative A is less preferred than alternative. D, but a_{13} claims otherwise. The most probable cause of this is a mistake in entering judgment a_{13}. Instead of placing a "1/3", the decision maker wrote the reciprocal value of "3". Indeed, this explanation is consistent with the decision making thinking of the particular decision maker, since the decision maker has done this before, by judging A/B as "3", B/C as "3", and A/C as again "3" (see the previous matrix). It can also be observed that the CI for matrix #2 is within control limits, which means that the first paradox example is not rejected as inconsistent for this particular decision maker.

In order to illustrate how mistakes in judgments are captured by the quality control approach, let us assume that this decision maker has deliberately made a mistake while entering judgments in matrix #2. For example, instead of entering:

$$A_{2'} = \begin{pmatrix} 1 & 3 & 3 \\ 1/3 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{pmatrix}$$

the decision maker entered:

$$A_{2''} = \begin{pmatrix} 1 & 3 & 1/3 \\ 1/3 & 1 & 3 \\ 3 & 1/3 & 1 \end{pmatrix}$$

For the latter matrix, consistency index is equal to 0.6666. Figures 9.4 and 9.5 demonstrate that in the latter case, an out-of-control condition occurs on both the moving average and moving range charts.

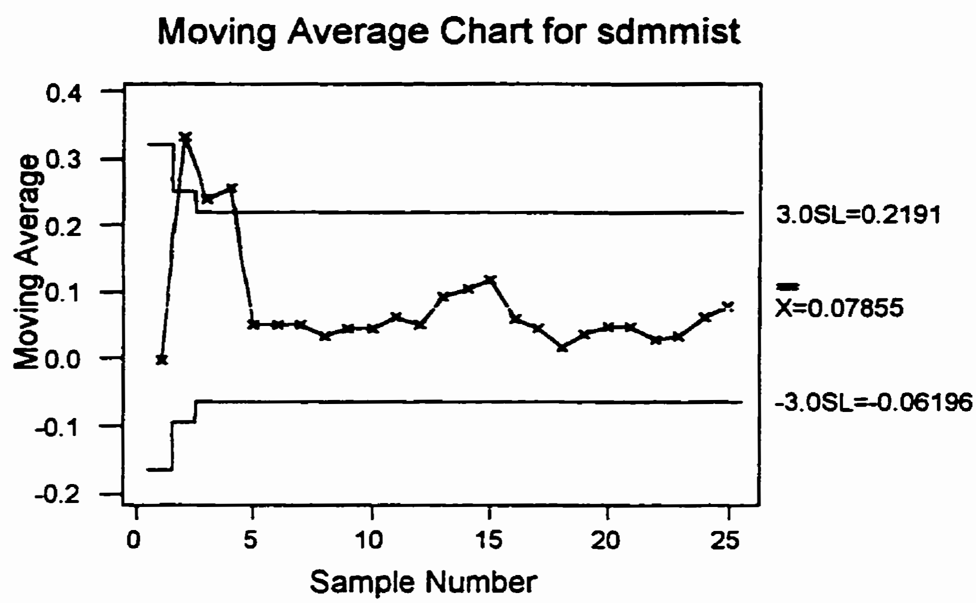


FIGURE 9.4: Judgment Mistake Causes Out of Control Conditions on the MA chart

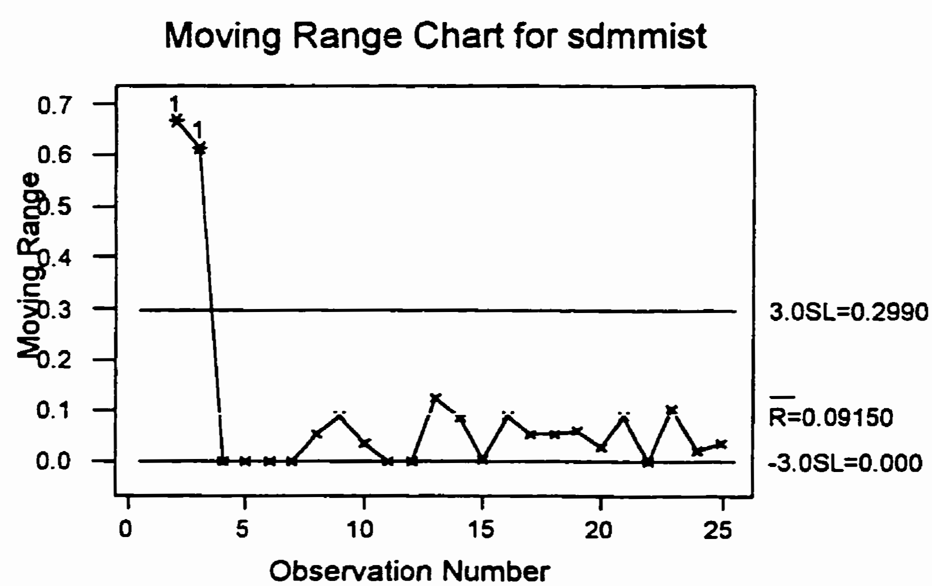


FIGURE 9.5: Judgment Mistake Causes Out of Control Conditions on the MR chart

9.2.2 Multiple Decision Makers

In the case of multiple decision makers, quality control of consistency can be performed using the simple Shewhart Xbar-R chart. For a given hierarchy, k decision makers each judge the preference of decision alternatives and the importance of decision attributes, and fill the N pairwise comparison matrices. Assuming that the decision makers have adopted the same hierarchy, they will compare the same attributes and alternatives, and fill in the same matrices. The accepted method (Aczel and Saaty, 1983) of synthesizing these ratio judgments is to take the geometric mean of their pairwise comparisons. Implicit in this approach is that each decision maker has an equal chance of being correct in his/her judgments. This means that for a particular element of a particular matrix A_i, k decision makers will result in k judgments with equal probability of being correct. Thus, each decision maker should have an equal chance of being consistent, when judging an entry in a matrix A_i. A decision maker j's consistency index for matrix A_i is denoted by $CI_{i,j}$. If the consistency index is adopted as a measure of consistency, then the average of $CI_{i,j}$ for a particular matrix A_i should follow approximately a normal distribution. Suppose there are N matrices with 3×3 elements or more (since a 2×2 matrix always has a CI=0), and the means of CIs for each such matrix A_i are calculated as $CI_i = (\sum_j CI_{i,j}) / k$, where j=1, 2, ..., k, and i=1, 2, ...N. We can then assume that 99.73% of all means will be within certain limits, i.e. within $\underline{CI} \pm 3\sigma_{CI}$, where $\underline{CI} = (\Sigma CI_i)/N$, and σ_{CI} is the standard deviation of averages CI_i. If the CI_i calculated for the matrix A_i falls within control limits, it is safe to assume that decision makers have been consistent with respect to this matrix (with a 0.23% possibility of an error in making this assumption). If it doesn't, then a special cause of variation might have occurred, and the matrices should be re-examined. Sample ranges (R_i = maximum $\{CI_{i,j} | j = 1, 2, ...k\}$ - minimum $\{CI_{i,j} | j = 1, 2, ...k\}$) are plotted on the R chart. Control limits are then calculated using the same procedure as for a single decision maker.

The Xbar chart will look at the variation of sample averages. If a point falls above the upper control limit, this may indicate that one or more decision makers made a mistake in their judgments. This point should then be examined further, by observing each decision maker's matrix from this sample. The fact that a point is outside control limits does not, however, automatically imply that a mistake has been made, i.e. that a special cause of variation was present. As we will show in the case study, it could simply mean that a decision maker has made a logical decision, but could not present his/her judgments in a 'consistent manner'. For example, the decision maker considers alternative A as '5' over alternative B, B as '5' over C, and A as '7' over C. Due to the fact that AHP judgment scale only goes up to 9, this decision maker's consistency index is higher, and thus may have caused an "out-of-control" situation. A point above the upper control limit on an Xbar chart may also indicate that the majority of decision makers were inconsistent in judging a particular set of attributes or alternatives. Non mutually-preferentially independent (MPI) attributes, or an unclear distinction between alternatives may have contributed to this situation. Other special causes of variation may be indicated by upward or downward trends, or a string of points above or below the central line. The explanation of these indications is similar to the single decision maker case.

The R chart looks for variation within samples. Again, a point outside limits could indicate that one or more decision makers has made a mistake. In this case, if a corresponding point on the Xbar chart is within control limits, chances are that a single decision maker is at fault. However, if the corresponding point on the Xbar chart is also above the upper control limit, this may indicate that the constructed hierarchy is erroneous in some way, since all DMs are having problems with a particular matrix. An upward trend may indicate the fatigue of a particular decision maker, a downward trend illustrates that decision makers are trying harder to be consistent as the process continues.

If the EWMA chart has been used for individual decision makers, the same chart can be applied to the multiple decision makers case by simply replacing individual values for CI_i with the average for all DMs, and σ with σ / $(k^{0.5})$. Also, in the case that there is a relatively small number of subgroups (i.e. N), EWMA can be used. Other techniques that can be applied include short-run charts presented in Hillier (1969) and Montgomery (1996).

In summary, a quality control approach in multiple DM cases provides an insight into how different DMs view the same decision problem, and thus gives an opportunity to identify individual and/or systematic errors. The following is the suggested procedure for quality control inconsistency checks in the case of multiple decision makers:

Step 1: Each decision maker j provides his or her input to the N pairwise comparison matrices $A_{1,j.}$, $A_{2,j}$, ... $A_{N,j}$ in the decision hierarchy where the ordering of the pairwise comparison matrices corresponds to the order of data input. A consistency index $CI_{i,j}$ is calculated for each matrix $A_{i,j}$.

Step 2: Calculate CI_i = for i=1, 2, ...N, $\underline{CI}$, and σ_{CI}.

Step 3: The Xbar and R control charts are constructed.

Step 4: Using standard quality control methodology, a determination is made on whether the process is out of control or not. If the process is out of control, a determination is made on why the process is out of control. If necessary some pairwise comparisons may be re-evaluated. If the process is in control the Analytic Hierarchy Process can continue.

9.2.2.1 Example

This section presents an example to illustrate the multiple decision makers procedure. In this case, six decision makers were making pairwise comparisons in 13 matrices with $n \geq 3$. The corresponding consistency indices are presented in Table 9.2.

Matrix	*DM1*	*DM2*	*DM3*	*DM4*	*DM5*	*DM6*
1	0.0432	0	0	0.0269	0	0.0679
2	0	0.0268	0.0268	0.011	0.0677	0.0145
3	0	0.162	0.0607	0.019	0.0516	0.1133
4	0.0202	0	0.0984	0.084	0.0515	0
5	0	0.0532	0	0.0347	0.0516	0.0878
6	0.117	0.0208	0.0515	0.0584	0.0515	0.1979
7	0.0393	0	0	0.0872	0.0515	0
8	0.0679	0.0432	0	0.04	0	0.2603
9	0.0164	0.0271	0	0.1141	0.0878	0.1739
19	0.1109	0.0549	0	0.0218	0.0514	0.019
11	0.0103	0.0849	0	0.0246	0.0514	0.0112
12	0.0267	0.0501	0	0.0312	0.0514	0.0524
13	0.1034	0.1431	0	0.0869	0.1773	0.0671

TABLE 9.2: Consistency Indices for Multiple Decision Makers

An Xbar-R control chart is plotted (Figure 9.6). It can be observed that the point corresponding to the matrix #8 on the R chart indicates a large variation between the decision makers, although it does not exceed the upper control limit. A closer look at the sample shows that the decision maker #6 had a CI=.2603, while two other DMs had CI=0. Thus, the decision analyst may decide to re-examine the DM#6's matrix.

Figure 9.7 illustrates that even if only one decision maker had made a mistake in entering a particular judgment (DM#5 entering matrix $A_{2''}$ instead of $A_{2'}$ above as in the example in section 9.2.1.1), this would still be captured by the R chart for multiple decision makers.

9.3 PRODUCT QUALITY CHARACTERISTICS

9.3.1 Hierarchy of Characteristics

Undoubtedly, like the products or services of any other organization, university's products have certain quality characteristics. It is evident that each product, namely student's education, a program/course and research has a set of qualities or characteristics that bear on the product's ability to satisfy customers' needs. It is also apparent that each of these sets of characteristics is complex, including more than one element-characteristic, and often there are numerous levels of characteristics. For example, if course evaluation results are perceived as a quality characteristic of a particular course, lower-level characteristics would be student evaluation of courses and instructors, evaluation by peers, as well as an assessment of the course performed by outside experts. Viewing the quality of a university through a few same-level indicators, such as the Macleans' magazine "Annual Rankings of Universities" in Canada, or the U.S. News and World Report's rankings in the United States, can often be perceived as not comprehensive and unjust by many universities.

However, in order to provide means for quality control and improvement in an academic environment, quality characteristics and their indicators or measures must be defined. How can we improve if we do not know what to improve? This is also a requirement of the ISO 9001 quality system standard. Section 4.17 of the standard

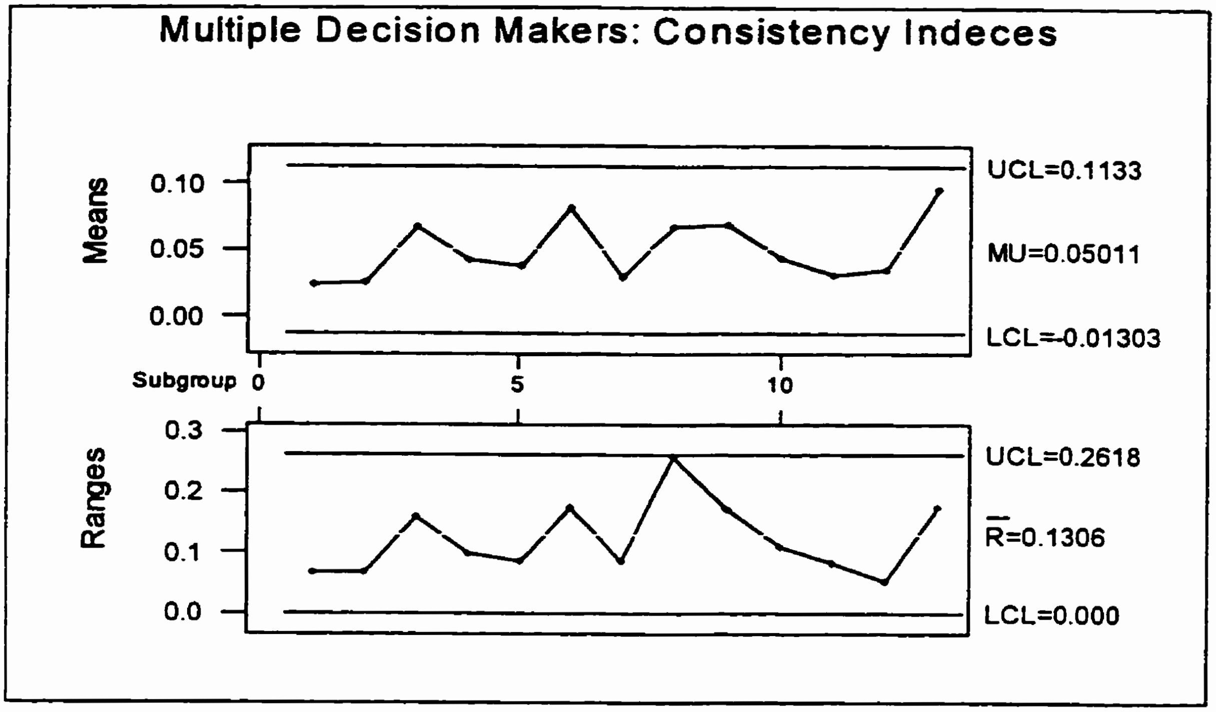


FIGURE 9.6: Shewhart's Control Chart for Multiple Decision Makers

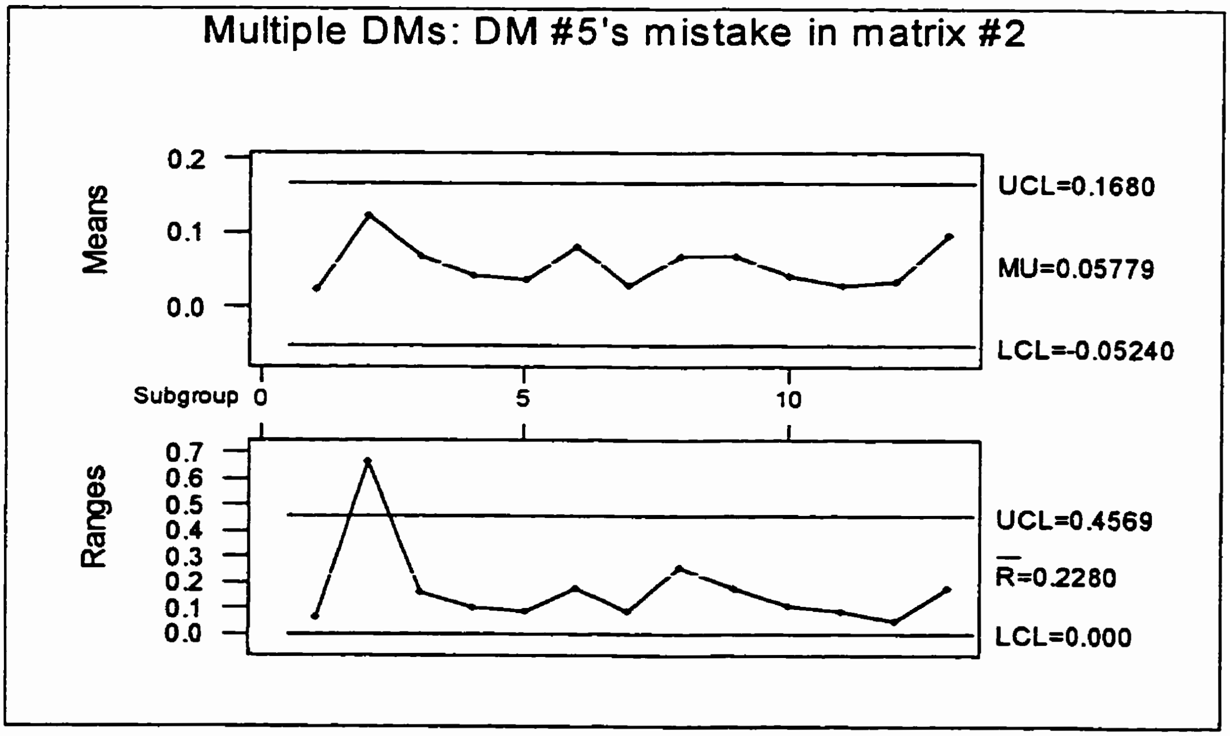


FIGURE 9.7: A Judgment Mistake Causes Out-of-Control Conditions

requires the establishment of internal quality audits 'to verify whether quality activities and related results comply with planned arrangements and to determine the effectiveness of the quality system". Indeed, without defined and documented quality characteristics of products and processes in a university, verification and validation of a planned arrangement for a quality system would be very hard, if not impossible to do.

Naturally, different universities and the different people working in them have differing views on what these characteristics are and should be, and how much weight should be given to each of them when designing and implementing teaching, learning and research activities. Following this fact, as section 2.3.2 emphasized, universities in Europe are developing self-assessment schemes aimed at a clear and systematic quality assurance of products. These schemes reported in literature always involve a set of characteristics used to define, measure, control, monitor and improve quality (e.g. Gelders et al, 1995; Pfeifer and Wunderlich, 1997; Hjälmered and Lumsden, 1994; Lindström, 1994). Therefore, each university, faculty or department should establish its own set of product quality characteristics, when embarking on continuous quality assurance and improvement. In the following sections, the development of such a set of characteristics in a department of mechanical and industrial engineering is addressed. Firstly, the methodology is detailed, followed by the description of results. Finally, during this process, important insights were gained and a summary, together with a proposed hierarchy of characteristics are presented.

9.3.2 Methodology

The development of product quality characteristics was conducted as a part of the ISO 9001 project in the department of mechanical and industrial engineering. Because the characteristics are multi-layered and their importance to the faculty and staff needed to be determined, the Analytical Hierarchy Process was chosen. The purpose of using AHP is to present a hierarchy of product quality characteristics and to determine the importance weight of each characteristic. The following steps were undertaken:

- Decision makers were defined
- A proposed hierarchy of characteristics was developed

- ◆ Decision makers were interviewed to provide AHP pairwise judgments
- ◆ The quality control approach presented in section 9.2 was used to monitor decision process
- ◆ Importance weights were synthesized and presented to decision makers
- ◆ Using the results, a set of the department's product quality characteristics was proposed

While the first four steps are presented in this section, and the fifth step is illustrated in section 9.3.3, the final step is discussed in section 9.3.4.

9.3.2.1 Selection of Decision Makers

Mechanical and industrial engineering undergraduate and graduate programs and courses, research projects and ultimately a student's knowledge and skills are designed and delivered by the academic staff of the department, i.e. members of the faculty. In a university environment, even the administrators are faculty members, such as the dean, associate deans or department heads. Therefore, while analyzing a decision of selecting a set of quality characteristics for the department, professors were considered to be the decision makers. At the time of conducting this decision analysis, there were twenty two professors in the department, with several being unavailable due to sabbatical leaves.

In consultation with the Associate Dean for Administration, requests for an interview were sent to thirteen full-time academic staff (Appendix 7-1). Four regretted to be unavailable for an interview, and one professor was away for two weeks at the time. After the scheduled interview, another professor requested some time to produce judgments, but has yet to return the questionnaire with judgments. Therefore, seven decision makers' judgments were considered for scaling product quality characteristics.

9.3.2.2 Development of an AHP Hierarchy

A hierarchy of product quality characteristics was developed with the participation of the Associate Dean of Engineering, who was also coordinating the ISO 9001 development project for the department. The hierarchy emphasizes a systems view of quality, using input, throughput and output quality characteristics for each of the three products (Figure 9.9). The partition of quality characteristics into these through groups helps to better understand the value-adding component of the university system, as well as a clear and convincing control of quality. However, the majority of existing university ranking schemes does not provide such a systematic presentation of quality characteristics. For instance, the widely cited and debated Maclean's magazine university rankings place 20% of the total ranking solely on the average high school grades of incoming students. While the quality of the raw material is undoubtedly very important for the overall quality of a product, the university did not add any value to these characteristics, i.e. no knowledge and skills were produced by the university in students. Therefore, a university cannot and should not claim credit for knowledge that students received somewhere else. Another shortcoming of such an approach to determining a quality characteristic is a lack of indicators for it. Is the high school GPA the only possible indicator of the quality of incoming students? It seems that the answer is negative.

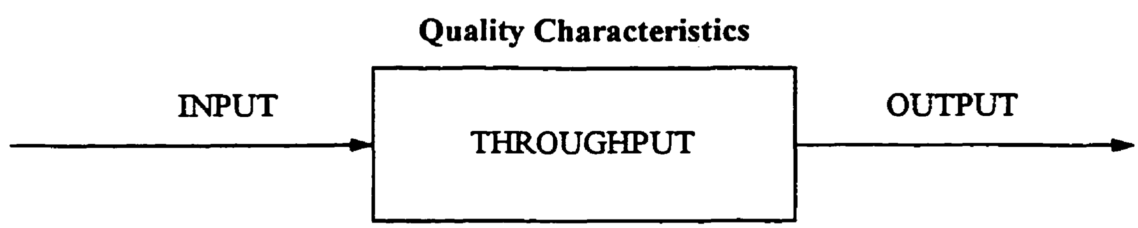


FIGURE 9.9: A System's View of Quality Characteristics

The following were the proposed characteristics.

♦ **Student's education.** As input indicators of the quality of student's education, the quality of incoming students, professors to students ratio, technicians and teaching assistants to students ratio, and resources spent per student are considered. The resources per student indicator are broken into two lower level indicators, namely the amount of operational expenses per student and the amount of available equipment for students. Throughput indicators include the course failure and attrition rates (percentage of students who failed or withdrew from a course), program attrition rates, student awards (with international/national and internal awards as sub-categories), as well as student success in design projects and competitions. Two output measures of quality are suggested: student employability, with the percentage of students employed in a job requiring an engineering degree as one indicator, and starting salary is considered as well. The reputation of graduates, as perceived by industry and graduate schools. The hierarchy of quality characteristics for student's education is presented in Figure 9.10.

● **Courses/Program.** Attractiveness of a course to students, published educational material, such as textbooks and compact disks, laboratory manuals and audio-visuals, as well as course validation and certification by the Canadian Engineering Accreditation Board are suggested as input characteristics. Throughput characteristics are scheduling of the course and effectiveness of the instructor in the classroom. Finally, output measures include teaching awards, course failure rates for a program, initiatives in engineering education (with presentations, journal publications and referee/editorial duties as sub-categories). Course/Program characteristics are presented in Figure 9.11.

♦ **Research.** University research is mainly conducted through research projects sponsored by industry and governmental agencies, as well as through graduate students working on their postgraduate degrees. Therefore, research quality characteristics were separated into two groups: *research productivity*, indicating the quality of sponsored research conducted by the department, and *research training*, signifying the training aspect of research through graduate students. Each of these two groups of characteristics were systematically classified into input, throughput and output subgroups. Input characteristics of research productivity were written and funded research proposals to sponsoring agencies, such as Natural Sciences and Engineering Research Council in Canada (NSERC), written and funded equipment proposals, as well as the number of graduate students and Post-Doctoral Fellows (PDFs) in the department. Working and submitted research papers and reports were considered to be throughput characteristics, while publications (journals and conferences), reputation (indicated by the number of invited/keynote speeches and editorial/referee duties in the department), and innovation (indicated by the number of patents obtained and new laboratories developed) were output quality characteristics. When research training is concerned, the amount of research/equipment grant money brought to the department, selection of graduate students, professors' involvement in research committees and studies, as well as the graduate students to professors ratio were selected as input measures. Three throughput measures were chosen: lead times to graduation and doctoral candidacy, and student evaluation of graduate courses. Finally, employability and publications of graduate students were output quality measures (Figure 9.12).

9.3.2.3 Interviews for Decision Making

The suggested hierarchy of the department's product quality characteristics was subsequently presented to seven faculty members who made their judgments on the relative importance of the proposed characteristics. Separate interviews, with an average length of about 2-2.5 hours were conducted with each professor. At the beginning of every interview, the context of developing a set of quality characteristics within the ISO 9001 quality system project was clarified, followed by an explanation of the Analytic Hierarchy Process procedures. The AHP was facilitated using pre-drafted pairwise comparison matrices (Appendix 7-2), which the interviewees subsequently filled out. Throughout the interviews, suggestions and recommendations for new or improved characteristics were made. These suggestions are presented in section 9.3.4.

9.3.2.4 Quality Control of the Decision Process

Quality control of the decision process was performed using the approach presented in section 9.2. First, each DM's judgments were viewed separately, and moving average/range charts drafted (Appendix 7-3). The consistency indices used for control charts are presented in Table 9.3. As we can observe from the control charts, decision making processes of DMs #1, 2, 6 and 7 appear to be under control. For decision maker #3, the moving range chart is out of control for subgroups #5 and 6, due to the large consistency index for matrix #5 (CI=1.21). This indicates a special cause of variation, because a mistake in the judgment has been made. The DM considered research productivity input to be 5 times a better quality characteristic than throughput, input about as good as output, and obviously made a mistake by entering 5/1 for throughput versus output, instead of 1/5 in the last judgment. If this mistake were corrected, the DM would be perfectly consistent for this matrix with the CI=0.

Matrix #	CI for DM1	CI for DM2	CI for DM3	CI for DM4	CI for DM5	CI for DM6	CI for DM7
1	0	0.1	0	0.45	0	0	0
2	0.02	0	0.05	0	0.11	0.07	0.13
3	0.04	0.07	0.19	0.07	0.09	0.13	0
4	0.02	0	0.13	0	0	0	0.13
5	0.03	0.08	1.21	0.12	0.13	0.12	0
6	0	0	0.05	0.15	0.28	0.1	0.13
7	0	0.21	0.31	0.01	0.04	0.05	0
8	0	0.01	0.13	0.12	0	0	0
9	0.03	0	0.05	0.2	0.03	0.01	0.13
10	0	0.02	0.28	0.16	0.04	0	0.01
11	0.02	0.09	0.37	0.19	0.12	0.04	0
12	0.01	0	0.21	0.13	0.13	0	0
13	0.02	0.05	0.54	0.17	0.04	0.06	0
14	0.06	0.01	0	0.06	0.04	0	0.09
15	0	0.05	0.02	0.1	0.04	0	0

TABLE 9.3: Consistency Indices for Decision Makers

For the DM #4, large CI for the first matrix caused an out-of-control condition for the first subgroup on both the moving average and moving range charts. Research was considered a '4' over courses/programs, a '6' over student's education; however, student's education was considered more important than courses/program by a '5'. In this case, it is not quite clear what the decision maker's judgments indeed were, and therefore repeated judgments for this particular matrix are suggested. Nevertheless, because this matrix addresses the issue of the relative importance of products, rather than quality characteristics of each product, it is not considered relevant for this study.

Finally, subgroup #5 for DM #5 lies on the upper control limit of the moving range control chart. In this case, the DM's compared research and equipment proposals as both weakly better characteristics than the number of graduate students in the department. However, he/she judged that equipment proposals are a better characteristic than research proposals ('5'). Commenting on this decision, the DM suggested that the former two characteristics really depend on the specific research area. For instance, in metallurgical and fluid mechanics research, equipment is absolutely essential, while in industrial engineering it may not be as important. Also, the availability of grants varies from one research area to the other. Hence, the DM judged equipment proposals as a better indicator of the quality of department's research. This judgment seems logical and certainly not random, and therefore should not be changed, i.e. a special cause of variation has not occurred.

After the analysis of each decision maker's process, an Xbar-R control chart for all seven DMs was drafted (Figure 9.10). While the Xbar chart is in control, the point corresponding to the matrix #13 is above the upper control limit on the range chart.

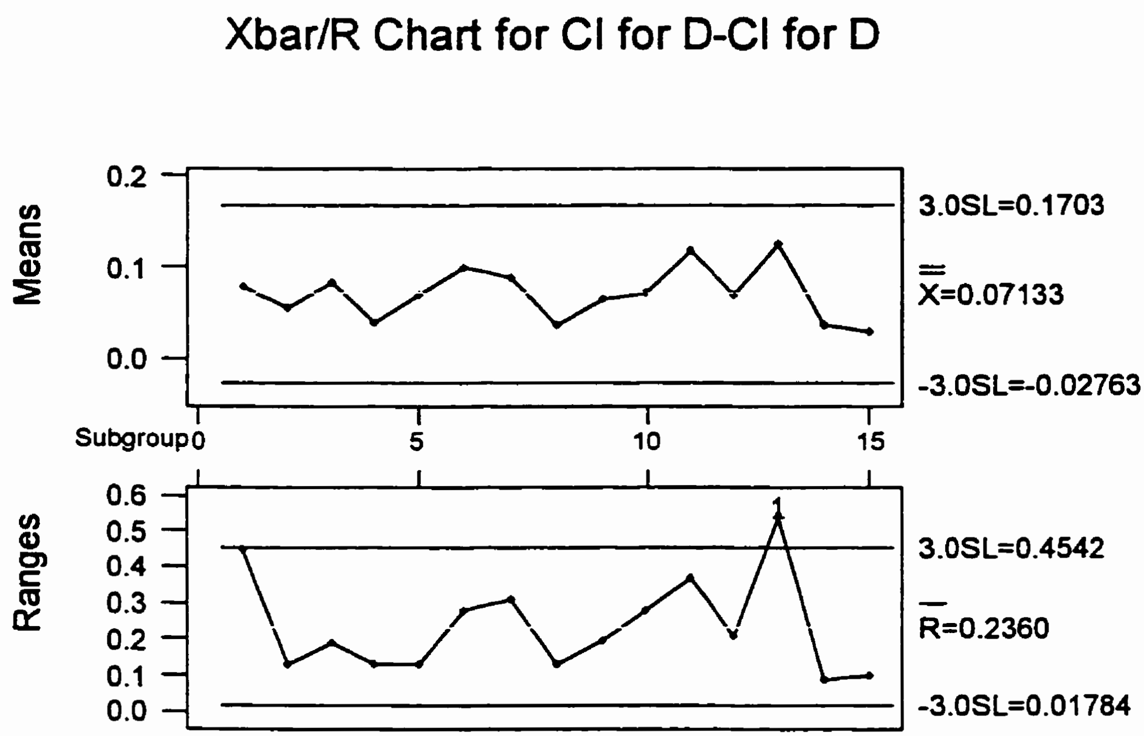


FIGURE 9.10: Xbar-R Control Chart for a Group Decision Making Process

This is caused by a large consistency index for the DM #3 (CI=0.54). Judging the input, throughput and output quality characteristics of student's education, DM #3 considered input a '9' over throughput and output. However, the decision maker also considered that throughput characteristics are much better indicators of quality than output, and selected a '9'. In other words, the DM probably thought that the suggested output characteristics should not even be in the hierarchy. For perfect consistency, the last judgment should have been an '81' instead of '9'. This would, however, exceed the 17-point AHP scale that only goes up to 9. Therefore, this logical decision would be rejected by a standard consistency test and the DM would have been forced to change it. Nevertheless, it was left unchanged in a quality control analysis, because it indicates a problem with the technique itself and not the decision making process. It is also interesting to note that if the obvious mistake in entering the matrix #5 judgment of DM #3 had not been corrected, the quality control approach for AHP consistency checks would have still found it on both Xbar and R control charts.

9.3.3 Results

After the elimination of special causes of variation (mistakes and illogical judgments) from the decision making process, the judgments of the selected seven decision makers were synthesized using the geometric mean. Table 9.4 presents the individual DMs' judgments, as well as the synthesized group judgments for the AHP hierarchy. Subsequently, weights for specific quality characteristics from the hierarchy were generated using Eigen-values of pairwise comparison matrices. For this purpose, the "Expert Choice" (EC) decision analysis software was used. The resulting weights for quality characteristics of student's education, courses/programs and research are presented in Figures 9.11, 9.12 and 9.13 respectively. These weights were calculated from thirty-one pairwise comparison matrices, comparing quality characteristics of the same level of hierarchy. For instance, in the matrix that compared publications, reputation and innovation as measures of quality of research output, publications were weighed at 0.385, reputation at 0.302, and innovation at 0.313 (Figure 9.13). The total of weights for the same level of characteristics must always be equal to one (0.385+0.302+0.313 = 1). The absolute weights for quality characteristics, given in percentage points, are provided in Table 9.5. These weights were obtained by multiplying the relative weight of a quality characteristics by the weights obtained for the corresponding group of characteristics. For example, the absolute weight for 'journal publications' was obtained by multiplying its

JUDGMENTS	DM 1	DM 2	DM 3	DM 4	DM 5	DM 6	DM 7	G. Mean
Research/Courses	1	0.33	1	4	1	7	1	1.37587
Research/St. Education	1	0.25	1	6	1	1	1	1.05963
Courses/St. Education	1	0.2	1	0.2	1	0.14	1	0.47815
Res. Training/Res. Productivity	4	0.5	1	1		3	0.33	1.12246
RT: Input/Thruput	2	4	2	1	5	9	3	2.99468
RT: Input/Output	1	1	2	1	0.2	4	0.33	0.91411
RT: Thruput/Output	0.33	0.25	0.5	1	0.11	0.2	0.33	0.31513
Grant Money/Equipment Money	2	3	1	1	0.2	4	1	1.25118
Grant Money/StudentProf Ratio	2	3	1	4	0.33	0.25	1	1.10409
Grant Money/Committees	6	4	3	7	7	3	7	4.96225
Grant Money/Student Selection	1	0.33	1	7	0.33	1	1	0.96473
Equipment Money/StudProf Ratio	3	1	0.33	3	3	0.2	1	1.0876
Equipment Money/Committees	5	3	0.33	7	9	1	7	3.00351
Equipment Money/Student Selection	1	0.25	0.33	6	1	0.33	1	0.77417
StudProf Ratio/Committees	4	4	0.33	4	5	5	7	3.23817
StudProf Ratio/Student Selection	1	0.33	1	4	0.2	0.33	1	0.70768
Committees/Student Selection	0.17	0.25	0.33	0.25	0.11	0.2	0.14	0.19577
Time Graduation/Time Candidacy	1	1	1	1	5	1	5	1.58382
Time Graduation/Student Evaluation	0.5	0.33	3	0.13	5	1	3	0.99082
Time Candidacy/Student Evaluation	0.33	0.33	9	0.13	1	1	0.2	0.59038
Employability/Publications	0.33	4	5	0.25	5	1	3	1.58382
RP: Input/Thruput	5	3	5	4	5	5	3	4.18543
RP: Input/Output	0.5	0.25	1	0.2	0.33	0.25	1	0.41397
RP: Thruput/Output	0.17	0.2	0.2	0.14	0.2	0.14	0.33	0.1904
Res. Proposals/Equipment Proposals	2	4	0.5	4	0.2	4	3	1.68396
Res. Proposals/Number of Students	2	4	1	5	3	0.5	0.2	1.42616
Equipment Proposals/Number of Students	1	1	1	4	3	0.33	0.2	0.96863
Res. Proposals Written/Res. Proposals Funded	0.25	0.25	1	0.13	0.11	0.25	0.11	0.21894
Eq. Proposals Written/Eq. Proposals Funded	0.25	0.25	1	0.13	0.11	0.25	0.11	0.21894
Working Papers/Research Reports	3	0.25	9	5	1	2	5	2.29711
Publications/Reputation	1	0.33	5	5	0.33	4	0.33	1.20568
Publications/Innovation	2	0.33	9	1	0.2	4	1	1.25118
Reputation/Innovation	2	0.25	3	0.25	0.33	2	3	0.95974
Journals/Conferences	4	3	9	9	5	5	4	5.1585
Keynote Presentations/Editorial Duties	1	3	5	5	3	1	3	2.53622
Patents/New labs	1	5	9	1	0.2	0.25	3	1.31363
Courses: Input/Thruput	1	1	3	0.2	1	5	3	1.36874
Courses: Input/Output	1	0.25	1	0.14	0.33	1	1	0.53101
Courses: Thruput/Output	1	0.33	1	0.25	0.33	0.2	0.33	0.40706
Attractiveness/Educational Material	0.33	4	1	0.2	3	4	3	1.38142
Attractiveness/Certification	0.2	4	0.5	0.11	0.2	1	0.2	0.40469
Educational Material/Certification	1	1	1	0.14	0.11	0.33	0.2	0.37578
Textbooks/Lab Manuals	1	5	5	5	3	1	5	2.93475

TABLE 9.4: Synthesized Judgments

JUDGMENTS	DM 1	DM 2	DM 3	DM 4	DM 5	DM 6	DM 7	G. Mean
Textbooks/Audio-Visuals	3	4	5	6	5	1	7	3.85272
Lab Manuals/Audio-Visuals	3	0.5	5	4	3	1	2	2.09982
Scheduling/Classroom Effectiveness	0.33	3	1	0.14	5	0.2	0.33	0.64731
Teaching Awards/Failure Rate	5	0.25	5	0.2	0.33	1	2	0.97429
Teaching Awards/EE Initiatives	2	2	5	1	3	0.2	4	1.73851
Teaching Awards/Course Evaluations	1	0.2	5	0.14	1	0.13	1	0.56268
Teaching Awards/Conformance	1	0.2	5	0.2	0.14	1	2	0.66439
Failure Rate/EE Initiatives	0.33	4	1	0.25	3	0.2	2	0.87731
Failure Rate/Course Evaluations	0.25	1	0.2	0.17	0.33	0.13	0.5	0.29027
Failure Rate/Conformance	0.14	4	5	0.2	0.2	1	1	0.73355
EE Initiatives/Course Evaluations	0.5	0.2	5	0.17	0.33	0.2	0.25	0.39067
EE Initiatives/Conformance	1	0.25	1	0.2	0.14	5	0.5	0.56268
Course Evaluations/Conformance	1	4	1	1	0.14	8	2	1.37182
EE Publications/EE Presentations	3	1	4	4	5	4	1	2.6671
EE Publications/EE Referee Duties	1	1	4	4	5	4	2	2.517
EE Presentations/EE Referee Duties	0.25	1	4	0.33	3	1	2	1.10409
Students' Evaluation/Peer Evaluation	3	2	9	3	0.2	4	1	2.00355
St. Education: Input/Thruput	1	3	9	4	0.33	7	0.33	1.8832
St. Education: Input/Output	0.33	3	9	0.13	0.2	5	0.33	0.86926
St. Education: Thruput/Output	0.5	2	9	0.11	0.33	0.33	1	0.7306
Student Selection/StudProf Ratio	3	5	1	0.2	3	1	0.33	1.16993
Student Selection/StudTA Ratio	5	5	1	0.33	3	4	0.25	1.58382
Student Selection/Resources per Student	2	1	1	0.2	5	1	0.25	0.90572
StudProf Ratio/StudTA Ratio	3	1	1	3	3	4	3	2.28375
StudProf Ratio/Resources per Student	2	0.33	1	4	3	1	3	1.57461
StudTA Ratio/Resources per Student	1	0.25	1	1	1	0.25	1	0.67295
Expenses/Equipment	0.5	0.2	0.33	0.2	0.2	1	0.33	0.33198
Failures/Program Attrition	1	3	1	4	3	1	1	1.66851
Failures/Student Awards	1	0.33	9	1	5	1	2	1.62561
Failures/Student Success	1	2	9	1	5	1	1	1.90186
Program Attrition/Student Awards	1	0.2	9	0.33	5	1	2	1.29171
Program Attrition/Student Success	1	2	9	0.33	3	1	1	1.51121
Student Awards/Student Success	1	5	0.5	4	1	1	0.5	1.2585
National/International Awards	7	0.33	1	7	0.33	4	7	2.05056
Design Projects/Competitions	1	3	0.5	0.25	5	1	0.25	0.89741
Employability/Reputation	0.25	0.2	1	7	5	0.25	1	0.88861
Percentage Employed/Starting Salary	3	4	0.5	7	3	3	3	2.73132
Graduate Schools/Professionals	1	0.25	1	0.2	0.33	1	1	0.55716

TABLE 9.4: Synthesized Judgments (Continued)

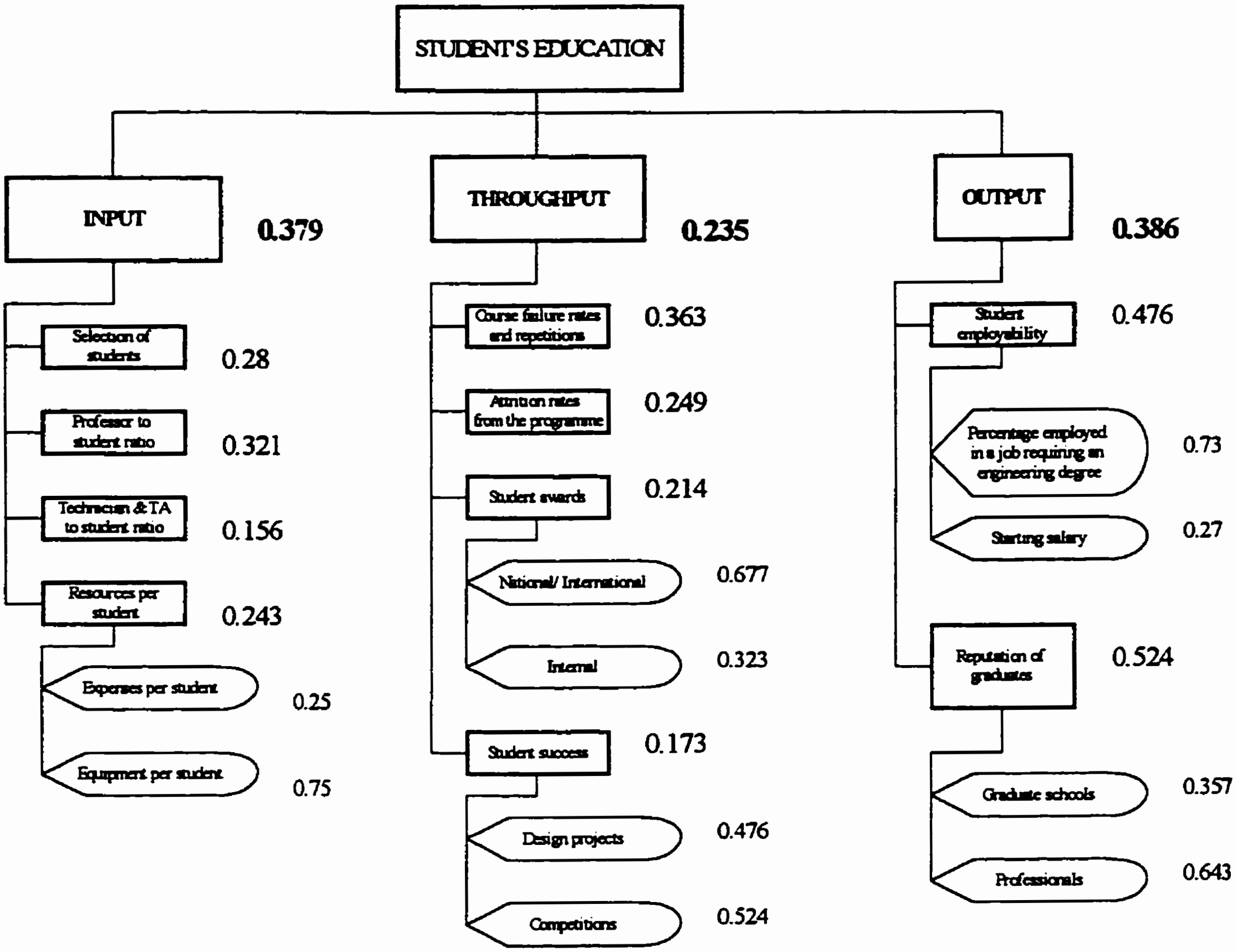


FIGURE 9.11: AHP Hierarchy of Student's Education Quality Characteristics

relative weight of 0.839 with the weight for 'publications' (0.385), weight for 'research productivity output' (0.599) and the weight for research productivity (0.476). The product of these four weights equals 0.092 or 9.2%. As a note, the sum of absolute weights of all quality characteristics for a particular product must equal 100%.

As we can observe from Table 9.5, faculty members weighed the following quality characteristics as the most important for the department:

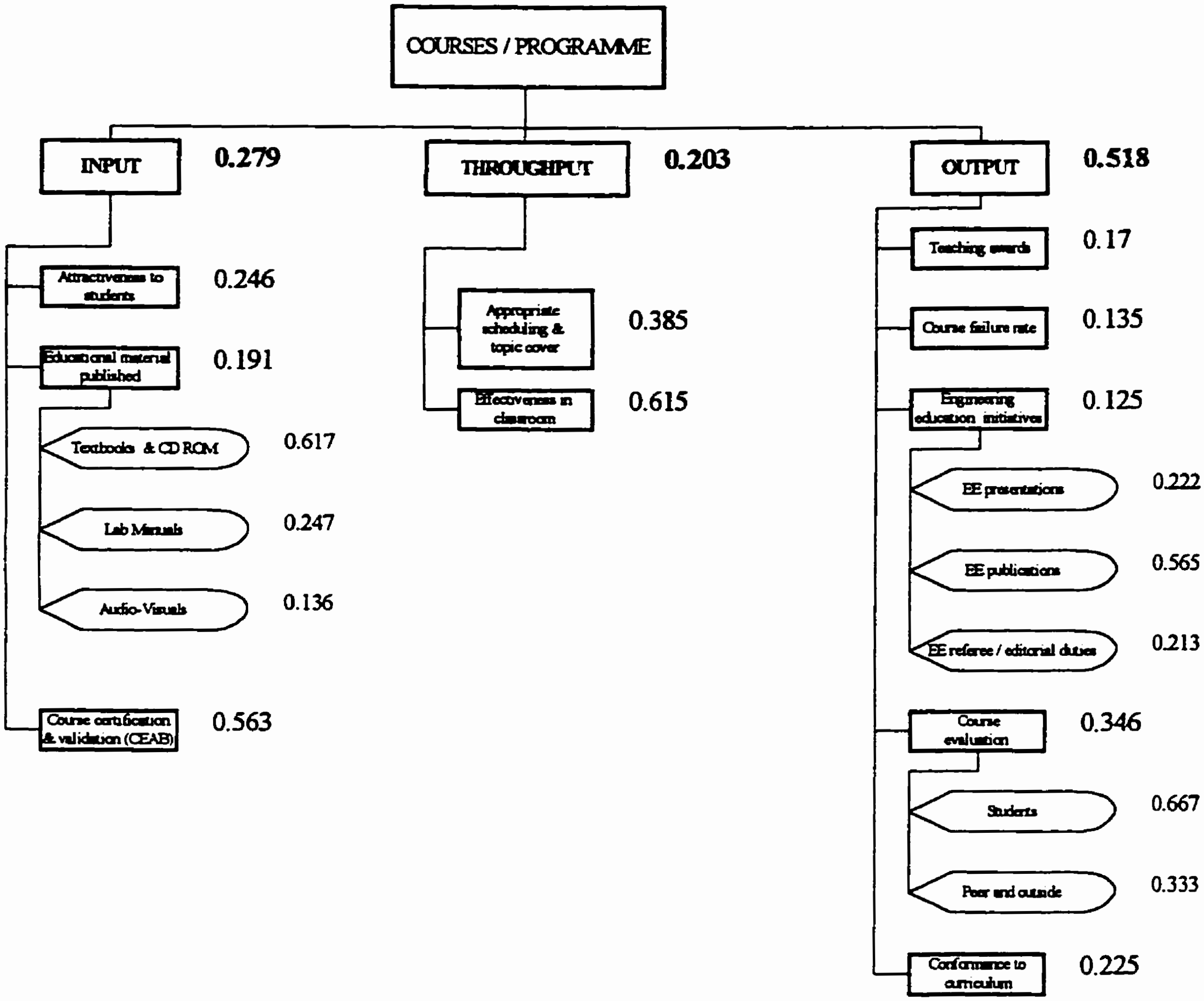


FIGURE 9.12: AHP Hierarchy of Course/Program Quality Characteristics

♦ **Student's education:** Percentage of students employed in a job requiring an engineering degree, reputation of graduates as perceived by employers from industry, professor to student ratio, selection of incoming undergraduate students, as well as course failure rates.

♦ **Courses/program:** Effectiveness in classroom, student course evaluations, conformance of courses to the prescribed curriculum, teaching awards and appropriate scheduling/topic cover.

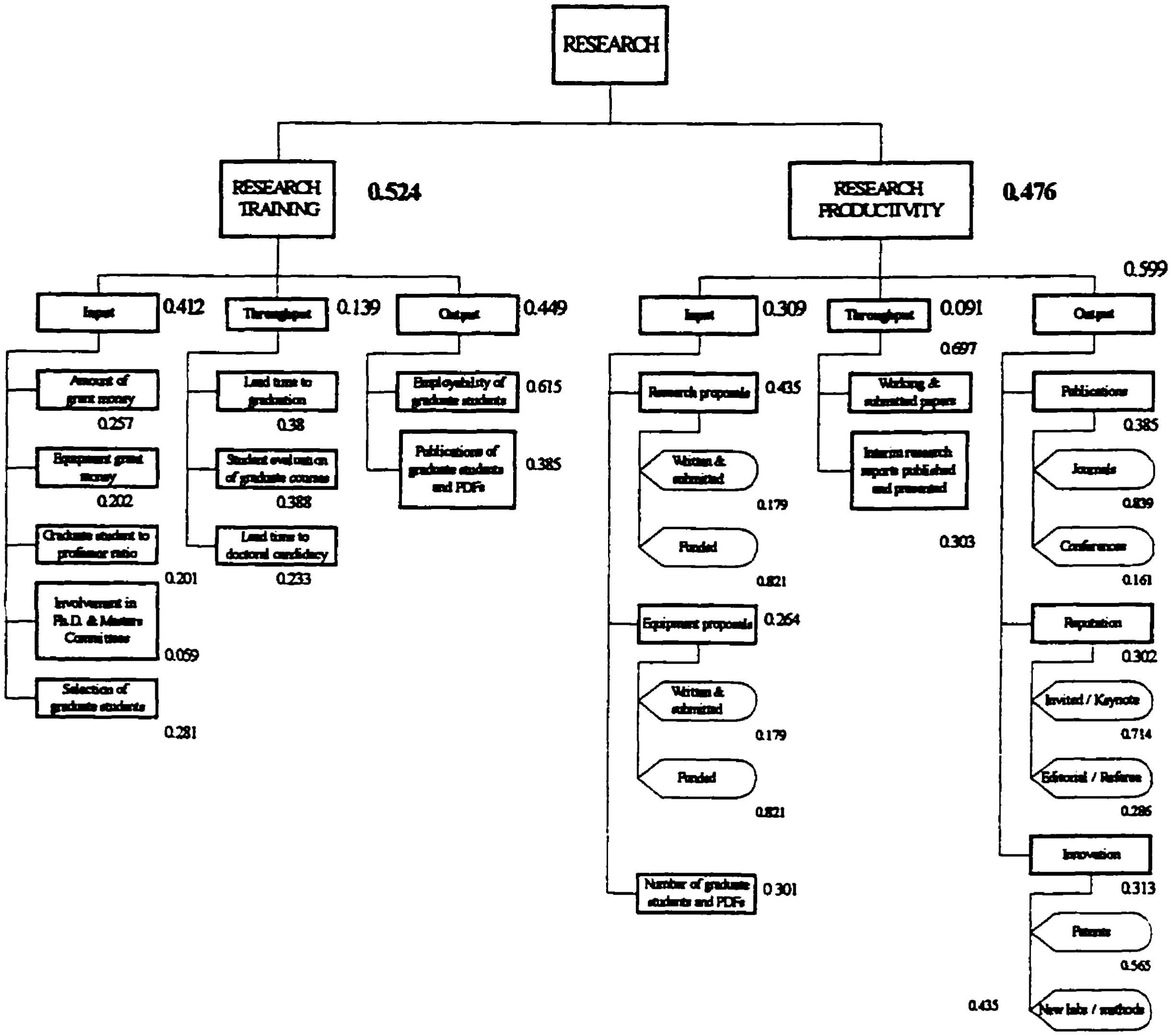


FIGURE 9.13: AHP Hierarchy of Research Quality Characteristics

♦ **Research:** Employability of graduate students, publications in journals by the faculty members of the department, publications of graduate students in the department, invited/keynote speeches, as well as the selection of incoming graduate students.

It is evident that the employability of undergraduate and graduate students is perceived as the most important quality characteristic of the department's products. Together with the reputation gained from industry as another crucial characteristic, these perceptions of faculty members validate the notion that the industry and society are

RESEARCH		COURSES / PROGRAM		STUDENT'S EDUCATION	
Employability of students	14.5	Classroom effectiveness	12.5	Percentage employed	13.4
Journal publications	9.2	Student course evaluation	12	Reputation from professionals	13
Publications of students	9.1	Conformance to curriculum	11.7	Professor to student ratio	12.2
Invited/keynote speeches	6.2	Teaching awards	8.8	Selection of students	10.6
Selection of grad. students	6	Scheduling & topic cover	7.8	Course failure rates/repetitions	8.5
Research grant money	5.5	Course failure rate	7	Reputation from graduate schools	7.2
Funded research proposals	5.3	Attractiveness to students	6.9	Equipment per student	6.9
Patents	5	Peer & outside evaluation	6	Technician & TA to student ratio	5.9
Number of graduate students	4.4	EE journal publications	3.7	Program attrition rates	5.9
Equipment grant money	4.4	Textbooks/CD ROMs	3.3	Starting salary	5
Student to prof. ratio	4.3	EE presentations	1.4	National student awards	3.4
New laboratories/methods	3.9	EE referee/editorial duties	1.4	Expenses per student	2.3
Funded equipment proposals	3.2	Laboratory manuals	1.2	Design projects success	2.1
Working papers	3	Audio-Visuals	0.7	Success in competitions	2.1
Student evaluation of courses	2.8			Internal student awards	1.6
Lead time to graduate	2.8				
Editorial/referee duties	2.5				
Conference publications	1.8				
Lead time to candidacy	1.7				
Research reports	1.3				
Involvement in committees	1.3				
Written research proposals	1.1				
Written equipment proposals	0.7				

TABLE 9.5: Absolute Weights for Quality Characteristics

primary customers of the university, specifying product requirements. Another premise of this thesis, namely, that courses and programs represent the technology to create the other two primary products: student's education and research (new knowledge), seems to be validated through the study, as well. The professors perceive that the primary products of the department are student's education (weight of 0.401) and research (weight of 0.373), almost doubling the importance of courses/programs (weight of 0.226).

Using these results and incorporating interviewees' comments and suggestions, we can propose a hierarchy of quality characteristics that the Department of Mechanical and Industrial Engineering could apply for controlling and improving quality. The proposed hierarchy is presented in the next section.

9.3.4 Suggested Quality Characteristics

While conducting interviews for AHP pairwise comparisons, comments and suggestions about quality characteristics and the hierarchy itself were provided by the faculty members. The following summarizes a list of their suggestions:

♦ As another indicator of the reputation of the department as a research output quality characteristics, the number of visiting professors in the department can be used.

♦ As an indicator of the quality of throughput in student's education, assessment of quality from the viewpoint of employers of co-operative students can be added.

♦ The citation index is another suggestion for an indicator of research output - reputation quality characteristic

♦ The amount of time that a professor spends with a graduate student can be an effective measure of the research training throughput

♦ Separation of negative and positive indicators (such as course failure rates and students awards) can be useful.

♦ Different courses have different priorities and quality indicators should be applicable to all. For example, technicians and teaching assistant to student ratio is very important for laboratory courses, however, some courses may not even require technicians or TAs.

♦ All quality indicators have an optimum value which is not necessarily equal to the maximum value. For instance, grant money as an indicator has an optimum value for each professor, and more money is not necessarily better. This is also applicable to other characteristics, such as the number of research and equipment proposals, number of graduate students and PDFs, number of publications, professor to student and technician/TA to student ratio, money per student, etc.

♦ The indicator of the published educational material is important in for the long-term, and not for any particular year.

♦ Classroom effectiveness may be considered as an input characteristic, rather than throughput, depending on the specific course in question. Another professor has suggested that it is a throughput measure of student's education.

♦ The indicators can be used at a departmental level, and some depend on a specific course or area of research. For instance, it is easier to raise money in some areas than in other ones.

● Courses/programs are extremely important as vehicles with which we gain outputs, rather that an output itself.

♦ Teaching awards are connected to a specific professor, rather than a course, and therefore should be a measure of a student's education.

♦ If we could measure the dedication and skills of a professor in teaching, it would be an excellent measure of quality.

Using these comments and the results of pairwise comparisons, a hierarchy of quality characteristics which a mechanical and industrial engineering department could use in controlling and improving quality is now provided. Figures 9.14, 9.15 and 9.16 present the proposed hierarchy for student's education, courses/program, and research, respectively. Each quality characteristic is followed by a proposed corresponding weight.

In terms of student's education, measures of the quality of incoming students, as well as available human, material and information resources are deemed very important as input quality characteristics. Course/program failure and attrition rates, paired with student awards and employers assessment of students are good indicators of the throughput quality, while employability and reputation of graduates are two crucial output quality characteristics. Combined, the latter two are suggested to carry 40% of the overall estimate of the quality of education provided by the department (Figure 9.14).

Courses and programs are applied by the department as a technology to create knowledge and skills. However, they can be marketed and sold as products in the near future, using the means of distance education and refreshment courses for engineers. When courses are viewed as a product, their attractiveness to students, educational material available, and course validation by the Canadian Engineering Accreditation Board are all important input quality characteristics. The quality of the delivery of courses can be measured by the effectiveness of professors in the classroom, appropriate scheduling and topic coverage, teaching awards and failure rates. After the course has been delivered, useful indicators of quality are student and peer course evaluations, initiatives in advancement of engineering education, and conformance of the course to planned arrangements, given in the course outline and/or General Calendar of the University.

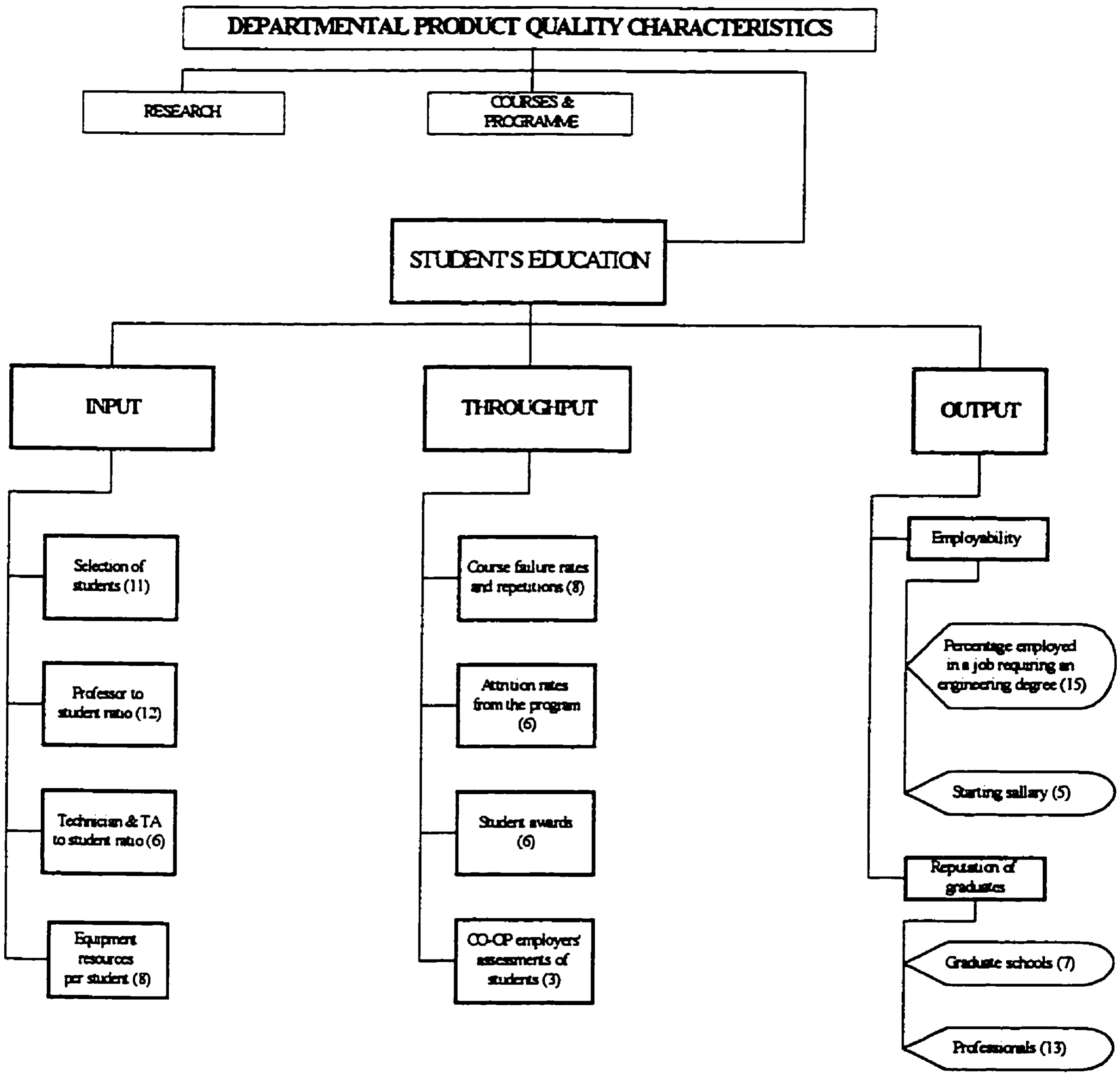


FIGURE 9.14: Suggested Student's Education Quality Characteristics (Absolute Weights)

Finally, the creation of new knowledge through research is a crucial product of a university. As the literature survey has shown, judging the quality of research can often be subjective, and sometimes quite controversial. However, quality assurance of research activities must be executed, and adequate confidence that the requirements for quality are

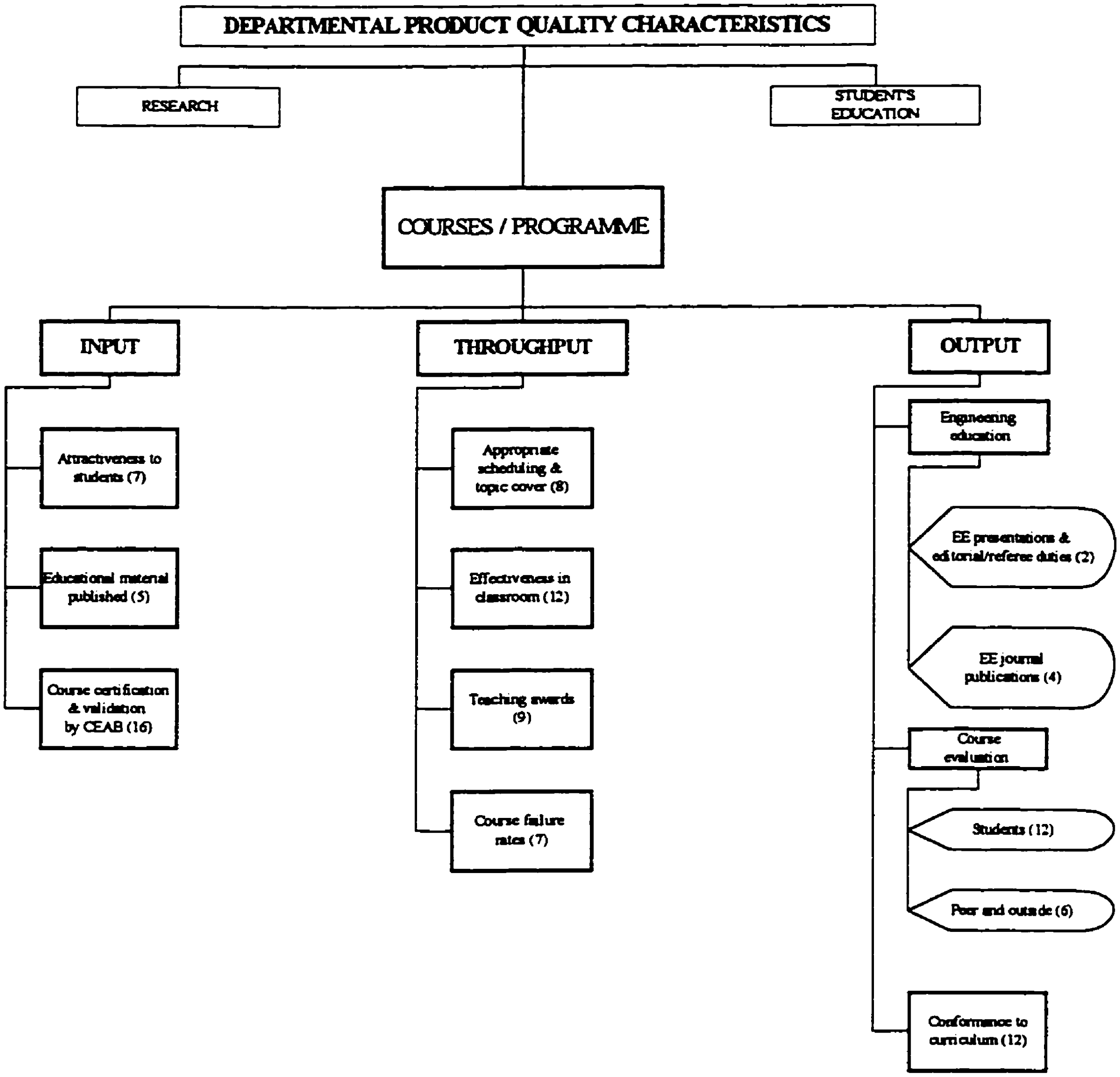


FIGURE 9.15: Suggested Course/Program Quality Characteristics (Absolute Weights)

met should be provided. Two components of research requiring quality assurance in an academic environment are:

- research training of graduate students

◆ sponsored research

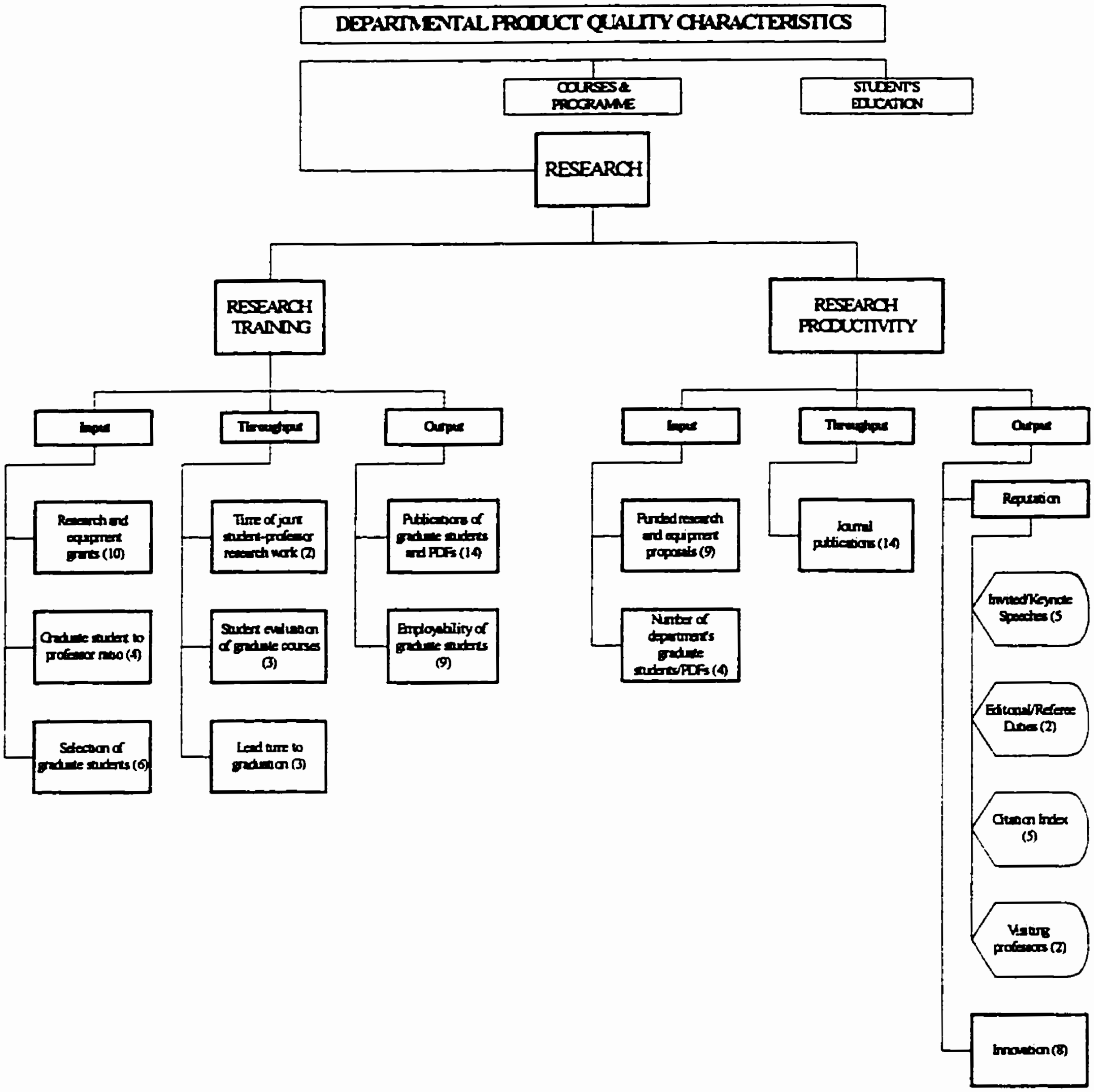


FIGURE 9.16: Suggested Research Quality Characteristics (Absolute Weights)

As for undergraduate student's education, important input quality characteristics of research training are the incoming quality of graduate students, and the availability of human and material resources. In graduate studies, the availability of resources implies financial support from research grants, as well. Throughput quality indicators are students' evaluation of graduate courses, professor's time spent with the individual student, and the lead time to graduation. Employability of graduate students, paired with their publications in scientific and professional journals account for 23% of the weight for the overall quality of research (Figure 9.16). In terms of sponsored research, the number of funded research and equipment proposals, and the number of graduate students in the department are suggested as input measures, while journal publications represent an important throughput characteristic. The quality of output can be measured with reputational characteristics, such as invited and keynote speeches of professors in national and international conferences, editorial and referee duties for journals, the citation index in journals, and the number of visiting professors in the department. Innovation through new methods and laboratories developed, together with patented works can be a good indication of output quality, as well.

CHAPTER TEN

CONCLUSIONS

This chapter discusses the main contributions of the work presented in the thesis, followed by a statement of the suggestions for further research.

10.1 CONTRIBUTIONS OF THE RESEARCH

In chapter 3, a model of a quality system has been developed. The model allows for:

- integration of quality assurance and quality management systems, including total quality management and quality improvement
- integration with environmental management and workplace health and safety systems
- better understanding of quality assurance concepts using control engineering theories
- documentation and implementation based on system engineering

This model emphasizes the importance of the systems view in quality assurance, engineering and management. It provides a framework for exposing the structure of complex management systems, and understanding various links and relationships among different constituents of the system. Also in Chapter 3, an improved model of the ISO 9001 quality system has been provided, considering the quality system structure along with the composition of quality system elements.

In chapter 4, a fully operational model of the university system has been developed, considering the shortfalls of the existing literature in analyzing:

- customers, suppliers and products
- research as an integral part of the university's products (services)
- links between specific customers and products
- product quality characteristics
- interrelationship of teaching, learning and research processes
- application of the ISO 9001 quality system in the university environment

This model pioneered the conceptualization of a university as a production organization.

In chapter 5, an interpretation of the ISO 9001 standard for a university was provided, incorporating:

- the system approach to quality assurance
- model of the university education system developed
- examples of the impact of the quality system on the university

This interpretation allows for the implementation of all twenty elements of the ISO 9001 quality system at the university, which was not possible using the approaches from existing literature. It also provides a complete and systematic approach of involving all three products of the university under one quality system, and the first account of research as a product to which ISO 9001 could be applied at the university. Also in the chapter, the two current engineering education accreditation schemes in Canada and the United States have been compared with the ISO 9001 quality system.

In chapter 6, a procedure for documentation and implementation of the ISO 9001 quality system in an engineering department, focusing on process control, internal quality audits and statistical techniques has been developed, and examples of documents provided. The procedure can be used by any university-level faculty or department with the objective of identifying major quality problems, as well as developing a meaningful quality system to address these problems and provide continuous quality improvement.

Chapter 7 introduced the idea of creating zero-defect products as an objective of the university-based quality system. The idea provides the possibility for a multitude of further research projects in a university environment. Also in Chapter 7, a case study of translating customer requirements into course specifications and a quality control plan has been provided.

In chapter 8, a statistical process control model for monitoring, control and improvement of the teaching process and learning outcomes has been developed. The model has considered lectures, tutorials and laboratory experiments as the most common constituents of an engineering undergraduate course. Some of the benefits of this approach include:

- information on the incoming variation in student 'baseline' knowledge is provided

• information on how much and how well the students have learned the material is provided

• 'before' and 'after' knowledge can be compared to roughly estimate the value-added outcome

• effects such as when a student knew the answer before but not after can be examined

• students are focused on the most important issues in a lecture

Using this approach, universities are able to make the claim for exceptional student performance and/or disprove the claims that their instructional systems are the cause of poor student performance. A case study which was presented in the chapter has illustrated a remarkable reduction of critical students' errors in a mechanical engineering laboratory. For instance, the most common error has been reduced from 60% to virtually 0% of student's reports, approaching the zero-defect goal.

In chapter 9, a set of quality characteristics of university's products using a modified Analytic Hierarchy Process (AHP) has been demonstrated. First, the paradoxes which may occur with the standard AHP procedure have been eliminated using a completely new approach to determining consistency of decision makers. Subsequently, this approach has been applied to develop a set of product quality characteristics for the department of mechanical and industrial engineering at a Canadian university. Hierarchically presented quality characteristics are used to measure, control and improve quality of teaching, learning and research.

10.2 SUGGESTIONS FOR FURTHER RESEARCH

The following are suggestions for further research. In terms of the systems approach to quality assurance, the impact of the presented model on the integration of different management and assurance systems should be researched in more detail. Among others, there is a definite need for research in the integration of quality and environmental management systems; quality, environmental, health, safety and financial audits systems; as well as the integration and harmonization of quality and ergonomics. Some of the suggested research has already been initiated (for example, see Karapetrovic and Willborn, 1998B, C and D). Application of system dynamics in quality assurance is another possible area of study.

Regarding the implementation of existing quality assurance schemes in a university environment, the fact that only a few universities world-wide are registered to ISO 9001 and/or ISO 9002 speaks for itself. The time when ISO 9000 and/or ISO 14000 registration becomes a requirement for all state-supported universities may not be too far away. In Europe, several governments have already pressed the issue, including Sweden, the United Kingdom, Denmark and France. With the ever-expanding European Union's regulations, European universities may face the same situation as their manufacturing counterparts. Therefore, the following areas of research are suggested. Methods for identifying the specific needs of the university's surrounding community or it's market, in terms of what graduates should emphasize their studies in, can be researched in more detail. Universities should also identify how they can best develop their programs and curriculum and re-size, not downsize their services in order to meet specific customer requirements. Defining what the "zero-defect" goal for one particular university means could be researched using surveys of administrators, faculty, staff and students. The applicability of different techniques in meeting the "zero-defect" goal, such as Quality Function Deployment, Statistical Process Control and Design of Experiments, for instance, can also be examined. Another project in facilitating this goal is to develop a self-evaluation scheme allowing the university to measure its progress toward zero defects. It is also possible to develop a meaningful way of making this strategy visible to the general public, the students and academic community.

For such quality assurance, the development of a ISO 9000 quality systems, as well as ISO 14000 environmental management systems in higher education should be researched. There is also a need to further integrate health, safety, ergonomic, financial and other management systems into a harmonized business system. Supporting technologies for such management systems, such as quality and environmental auditing for improved performance can be harmonized and integrated, as well. Difficulties in the integration, harmonization should be researched in much more detail, since there are legitimate concerns of many interested parties.

Since it has been proven that ISO 9000 quality systems provide a sound basis for the implementation of Total Quality Management, the integration of ISO 9000 and TQM techniques can also be addressed in further research.

REFERENCES:

- ABET, 1996., *Criteria for Accrediting Programs in Engineering*, Accreditation Board for Engineering and Technology (from the World Wide Web at http://www.abet.ba.md.us)

- ABET, 1997A, *ABET Vision*, Accreditation Board for Engineering and Technology (from the World Wide Web at http://www.abet.ba.md.us)

- ABET, 1997B, *Engineering Criteria 2000*, Accreditation Board for Engineering and Technology (from the World Wide Web at http://www.abet.ba.md.us)

- ABET, 1997C, *Program Criteria for Mechanical and Similarly Named Engineering Programs*, provided by the American Society of Mechanical Engineers (ASME) at http://www.asme.org/educate/abetcrit.html

- Aczel, J, and Saaty, T.L., 1983., "Procedures for Synthesizing Ratio Judgments," *Journal of Mathematical Psychology*, Vol. 27, pp. 93-102.

- Adams, H.W., Haker, W., 1996., 'Generic Management System", *Qualität und Zuverlässigkeit*, Vol. 41, No. 7, pp. 776-780

- AFNOR, 1993., *Requests for Training*, French Standard No. X 50-756, l'Association Francaise de Normalisation, Paris la Defense, France

- Albayrakoglu, M.M., 1996., 'Justification of New Manufacturing Technology: A Strategic Approach Using the Analytical Hierarchy Process", Production and Inventory Management Journal, Vol. 37, No. 1, pp. 71-76

- Alekseyev, O.V., 1994., 'The New Legislation on Education and a National Policy for Improving the Quality of the Education of Engineers in Russia", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 313-319

- Alexander, F., 1996., 'ISO 14001: What Does It Mean for IE's ?", *IIE Solutions*, January, p. 14-18

- Angelo, T.A., Cross, K.P., 1993., *Classroom Assessment Techniques: A Handbook for College Teachers*, Jossey-Bass Publishers, San Francisco

- Arcaro Jerome, 1995A, *Quality in Education: An Implementation Handbook*, St. Lucie Press, Delray Beach, Florida, p. 135

- Arcaro Jerome, 1995B, *The Baldridge Award for Education*, St. Lucie Press, Delray Beach, Florida

- Arcaro Janice, 1995., *Creating Quality in the Classroom,* St. Lucie Press, Delray Beach, Florida

- Armstrong, S.J., Sperry, T., 1994., "The Ombudsman: Business School Prestige-Research Vs. Teaching", *Interfaces,* Vol. 24, No. 2, p. 13-22

- AHEC, 1995., *Achieving Quality,* Australian Higher Education Council, Australian Government Printing, Canberra (referenced in Maling, 1995)

- Bailey, D., Bennett, J.V., 1996., "The Realistic Model of Higher Education", *Quality Progress,* Vol. 29, No. 11, p. 77-79

- Bakos, J.D., 1996., "Direct Outcome Based Assessment Measures", Journal of Professional Issues in Engineering Education and Practice, Vol. 122, No. 1, p. 31-34

- Bard, J.F., 1992., "A Comparison of the Analytic Hierarchy Process With Multiatribute Utility Theory: A Case Study", *IIE Transactions,* Vol. 24, No. 5, pp. 111-121

- Beechner, A.B., Koch, J.E., 1997., "Integrating ISO 9001 and ISO 14001", *Quality Progress,* Vol. 30, No. 2, p. 33-38

- Besterfield, D.H., 1994., *Quality Control,* Prentice Hall, New York

- Bilanski, W.K., 1996., "Canadian Engineering Accreditation in the 21st Century - A Critique", *Proceedings of the Tenth Canadian Conference on Engineering Accreditation,* Kingston, Ontario, p. 229-236

- Black, J.T., 1996., "Who's the Customer", *Journal of Manufacturing Systems,* Vol. 15, No. 1, editorial

- Bloom. B.S., Hastings, J.T., Madaus, G.F., 1971., *Handbook of Formative and Summative Evaluation of Student Learning,* McGraw Hill, New York, p. 271-273

- Boardman, T.J., Boardman, E.C., 1990., "Don't Touch That Funnel", *Quality Progress,* Vol. 23, No. 12, p. 65-69

- Bokhoven, J.D., Herrmann, J., Schlichter, C., 1996., "Alles in Einem", *Qualitat und Zuverlassigkeit,* Vol. 41, No. 7, p. 788-791

- BSI, 1994., *BS 5750: Guidance Notes for Application to Education and Training,* British Standards Institute, Milton Keynes, U.K.

- Burnet, G., Greisch, J.R., 1993., "The Ten Most Outstanding Engineering Education and Engineering Technology Achievements of the Past Century", *Journal of Engineering Education,* Vol. 83, No. 1, p. 3-5

- Caillibot, P., 1997., 'Changes in the ISO 9000 series", *Quality Progress*, Vol. 30, No. 2, pp. 19

- Campbell, I., 1996., 'Qualitatsnormen 2000", *Qualitat und Zuverlassigkeit,* Vol 41, No. 10, p. 1125-1126

- Castillo, E., Mackin, P., Montgomery, D.C., 1996., 'Multiple-Criteria Optimal Design of Xbar Control Charts", *IIE Transactions*, Vol. 28, p. 467-474

- Castillo, E., Montgomery, D.C., 1996., "A General Model for the Optimal Economic Design of Xbar Charts Used to Control Short or Long Run Processes", *IIE Transactions*, Vol. 28, p. 193-201

- Catania, P., 1995., 'Systems Engineering Education, Research and National Policies", *Australasian Journal of Engineering Education*, Vol. 6, No. 1

- CEAB, 1992., *CEAB Questionnaire for 1992.*, Canadian Engineering Accreditation Board

- CEAB, 1995., *CEAB Annual Report*, Canadian Engineering Accreditation Board (Abstracted in Bilanski, 1996)

- Cengel, Y.A., Boles, M.A., 1994., *Thermodynamics: An Engineering Approach*, McGraw Hill, New York, p. xx

- CEQB, 1992., *Examination Syllabus: 1992 Edition*, Canadian Engineering Qualifications Board, Ottawa, Ontario

- CCPE, 1992., *Admission to the Practice of Engineering in Canada*, Canadian Council of Professional Engineers, Ottawa, Ontario

- Chin, Y.Y., Chye, T.T., 1994., 'Quality Control in the Educational Service- A Singapore Experience", *Asia-Pacific Journal of Quality Management*, Vol. 6, No. ?, p. 36-43

- Clarkin, R., Dow, K., 1997., 'ISO 9000 documentation: on-line or on-paper", *Quality Progress*, Vol. 30, No. 5, pp. 168

- Cleland, D.I., King, W.R., 1983., *System Analysis and Project Management*, McGraw-Hill, New York

- Cloutier, M.G., Richards, J.D., 1994., 'Examining Customer Satisfaction in a Big School", *Quality Progress*, Vol. 27, No. 9, p. 117-119

- Coate, L.E., 1992, *Total Quality Management at Oregon State University*, Corvallis: Oregon State University, p.14 (abstracted in Lewis and Smith, 1994)

- Crosby, P., 1997, 'Keeping Neat Records of Noncompliance Is Not Quality", Quality Progress, Vol. 30, No. 5, p. 79-80

- Dalton, W.K., 1995., "Assessing Student Learning: It Can Be More Than a Survey", *Proceedings of the 1995 Annual Conference of the American Society for Engineering Education* (http://www.purdue.edu/fre/asee/fie95/2c1/2c14.htm)

- Doherty, G.D., 1995. A, 'BS 5750 parts 1 and 2/ISO 9000 (series); 1987 and Education: Do they Fit and Is It Worth It ?", *Quality Assurance in Education*, Vol. 3, No. 3, p. 3-9

- Doherty, G.D., 1995. B, 'Quality Assurance in Education: The Coat of Many Colors", *Proceedings of the IEE Science, Education and Technology Division Colloquim on Quality in Higher Education*, p. 11/1-11/10, Stevenage, U.K.

- Doherty, G.D., 1996, "Welcome", editorial address, *BSI Quality Assurance*, Vol. ?

- Doyle, J.R., Arthurs, A.J., 1996., 'Judging the Quality of Research in Business Schools: The UK as a Case Study", *OMEGA*, Vol. 23, No. 3, p. 257-270

- Doyle, K.O., 1975., *Student Evaluation of Instruction*, D.C. Heath. Lexington, MA

- Duggins, R.K., 1996., "Assessing University Research", Australasian Journal of Engineering Education, Vol. 7, No. 1

- Edgerton, R., 1993., 'The New Public Mood and What It Means to Higher Education", *AAHE Bulletin*, Vol. 45, No. 10, p. 7

- Ensby, M., Mahmoodi, F., 1997., 'Using the Baldridge Award Criteria in College Classrooms", *Quality Progress*, Vol. 30, No. 4, p. 85-91

- Evans, J.R, Lindsay, W.M., 1996., *The Management and Control of Quality*, West Publishing, Minneapolis

- Evans, J.R., 1996., 'What Should Higher Education Be Teaching About Quality", *Quality Progress*, Vol. 29, No. 8, pp. 83-88

- Evans, D.L., Shank, D.L., 1992., "Attributes for the Baccalaureate Engineer: What Are the Desires of Industry", *Proceedings of the Third World Conference on Engineering Education*, Portsmouth, U.K., Vol. 1, p. 123-128

- Faculty of Management, 1996., *A Semi-Radical Plan for the Future*, Faculty of Management, University of Manitoba, October 16, p. 3

- Farahmand, K., Ashtijou, M., 1995., "Quality in Engineering Education, Engineering Curriculum to Keep Up With Future Trends in Industry", *Proceedings of the 1995 Annual American Society for Engineering Education Conference*, Vol. 2, p. 2096-2100

- Feigenbaum, A.V., 1994., "Quality Education and America's Competiteveness", *Quality Progress*, Vol. 27, No. 9, p. 83-84

- Forrester, J.W., 1993.,"System Dynamics as an Organizing Framework for Pre-College Education", *System Dynamics Review*, Vol. 9, No. 2, pp. 183-194

- Fram, E.H., Camp, R.C., 1995., "Finding and Implementing Best Practices in Higher Education", *Quality Progress*, Vol. 28, No. 2, p. 69-73

- Freeman, R., 1992., *Quality Assurance in Training and Education*, Kogan Page Limited, London

- Gateway, 1997., *Central Evaluation Plan*, Gateway Engineering Education Coalition (from the World Wide Web at http://www.vpr.drexel.edu/Gateway/evaluation.html)

- Gelders, L., Proost, A., Van Der Heyde, C., 1995., "ISO 9001 Certification in an Academic Unit", *European Journal of Engineering Education*, Vol. 20, No. 4, pp. 407-411

- Genest, C., Zhang, S.S., 1996., "A Graphical Analysis of Ratio-Scaled Paired Comparison Data", Management Science, Vol. 42, No. 3, pp. 335-349

- Grant, E.L., Leavenworth, R.S., 1996., *Statistical Quality Control*, McGraw Hill, New York

- Gupta, S.K., 1993, "Quality Improvement in Teaching", *Explorations in Teaching and Learning*, Vol. 3, No. 3, p. 4-5, Academy for the Art of Teaching, Florida International University (abstracted in Lewis and Smith, 1994)

- H3E, 1997A, *H3E - Higher Engineering Education for Europe*, Higher Engineering Education for Europe (http://www.fsa.ucl.ac.be/H3EWWW/H3E.index.html)

- H3E, 1997B, *Working Group2: Quality and Recognition in Higher Engineering Education*, Higher Engineering Education for Europe (from the World Wide Web at http://www.fsa.ucl.ac.be/H3EWWW/pres/index.html)

- H3E, 1997C, *Theme 3: Quality Assurance and Mutual Recognition*, Higher Engineering Education for Europe (from the World Wide Web at http://www.fsa.ucl.ac.be/H3EWWW/pres/theme3.html)

- Hale, F.J. 1988., *Introduction to Control System Analysis and Design*, Prentice Hall, Englewood Cliffs, New Jersey

- Halpern, S., 1978., *The Assurance Sciences: An Introduction to Quality Control and Reliability*, Prentice Hall, Englewood Cliffs, New Jersey

- Harris, B., Owen, J., 1994., "The Development of a Quality System for Higher Education", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 329-349

- Harris, T., 1996, "Learning the Quality Way", *BSI Quality Assurance*

- Hartig, D., 1995., "Es Kann Nur Eines Geben", *Qualitat und Zuverlassigkeit*, Vol. 40, No. 8, pp. 888-889

- Helms, S., Key, C.H., 1994., "Are Students More Than Customers in the Classroom?", *Quality Progress*, Vol. 27, No. 9, pp. 97-99

- Hemenway, C.O., Hale, G.J., 1996., "The TQEM-ISO 14001 Connection", *Quality Progress*, Vol. 29, No. 6, pp. 29-34

- Hillier, F.S., 1969., "Xbar and R-Chart Control Limits Based on a Small Number of Subgroups", *Journal of Quality Technology*, Vol. 1, No. 1, pp. 17-25

- Hjälmered, J.O., Lumsden, K., 1994., "Quality Assessment for a University Curriculum", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 321-327

- Ho, S.K., Wearn, K., 1995., "A TQM Model for Higher Education and Training", *Training for Quality*, Vol. 3, No. 2, pp. 25-33

- Horine, J.E., 1992., "Reading, Writing, and Quality Tools", *Quality Progress*, Vol. 25, No. 10, p. 33-35

- Hosotani, A., 1991., *Japanese Quality Concepts*, Erwin Publishers, New York

- Hulshoff, M.A., Ori, H.R., 1994., "Developing a Quality Programme for Higher Education at the Hogeschool Utrecht: A Dutch Case Study", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 303-312

- Hyde, R.A., Karney, B. W., 1996, "The Canadian Engineering Accreditation Board: An Historical Perspective", *Proceedings of the Tenth Canadian Conference on Engineering Accreditation*, Kingston, Ontario, p. 237-244

- Janna, W.S., Jakubowski, G.S., 1991., "A Rating System for Evaluating the Performance of Engineering Faculty", *International Journal of Applied Engineering Education*, Vol. 7, No. 3, p. 168-183

- Jeswiet, J., 1995., "Accreditation of a Mechanical Engineering Program", *International Journal of Engineering Education*, Vol. 11, No. 3, p. 14-20

- Kang, M., Stam, A., 1994., "PAHAP: A Pairwise Aggregated Hierarchical Analysis of Ratio-Scale Preferences", *Decision Sciences*, Vol. 25, No. 4, pp. 607-624

- Karapetrovic, S., Willborn, W., 1998A, "The Systems View for Clarification of Quality Vocabulary", *International Journal of Quality and Reliability Management*, Vol. 15, No. 1, pp. 99-120

- Karapetrovic, S., Willborn, W., 1998B, "Intergration of Quality and Environmental Management Systems", *TQM Magazine*, Vol. 10, No. 3, pp. 204-213

- Karapetrovic, S., Willborn, W., 1998C, "Connecting Internal Management Systems in Service Organizations", *Managing Service Quality*, Vol. 8 (to appear)

- Karapetrovic, S., Willborn, W., 1998D, "Integrated Audit of Management Systems", *International Journal of Quality and Reliability Management*, Vol. 16, No. 3 (to appear)

- Karapetrovic, S., Rajamani, D., Willborn, W., 1998A, "Quality Assurance in Engineering Education: Comparison of Accreditation Schemes and ISO 9001", *European Journal of Engineering Education*, Vol. 23, No. 2, pp. 199-212

- Karapetrovic, S., Rajamani, D., 1998., "An Approach to the Application of Statistical Quality Control Techniques in Engineering Courses", *Journal of Engineering Education*, Vol. 87, No.2, pp. (in press)

- Karapetrovic, S., Rosenbloom, E.S., 1998., "A Quality Control Approach to Consistency Paradoxes in AHP", submitted to the *European Journal of Operations Research*, May 1997.

- Karapetrovic, S., Rosenbloom, E.S., Ruth, D.W., Sefid-Gar, M., 1998B, "Engineering Program Decision Analysis Using AHP", to appear in the *Proceedings of the 11th Canadian Conference on Engineering Education*, DalTech, Halifax, N.S.

- Karapetrovic, S., Rajamani, D., Willborn, W., 1998C, "University, Inc.", *Quality Progress*, Vol. 31 (to appear)

- Karapetrovic, S., Rajamani, D., Willborn, W., 1997A, "The University Manufacturing System: ISO 9000 and Accreditation Issues", *International Journal of Engineering Education*, Vol. 13, No. 3, pp. 180-189

- Karapetrovic, S., Willborn, W., 1997, "Creating Zero Defect Students", *TQM Magazine*, Vol. 9, No. 4, pp. 287-291

- Karapetrovic, S., Rajamani, D., Willborn, W., 1997B, 'ISO 9000 for Small Business: Do it Yourself', *Industrial Management*, Vol. 39, No. 3, pp. 24-31

- Karapetrovic, S., Rajamani, D., Willborn, W., 1997C, 'ISO 9001 Quality System: An Interpretation for the University", *International Journal of Engineering Education*, Vol. 13 (to appear)

- Karapetrovic, S., Rajamani, D., Schilling, R., 1996., "Application of Quality Control Tools in the Mechanical Engineering Laboratory", *Proceedings of the Tenth Canadian Conference on Engineering Education*, Queen's University, Kingston, Ont., pp. 101-108

- Karapetrovic, S., 1995., *The Application of ISO 9000 to a Small Business*, Master of Science Thesis, University of Manitoba

- Kennedy, W.J., 1996., "Change in the Fundamentals Exam for Fall 1996", *IIE Solutions*, Vol. 28, No. 8, p. 16-17

- Kiesgen, G., Schnauber, H., Wupperman, V., 1995., 'Synergien Nutzen", *Qualitat und Zuverlassigkeit*, Vol. 40, No. 6, pp. 702-706

- Kirby, K.E., Leitnaker, M.G., Moore, C.F., Ranney, G.B., Sanders, R.D., 1990., 'Engineering Control Systems and Quality Improvement in Manufacturing", *Quality Progress*, Vol. 23, No. 12, pp. 79-82

- Klarin, M., 1994., *Industrial Engineering: Book 1 - Organization of Production Systems*, Faculty of Mechanical Engineering, University of Belgrade (In Serbian)

- Klaus, L.A., 'Quality Progress' Sixth Quality in Education Listing", *Quality Progress*, Vol. 29, No. 8, pp. 29

- Klein, M., 1996., "Composite Shewhart-EWMA Statistical Control Schemes", *IIE Transactions*, Vol. 28, p. 475-481

- Lane, E.F. and Verdini, W.A., 1989., "A Consistency Test for AHP Decision Makers", *Decision Sciences*, Vol. 20, pp. 575-590.

- LeBold, W.K., Budny, D.D., Ward, S.K., 1995., 'How Do Students Grade Their Learning?", *Proceedings of the 1995 Annual Conference of the American Society for Engineering Education* (http://www.purdue.edu/fre/asee/fie95/2c1/2c15/2c15.htm)

- Lefevre, H.L., 1990., "Variation in the Service Sector", *Quality Progress*, Vol. 23, No. 12, p. 60-62

- Lewis, R.G., Smith, D.H., 1994., *Total Quality in Higher Education*, St. Lucie Press, Delray Beach, Florida

- Lindström, J., 1994., "A System for Quality Improvement in Higher Education", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 255-261

- Lo, V.H.Y., Sculli, D., 1996., "An Application of TQM Concepts in Education", *Training for Quality*, Vol. 4, No. 3, pp. 16-22

- Lowry, C.A., Montgomery, D.C., 1995., "A Review of Multivariate Control Charts", *IIE Transactions*, Vol. 27, p. 800-810

- Lu, M.H., Madu, C.N., Kuei, C.H., Winokur, D., 1994., 'Integrating QFD, AHP and Benchmarking in Strategic Marketing", *Journal of Business and Industrial Marketing*, Vol. 9, No. 1, pp. 41-50

- Ludwig, A., Weseslindtner, H., 1996, 'Lehre ist Dienstleistung", *Qualitat und Zuverlassigkeit*, Vol.41, No. 2, p. ?

- Maling, J.H., 1995., 'Quality, Engineering and Education", *Australasian Journal of Engineering Education*, Vol. 6, No. 2

- Maleyeff, J., Webster, S., 1994., 'Making the Right Choice", *Quality*, Vol. 33, No. 2, pp. 65-67

- Matthews, W.E., 1993., "The Missing Element in Higher Education", *Journal for Quality Participation*, Vol. 16, Issue 1, p. 102-108

- Mayo, G., 1990., 'Satisfying Average Weight Requirements", *Canadian Packaging*, March, p. 33-36

- McKeachie, W.J., Pintrich, P.R., Lin, Y., Smith, D.A.F., 1986., *Teaching and Learning in the College Classroom: A Review of the Research Literature*, University of Michigan, Ann Arbor, p. 76

- Montgomery, D.C., 1991., *Introduction to Statistical Quality Control*, John Wiley, New York

- Montgomery, D.C., 1992., 'The Use of Statistical Process Control and Design of Experiments in Product and Process Improvement", *IIE Transactions*, Vol. 24, No. 5, p. 4-17

- NACCB, 1994., *Guidelines on the Application of the ISO 9000 Series to Further Education and Training*, National Accreditation of Certification Bodies, London, U.K.

- Nolan, K.M., 1990., 'Planning a Control Chart", *Quality Progress*, Vol. 23, No. 12, p. 51-55

- Ogata, K., 1970., *Modern Control Engineering*, Prentice Hall, Englewood Cliffs, New Jersey

- Owlia, M.S., Aspinwall, E.M., 1997., 'TQM in Higher Education - A Review", *International Journal of Quality and Reliability Management*, Vol. 14, No. 5, pp. 527-543

- Richmond, B., 1993., 'Systems thinking: critical thinking skills for the 1990s and Beyond", *System Dynamics Review*, Vol. 9, No. 2, p. 113-133

- Pagano, M, 1995., 'Counting Beans or Inspecting The Whole Crop: How Should Engineering Technology Programs Be Assessed", *Proceedings of the 1995 Annual Conference of the American Society for Engineering Education*, p. 2004-2009 (abstracted in Dalton, 1995)

- Perez, J., 1995., 'Some Comments on Saaty's AHP", *Management Science*, Vol. 41, No. 6, pp 1091-1095

- Pfeifer, T., Wunderlich, M., 1997., 'Establishing Quality Systems in Research Institutes: A Progress Report", *TQM Magazine*, Vol. 9, No. 3, pp. 221-227

- Phelan, R.M., 1977., *Automatic Control Systems*, Cornell University Press, Ithaca

- Pollock, A., 1995., 'Role of Quality Assurance Units in Higher Education", *Proceedings of the IEE Science, Education and Technology Division Colloqium on Quality in Higher Education*, p. 1/1-1/2, Stevenage, U.K.

- Prabhu, S.S., Runger, G.C., Keats, J.B., 'Xbar Chart with Adaptive Sample Sizes", *International Journal of Production Research*, Vol. 31, No. 12, p. 2895-2909

- Prados, J.W., 1997., 'Engineering Criteria 2000 - A Change Agent for Engineering Education", *Journal of Engineering Education*, Vol. 86, No.2, p. 69-70 (editorial)

- Provost, L.P., Norman, C.L., 1990., 'Variation Through the Ages", *Quality Progress*, Vol. 23, No. 12, p. 39-44

- Przygodzki, J.R., Beres, K.S., 1995., "Modernization of the Education System of Kielce Technological University", *Australasian Journal of Engineering Education*, Vol. 6, No. 1

- Quesenberry, C.P., 1991., "SPC Q Charts for Binomial Parameter p: Short or Long Runs", *Journal of Quality Technology*, Vol. 23, pp. 239-246

- Ranney, G.B., 1990., "The Implications of Variation", *Quality Progress*, Vol. 23, No. 12, p. 71-77

- Reavill, L.R.P., 1998., "Quality Assessment, Total Quality Management and the Stakeholders in the UK Higher Education System", *Managing Service Quality*, Vol. 8, No. 1, pp. 55-63

- Riggs, J.L., 1987., *Production Systems: Planning, Analysis and Control*, Waveland Press, Prospect Hights, Illinois

- Runger, G.C., Montgomery, D.C., 1993., "Adaptive Sampling Enhancements for Shewhart Control Charts", *IIE Transactions*, Vol. 25, No. 3, p. 41-51

- Saaty, T.L., 1992., "A Natural Way to Make Momentous Decisions", *Journal of Scientific and Industrial Research*, pp. 561-571.

- Schargel, F.P., 1994., "Teaching TQM in an Inner City High School", *Quality Progress*, Vol. 27, No. 9, p. 87-90

- Schenkerman, S., 1997., "Inducement of Nonexistant Order by the Analytic Hierarchy Process", Decision Sciences, Vol. 28, No. 2, pp. 475-482

- Schneider, S.C., Niederjohn, R.J., 1995., "Assessing Student Learning Outcomes Using Graduating Senior Exit Surveys and Alumni Surveys", *Proceedings of the 1995 Annual Conference of the American Society for Engineering Education* (from the World Wide Web, at http://www.purdue.edu/fre/asee/fie95/2c1/2c11.htm)

- Schoner, B., Wedley, W.C., Choo, E.U., 1992., "A Rejoinder to Forman on AHP, with Emphasis on the Requirements of Composite Ratio Scales", *Decision Sciences*, Vol. 23, No. 2, pp. 509-517

- Seymour, D., 1993., *On Q: Causing Quality in Higher Education*, Macmillan, New York, p. 25

- Shewhart, W.A., 1931., *Economic Control of Quality of Manufactured Product*, Van Nostrand, New York

- Sirvanci, M., 1996., "Are Students the True Customers of Higher Education", *Quality Progress*, Vol. 29, No. 10, p. 99-102

- SME, 1998., 'Manufacturing Skills of Recent Grads Lacking", *Quality Progress*, Vol. 31, No. 1, pp. 11-13

- Sparkes, J., 1994., "Achieving Quality in Engineering Degrees in the UK", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 291-301

- Stratton, B., 1993, "A Few Words About the Last Word", *Quality Progress*, Vol. 26, No. 10, p. 63-66

- Struebing, L., 1996., "9000 Standards ?", *Quality Progress*, Vol. 29, No. 1, p. 23-28

- Stuart, M., Mullins, E., Drew, E., 1996., 'Statistical Quality Control and Improvement", *European Journal of Operational Research*, Vol. 88, p. 203-214

- Succeed, 1997., *Evaluation and Assessment Primer*, SUCCEED Engineering Education Coalition (from the World Wide Web at http://www.succeed.engr.vt.edu/walker.html)

- Sullivan, L.P., 1986., 'Quality Function Deployment", *Quality Progress*, Vol. 19, No. 6, pp. 41-50

- Synthesis, 1997., *The Synthesis Coalition: Assessment*, Synthesis Engineering Education Coalition (from the World Wide Web at http://www.synthesis.org)

- Tannock, J.D.T., Burge, S.E., 1994., 'The EPC Model for Quality Assurance in Higher Education", *European Journal of Engineering Education*, Vol. 19, No. 3, pp. 263-274

- Tavana, M., Banerjee, S., 1995., 'Strategic Assessment Model (SAM): A Multiple Criteria Decision Support System for Evaluation of Strategic Alternatives", *Decision Sciences*, Vol. 26, No. 1, pp. 119-143

- The Mission of the University of Manitoba, 1997., *General Calendar*, University of Manitoba, p. 4

- Triantaphyllou, E., Sanchez, A., 1997., "A Sensitivity Analysis Approach for Some Deterministic Multi-Criteria Decision Making Methods", Decision Sciences, Vol. 28, No. 1, pp. 151-194

- Tsui, K.L., 1992., "An Overview of Taguchi Method and Newly Developed Statistical Methods for Robust Design", *IIE Transactions*, Vol. 24, No. 5, p. 44-57

- Vandenberghe, D.G., 1996., "The Practical Integration of Management and Statistical Methods in an Undergraduate Quality Control Class", *Proceedings of the Tenth Canadian Conference on Engineering Education*, Queen's University, Kingston, Ontario, pp. 177-184

- Vazzana, G., Bachmann, D., Ellrink, J., 1997., "Does Higher Education Practice What It Teaches?", Quality Progress, Vol. 30, No. 12, pp. 67-70

- Velury, J., 1996., "ISO 9000: Focusing on Quality Systems", *Industrial Management*, Vol. 38, No. 6, pp. 11-15

- Walker, A.J., 1997., "Impact of an ISO 9001 Compliant Quality Management System on a University Research Enterprise", The *TQM Magazine*, Vol. 9, No. 6, pp. 397-402

- Weber, A., "What to Chop", *Newsweek*, April 29, pp. 59-62

- Weller, D.L., 1996., "Benchmarking: A Paradigm for Change to Quality Education", *The TQM Magazine*, Vol. 8, No. 6, pp. 24-29

- Willborn, W., 1997., *Report of WG7: Subgroup for Definitions and Glossary*, ISO TC 176/SC3/WG7/N84a

- Willborn, W., 1995., *Quality Management and Introduction of ISO 9000 in Training/Education Institute*, Course Notes, SHAMA Management and Consultants, Singapore

- Willborn, W., Chang, T.C.E., 1994, *Global Management of Quality Assurance Systems*, McGraw Hill, New York

- Yokomoto, C.F., 1995., "What Pre-exam and Post-exam Quizzes Can Tell Us About Test Construction", *Proceedings of the 1995 Annual Conference of the American Society for Engineering Education* (from the World Wide Web, at http://www.purdue.edu/fre/asee/fie95/2c12/2c12.htm)

- Zaciewski, R.D., 1993., "Instructional Process Control", *Quality Progress*, Vol. 25, No. 1, p. 61-64

- Zahedi, F., 1986., "The Analytic Hierarchy Process - A Survey of the Method and its Applications," *INTERFACES*, Vol. 16, 96-108.

APPENDIX I

University Of Manitoba

DEPARTMENT OF MECHANICAL AND
INDUSTRIAL ENGINEERING

QUALITY MANUAL

(Draft 2)

CONTROLLED COPY #2

0. FOREWORD

THE DEAN OR DEPARTMENT HEAD ARE INVITED TO WRITE A BRIEF FOREWORD HERE. THE FOREWORD MIGHT REFER TO THE INNOVATIVE CHARACTER OF THE PROJECT, THE ASSISTANCE AND SUPPORT THEY PROVIDE, AND THE RELATION TO THE DEPARTMENT / FACULTY MISSION.

	Name:	Signature:
Prepared by:		
Revised by:		
Approved by:		

1.1 TABLE OF CONTENTS

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.2 QUALITY SYSTEM AND QUALITY ASSURANCE

We, the people of the Department of Mechanical and Industrial Engineering at the University of Manitoba, recognize that quality does not just happen. Quality must be planned, designed, created and improved. It is the result of a systematic effort. Our goal is to provide the best quality of teaching, learning and research in mechanical and industrial engineering. In our efforts to achieve this goal, we have designed, documented and implemented the department's quality system according to the model illustrated in Figure 1. The **Quality System** is viewed as a "set of interdependent processes that function harmoniously, using various resources, to achieve the objectives related to quality" [1].

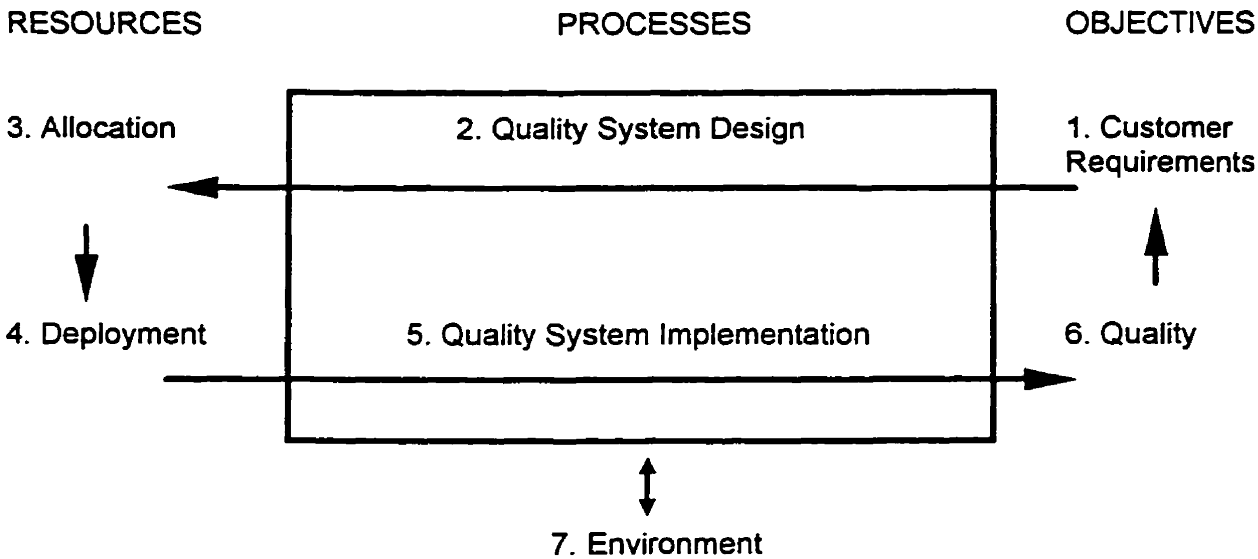


FIGURE 1: A Simple Graphical Model of the Quality System [1]

Our objectives are focused on meeting the expectations, requirements and needs of our customers: future employers of our students, accrediting agencies, government, research sponsors, alumni, our broad community and students. **Quality Assurance** means providing confidence to them that their requirements and needs for quality education and research are and will be met. To provide such confidence to our customers in Canada and abroad, we have developed a quality system that conforms to the requirements of the ISO 9001 International Standard for quality assurance. The benefits of the ISO 9001 quality system for the department are emphasized in the next section.

REFERENCE: [1] Karapetrovic, S., Willborn, W., 1998., "The System's View for Clarification of Quality Vocabulary", *International Journal of Quality and Reliability Management*, Vol. 15, No. 5

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.3 Benefits of a Quality System in the Department

The following benefits from a well documented and implemented quality system in the Department of Mechanical and Industrial Engineering at the University of Manitoba have been foreseen by Dr. Walter Willborn, the Canadian delegate in the ISO technical committee for quality standards:

• Quality System will enhance the status and positive image of the Department, Faculty, University and possibly even the local community

• A university department with a quality system that complies with the world-wide accepted standard of the International Organization for Standardization (ISO 9001) will pioneer meaningful public scrutiny and official recognition of its efforts to assure the quality of its work and service

• Quality System documentation will guide teaching, learning and research in a convenient, predictable and generally acceptable way

• The system does not add work and paper trails where general and individual benefits can not be seen or recognized

• Internal quality auditing, a built-in system element, allows each faculty and staff member to raise and resolve practical problems

• Once the system is well understood, its various benefits recognized, and records show adequate and effective implementation, the system will be audited by an external, well selected auditor and registrar. These audits are designed to identify problems and improvements from the faculty and staff point of view

• The registered and well maintained Quality System will serve as the basis for complying with upcoming related standards for the control of environmental (ISO 14000) and workplace health and safety factors (ISO 18000)

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.4 Brief Overview of the ISO 9001 International Standard

As a result of the worldwide trend to ensure consistent and standardized processes that will yield products that meet and/or surpass customer's implied or stated needs, The International Organization for Standardization (ISO) has developed a series of quality standards named ISO 9000. The standards present three models (ISO 9001, 9002 and 9003), which stipulate a number of requirements on which an organization's quality system can be assessed by an external party (registrar) according to ISO 10011 quality system audits standard. If these minimum requirements are met, a registrar accredited by a national accreditation institution issues a certificate of compliance and the organization's quality system becomes ISO 9001/2/3 registered.

The ISO 9001 standard is a model for quality assurance in design/development, production, installation and servicing. ISO 9002 essentially stipulates the same requirements for a quality system as ISO 9001, however, design/development and servicing activities are excluded. Finally, ISO 9003 covers final inspection and test only. In the upcoming major revision of the ISO 9000 standards, all three models will be blended into one, the most comprehensive ISO 9001 model. For this reason, as well as the fact that the department designs its programs, courses and services, we have chosen to develop a quality system that conforms to the requirements of the ISO 9001 standard. ISO 9001(1994 edition) stipulates a total of twenty requirements (Figure 2).

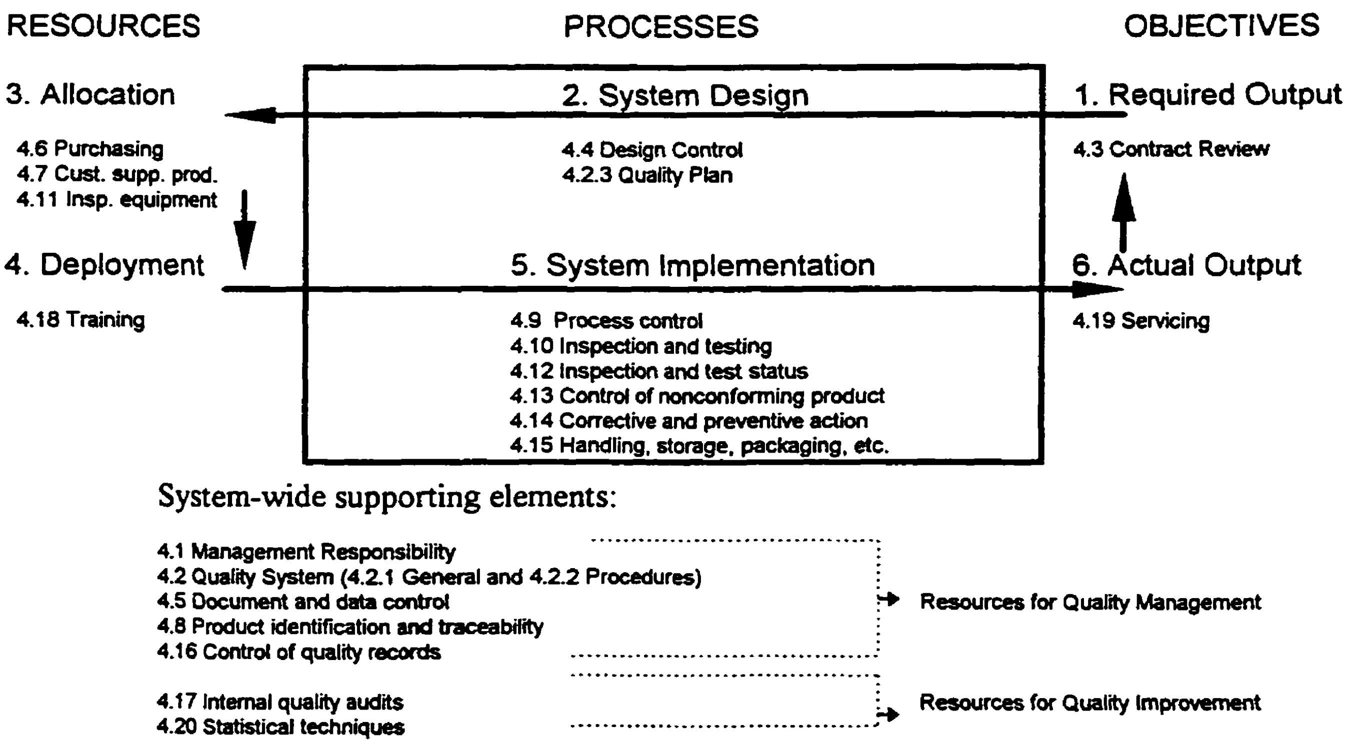


FIGURE 2: Graphical Model of an ISO 9001 Quality System [1]

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.5 Interpretation of Concepts and Terms

The ISO 9001 standard was written by engineers and quality professionals from large industries with a manufacturing organization in mind. Although the standards are generic, i.e. they are universally applicable to service and non-profit organizations, health care and education, the documentation and implementation of an ISO 9001 quality system in the university environment requires an interpretation of the standard. For the purpose of implementing this standard in the department of mechanical and industrial engineering, the 1994 (latest) edition has been interpreted using analogies with a manufacturing organization. During the research of the applicability of ISO 9001 in an engineering faculty, it was found that the university processes and resources can be viewed within the concept of a manufacturing system, thereby creating a 'University Manufacturing System" (UMS). While a detailed explanation and workings of the UMS is available elsewhere [2], the concepts and terms from the ISO 9001 standard have been interpreted in the following two tables.

MANUFACTURING	UNIVERSITY: Faculty of Engineering
Product	(a) Students knowledge, experience & skills (b) Programs and Courses (c) Research Output
Customers	(1) Industry, Community and Research Sponsors (2) Association of Professional Engineers of Manitoba (APEM) and the Canadian Engineering Accreditation Board (CEAB) (3) Alumni
Supplier	The Department of Mechanical/Industrial Engineering
Subcontractors	High-Schools, Colleges and other Universities
Executive Management	(1) Faculty: Dean, department heads and directors (2) Department: Head and associate heads
Design Plan	(a/b) Industrial Engineering Undergraduate Program, Mechanical Engineering Undergraduate Program, M.Sc (ME) program (c) Research objectives and purpose
Designer	Faculty member
Process Plan	(a) Individual student curriculum (b) Course outline (plan) (c) Research Project Plans

TABLE 1: Summary of Concepts

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

MANUFACTURING	UNIVERSITY: Faculty of Engineering
Raw Material	(a/b) Students knowledge of basic sciences before entering the faculty (c) Existing theoretical and practical knowledge
Value Adding to Material	(a/b) Value adding to students knowledge, experience and skills (c) New knowledge
Manufacturing Process	Teaching/Learning/Research process
Lead Time	(a/b) For programs: 4 years, for courses: 1 or 2 semesters
Part	(a/b) Students knowledge accumulated in a course
Operation/Tool	(a/b) Lecture
Machine/Technology	"Learning and/or Research Opportunity"
Operator	(a/b) Instructor, Teaching Assistant (c) Researcher, Research Assistant
Part Specification	(a/b) Course Specification in General Calendar
Inspection	(a/b) Exams, Tests, Assignments, Quizzes, Projects

TABLE 1: Summary of Concepts (continued)

TERM	EXPLANATION
Quality Policy	The overall quality intentions and direction of the department, as formally expressed by the dean or department head.
Quality Management	Process consisting of quality planning, quality control and quality improvement.
Quality Planning	Process of identifying the customer's requirements and objectives for quality, as well as designing the quality system and allocating resources
Quality Control	The operational techniques and activities that are used to fulfill requirements for quality at the department level.
Quality Improvement	Process of increasing the effectiveness and efficiency of the quality system

TABLE 2: Summary of Terms

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

TERM	EXPLANATION
Quality Assurance	All those planned and systematic actions necessary to provide adequate confidence to the customers & department executive management that the product will satisfy given requirements for quality.
Quality System	Set of interdependent process that function harmoniously, using various resources to achieve objectives related to quality.
Management Review	Management review is conducted by the executive management of the department and includes: (1) Internal Quality Audits (2) An overview & analysis of quality policy (3) The analysis of customers requirements and their relationship to the policy/objectives
Quality System Review	A formal evaluation by the dean and department heads of the status and adequacy of the quality system in relation to quality policy and new objectives resulting from changing circumstances.
Design Review	A formal evaluation by the department heads of the product design to evaluate product requirements and the capability of the product to meet these requirements.
Inspection	That aspect of the faculty-wide quality control that measures, examines and tests one or more characteristic of the product and compares these with specified requirements to determine conformity.
Nonconformity	The nonfullfilment of specified requirements (ISO 8402-94) Examples: student failure, course failure, research project failure
Defect	The absence of one or more quality characteristics from intended specifications.

TABLE 2: Summary of Terms (Continued)

[2] Karapetrovic, S., Rajamani, D., Willborn, W., 1996., "The University Manufacturing System: ISO 9000 and Accreditation Issues", *International Journal of Engineering Education*, currently available on the World Wide Web at http://www.fh-hamburg.de/ihw/articles/999989/article.htm

1.6 Overview of the Quality System Documentation

The ISO 9001 standard requires the quality system to be adequately documented and implemented. The department's quality system documentation has been designed in four tiers (Figure 3). The **Quality Manual** describes the overall quality system and refers to the necessary quality system procedures. The manual is designed as an intermediate document between the ISO 9001 standard and quality system procedures. There are twenty procedures, each addressing one requirement of the ISO 9001 (1994). Each **procedure** illustrates one or more processes, such as purchasing, appointment of teaching assistants and teaching process control. Input and output elements of these processes are drawn out, and the process flow is presented in the flowchart form. A summary of symbols used for flowcharting is given in Figure 4. Responsibilities and authorities for different activities in the process are provided in responsibility matrices. Process activities that need separate written guidelines are addressed by appropriate **instructions.** Finally, to verify compliance with the quality system requirements, **records** are available.

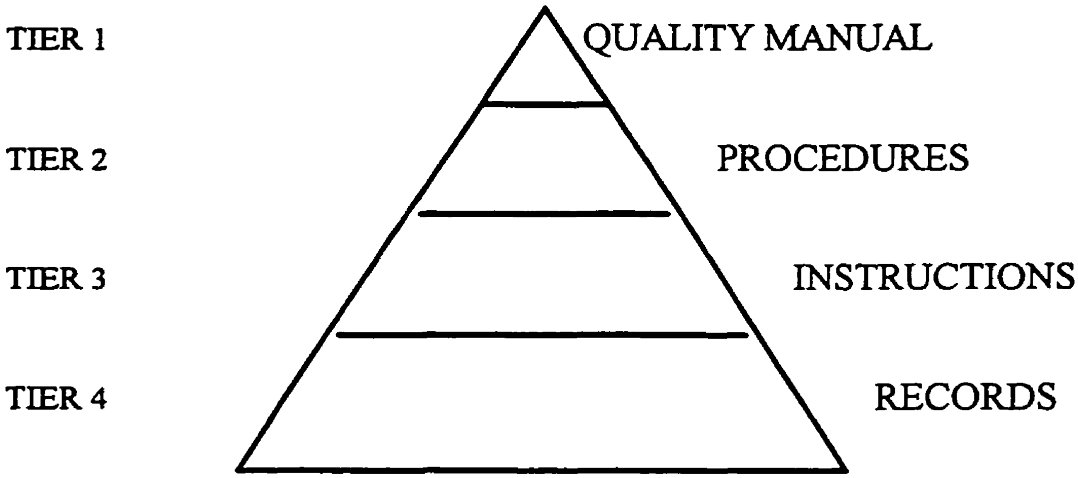


FIGURE 3: Four Tiers of the Quality System Documentation

To facilitate clear identification of all documentation pertaining to the quality system, each document bears a unique code. The code consists of three letters and a number. The first letter signifies the type of the document. For example, the Quality Manual's code starts with the letter 'M', procedures with the letter 'P', instructions with 'I', and records with 'R'. The next two letters identify the requirement of the ISO 9001 standard that the particular document addresses or pertains to, and the number is an ordinal number of the document. For instance, PPC1 is the procedure for process control, and RPU23 is a purchasing record. The manual, procedures and instructions have the same header and footer, illustrated on this page.

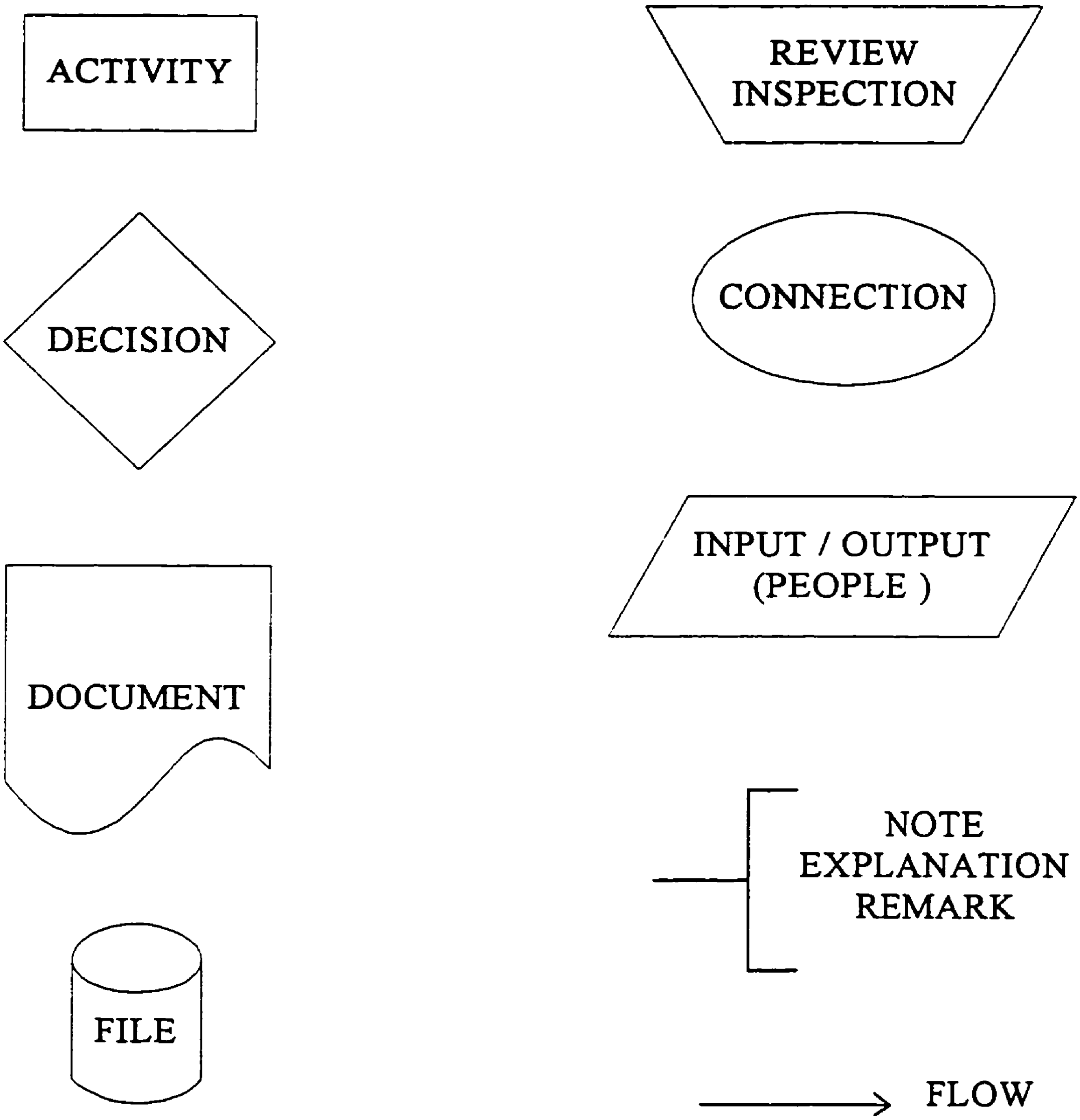


FIGURE 4: Flowcharting Symbols

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

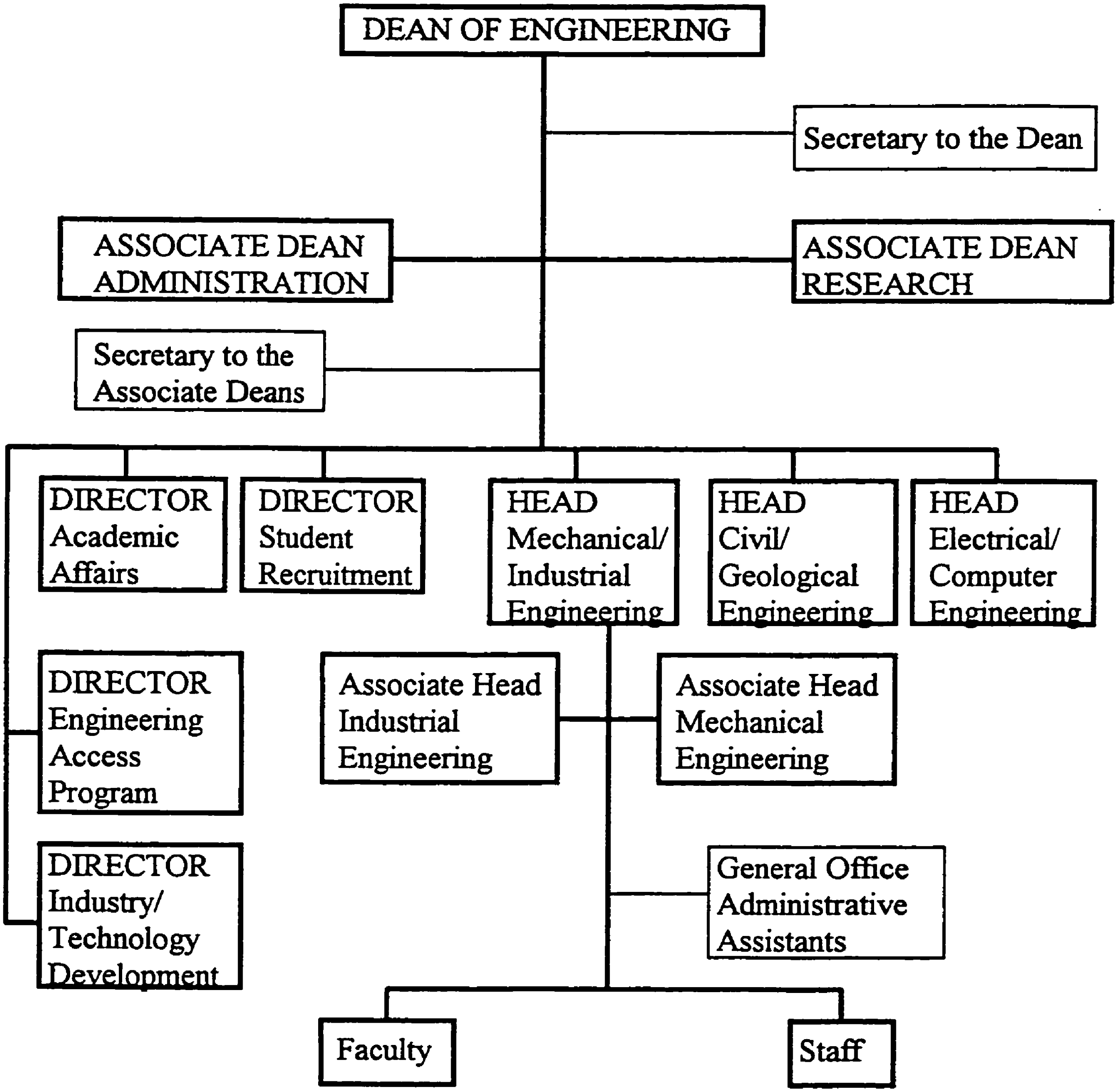
1.7 Quality Policy Statement

The Department of Industrial Engineering, University of Manitoba, has committed itself to provide the best quality in teaching, learning and research. Meeting the need of its students, their future employers and that of the community in general is the main objective. A well documented and implemented quality assurance system, that complies with the international ISO 9001 Standard, and will be registered, supports this policy. All members of the Department understand and follow this quality policy.

SIGNATURE AND DATE

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.8 Organizational Structure



	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.9 Record of Changes

This Quality Manual may contain only the pages approved by the Head of the Department of Mechanical and Industrial Engineering. The ISO 9000 Representative shall:

- process all approved changes
- insert approved pages into the Master and official distribution copies
- fill out the record of changes in the Master and official distribution copies
- destroy all obsolete pages
- distribute approved copies of the Manual to the persons designated as custodians (see section 1.10 of this Manual)

The Master Copy of this Quality Manual, kept in the Dean's Office (room 350), shall be the final authority as to the status of all sections in the manual.

Section	Page	Comments	Date	Signature

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

1.10 CONTROLLED DISTRIBUTION LIST

The copies of this Manual and the Quality System Procedures are kept by the custodians, as per the following list.

Copy No:	Copy Custodian
Master	Dean of Engineering (Dr. Donald Shields)
1	Associate Dean (Dr. Douglas Ruth)
2	Dr. Walter Willborn
3	Dr. Divakar Rajamani
4	Stanislav Karapetrovic
5	Department Head (Dr. A.S. Alfa)

The information presented in this Manual is not confidential. Copies of the Manual are available for external purposes by contacting the ISO 9000 Representative. However, these copies will be considered as "uncontrolled", which means that they will not be automatically updated.

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

2.2.1 OBJECTIVES

The Department has established and maintains a documented procedure for design control and verification to ensure that design meets specified requirements. The objective is to demonstrate the department's ability to translate customers specifications into design input requirements, to perform the design of programs, courses, student knowledge, individual student's program of study and research, to verify design output against design input requirements, to validate design output against customers' requirements and specifications, and to identify, document, review and approve design changes and modifications.

2.2.2 SCOPE

This element of the quality system covers design control of the programs and courses offered by the Faculty, design control of individual student's programs of study, and design control of the research conducted in the Department

2.2.3 RESPONSIBILITY AND AUTHORITY

Specific responsibilities and authorities for design control are identified in section 4.3 of the Procedure for Design Control PDC-1. Overall responsibility for program design and review is placed on the Program Review Committee of the Faculty of Engineering. Individual faculty members and instructors are responsible for design control of specific courses, as well as research projects they are conducting.

2.2.4 APPLICATION

2.2.4.1 General

The department has established and maintains procedure PDC-1 to control and verify the design of its products in order to ensure that the specified requirements are met.

2.2.4.2 Design and Development Planning

The department prepares plans for each design and development activity. The plans describe these activities, and define the responsibility for their implementation. The documents include program/course design plans and research project plans.

2.2.4.3 Organizational and Technical Interfaces

The responsibilities and authorities, as well as the interrelationships (vertical and lateral) between the personnel which input into the design process are defined and documented in the Procedure for Design Control PDC-1.

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

2.2.4.4 Design Input

Design input requirements for department's undergraduate and graduate programs include suggestions on new programs from professional engineering institutions, such as the Association of Professional Engineers of Manitoba (APEM) and the Canadian Engineering Accreditation Board (CEAB), faculty executive committee's reports on the development and feasibility of new programs, as well as analyses of customers' needs and the department's market position.

Design input requirements for courses include specific course descriptions from the General Calendar of the University of Manitoba, surveys of the needs of industry, government and community, and similar course designs from other universities and/or departments.

Design input requirements for individual student curriculum encompass program regulations.

Finally, design input for the research project includes the requirements from the research contract, analysis of available literature and the need for research.

2.2.4.5 Design Output

Product design output is documented in program descriptions and regulations (General Calendar of the University), course plans, individual student program plans and research projects plans. The plans document the following:

- how the program/course/research aims/objectives are to be achieved
- the description of the skills, competencies and knowledge to be developed
- that the course/program/research content is relevant to its aims and objectives
- that the environment and resources are appropriate to the aims of the program/course/research
- that the above have been reviewed.

2.2.4.6 Design Review

Review of the design output is planned, conducted and documented according to the Procedure for Design Control PDC-1. Records of design reviews are maintained.

2.2.4.7 Design Verification

In addition to conducting design reviews, design verification is planned, performed and documented according to the Procedure for Design Control PDC-1. Design verification consists of comparing design output versus the input and confirming that the design output meets design input requirements. Records of design verification are maintained.

2.2.4.8 Design Validation

Design validation follows design verification. It is conducted against defined customer needs and/or requirements. The purpose is to ensure that customers needs and/or requirements are properly translated into the design output. Records of design validation are maintained.

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

2.2.4.9 Design Changes

Procedure for Design Control PDC-1 identifies changes that need formal design approval. The procedure manages any changes that occur during the product design/development or as a result of subsequent evaluation and review.

2.2.5 REFERENCE DOCUMENTS

(1) Procedure for Design Control PDC-1
(2) General Calendar of the University of Manitoba (1997/98)

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

2.7.1 OBJECTIVES

The department has defined and maintains a documented procedure to control the teaching, learning and research processes. The objective is to ensure proper identification and planning of these processes, and to ensure that they are carried out under controlled conditions. Controlled conditions include documents defining the manner in which the teaching, learning and research processes are carried out, use of suitable equipment and working environment, compliance with reference course and research project quality plans, monitoring and control of critical quality characteristics and suitable process parameters, as well as preventive and corrective maintenance of equipment used for teaching, learning and research purposes.

2.7.2 SCOPE

Processes which directly affect quality in the department are learning, teaching, and researching. These processes create student knowledge, experience and skills, courses and programs, as well as new knowledge and theories. Process control element of the quality system covers the control of the academic progress of students, including the determination and review of student academic status, control of the teaching and research processes, maintenance of equipment used in teaching, learning and research, and the maintenance of facilities.

2.7.3 RESPONSIBILITY AND AUTHORITY

Faculty members have a direct responsibility for all aspects of learning/teaching/research process control. The control of the academic progress of students is the responsibility of the engineering board of examiners. Responsibility and authority for specific activities and processes are provided in section 4.3 of the Procedure for Process Control PPC-1.

2.7.4 APPLICATION

Process control is governed by the procedure PPC-1. Appropriate records are kept and maintained for processes, activities, equipment and personnel, according to the Procedure for Control of Quality Records PQR-1, and the Procedure for Document and Data Control PDD-1.

2.7.5 REFERENCE DOCUMENTS

(1) Procedure for Process Control PPC-1
(2) Procedure for Control of Quality Records PQR-1
(3) Procedure for Document and Data Control PDD-1

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

APPENDIX II

University of Manitoba *Faculty of Engineering* Industrial Engineering	Title: **PURCHASING PROCEDURE**	Status & Issue No: DRAFT 2
		Date of Issue: April 16, 1997
		Page 1 of 11
CONTROLLED COPY #		Code : PPU-1
DO NOT DUPLICATE	Compliance with ISO 9001: 4.6 Purchasing	

1. PURPOSE

The purpose of this procedure is to ensure adequate admission of undergraduate and graduate students to the department, and the acquisition and deployment of resources required for program/course delivery and research and development activities. The objective is to demonstrate the ability to admit students who meet department's entrance standards, and to demonstrate the ability to acquire only high quality resources for use in program/course delivery and research.

2. SCOPE

This procedure applies to the processes listed herein. Each process is identified with a code. The code is in the format x y z, where x represents the number of the ISO 9001 requirement to which the process applies (e.g. 3 for Contract Review), y stands for the type of product (PRG-Program, STU-Student Knowledge, RES-Research), and z is the ordinal number of the process.

6PRG1 • Purchasing of material and information, i.e. hardware and software resources required for the proper delivery of programs, courses and research projects

6PRG2 • Appointment of teaching assistants

6STU1 • Admission of undergraduate students

6STU2 • Admission of postgraduate students, including Master of Science, Master of Engineering, Doctor of Philosophy, and Post Doctoral Fellows

6RES1 • Admission (appointment) of research assistants and research associates

3. DEFINITIONS

- **Graduate Students:** Students enrolled in Master of Engineering, Master of Science, or Doctor of Philosophy programs in the department
- **Teaching Assistants (TA):** Students enrolled in Master of Engineering, Master of Science, or Doctor of Philosophy programs in the department who perform marking, grading or demonstrate laboratory experiments to undergraduate students
- **Research Assistants (RA):** Students enrolled in Master of Engineering, Master of Science, or Doctor of Philosophy programs in the department who perform research activities within contracted research projects

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

• **Research Associates:** People who assist faculty members in their research, but are not enrolled in a postgraduate program in the department

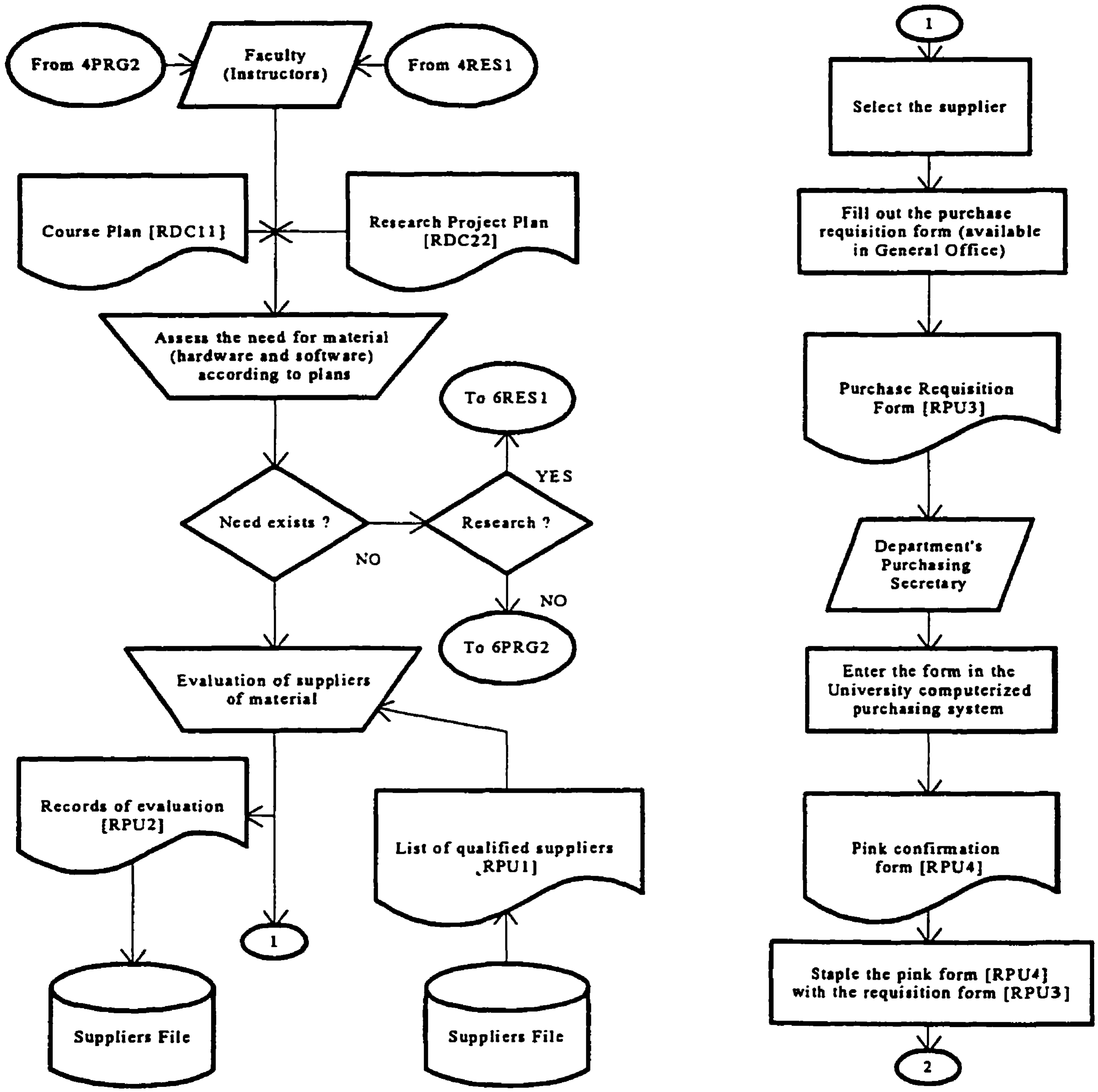
4. PROCEDURE

4.1 Input Elements

INPUT ELEMENTS			SUPPLIERS
Process	Name	Ref.	
6PRG1	1. Course Plan	[RDC11]	Faculty members
	2. Research Project Plan	[RDC22]	
6PRG2	1. Course Plan	[RDC11]	Faculty members
6STU1	1. High-School Diploma	[RPU11]	Students
	2. Transcripts	[RPU12]	
6STU2	1. Application for Admission	[RPU19]	Students
	2. Transcripts	[RPU20]	
	3. Letters of Reference	[RPU21]	Student's Teachers
	4. Proof of English Proficiency	[RPU22]	Students
6RES1	1. Research Project Plan	[RDC22]	Researcher(Faculty)

4.2 Flowcharts

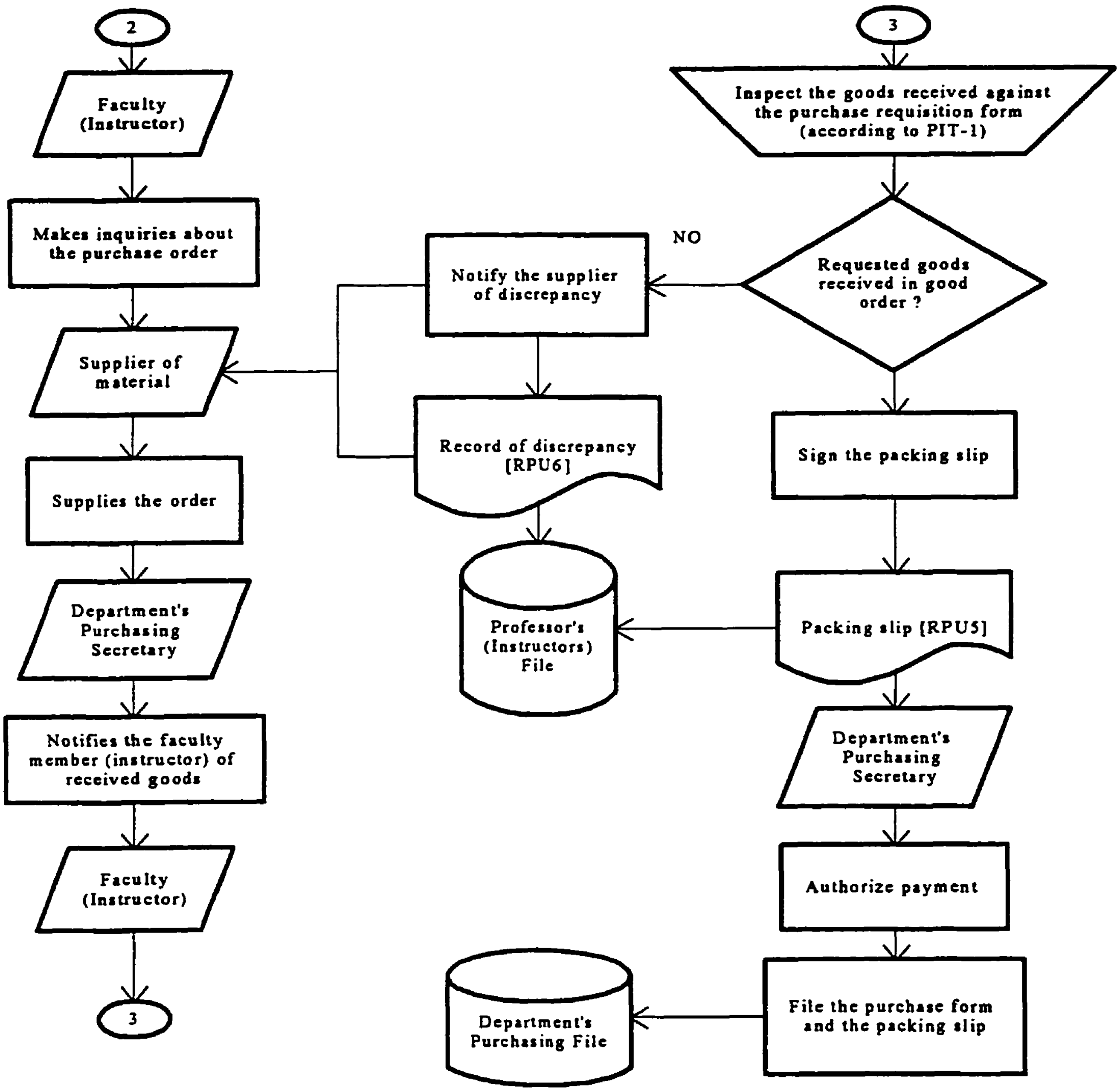
PURCHASING OF MATERIAL (6PRG1)



	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

University of Manitoba *Faculty of Engineering* Industrial Engineering	Title: **PURCHASING PROCEDURE**	Status & Issue No: DRAFT 2 Date of Issue: April 17, 1997 Page 4 of 11 Code : PPU-1
CONTROLLED COPY # DO NOT DUPLICATE	Compliance with ISO 9001: 4.6 Purchasing	

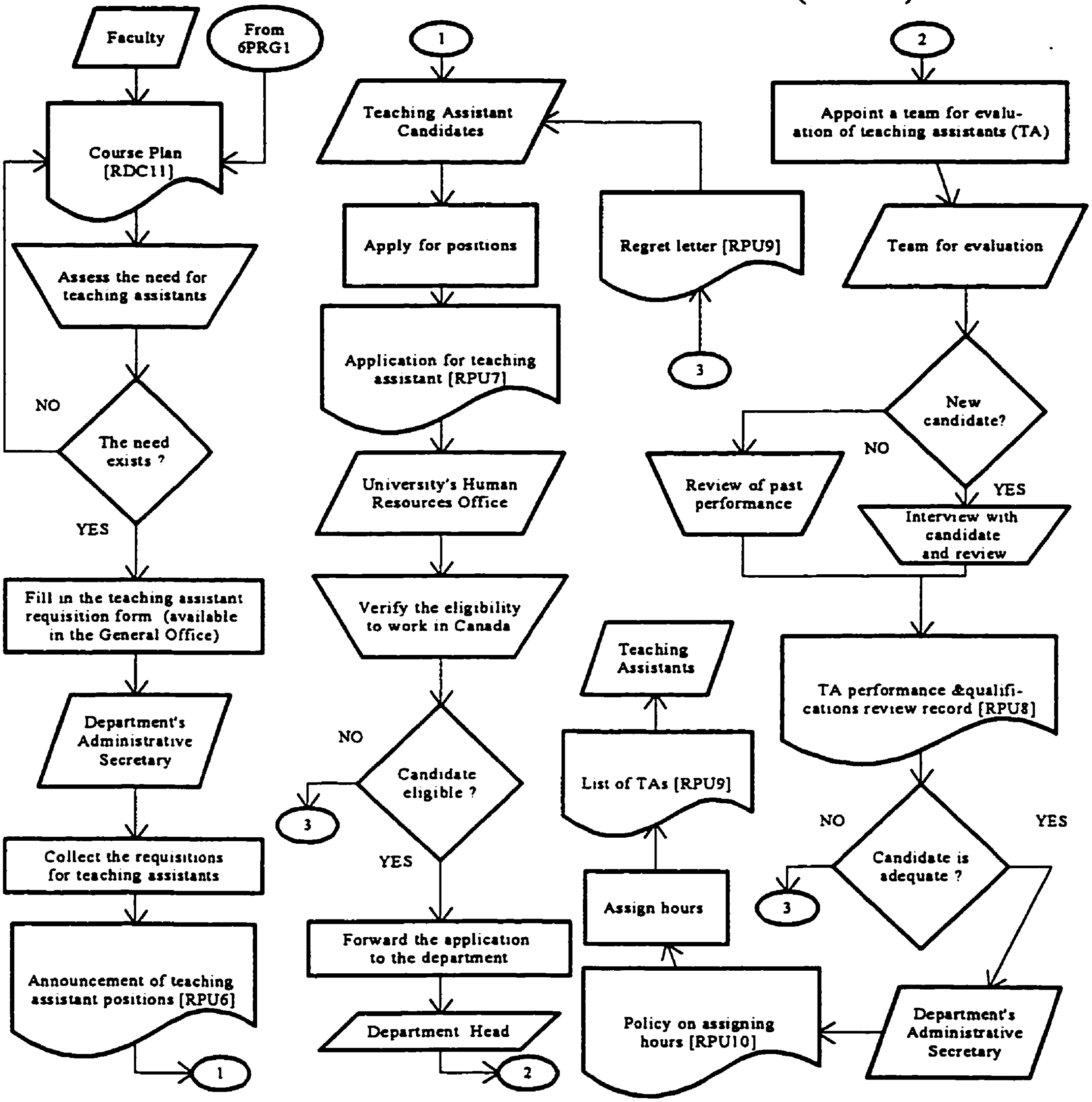
PURCHASING OF MATERIAL (6PRG1)



	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

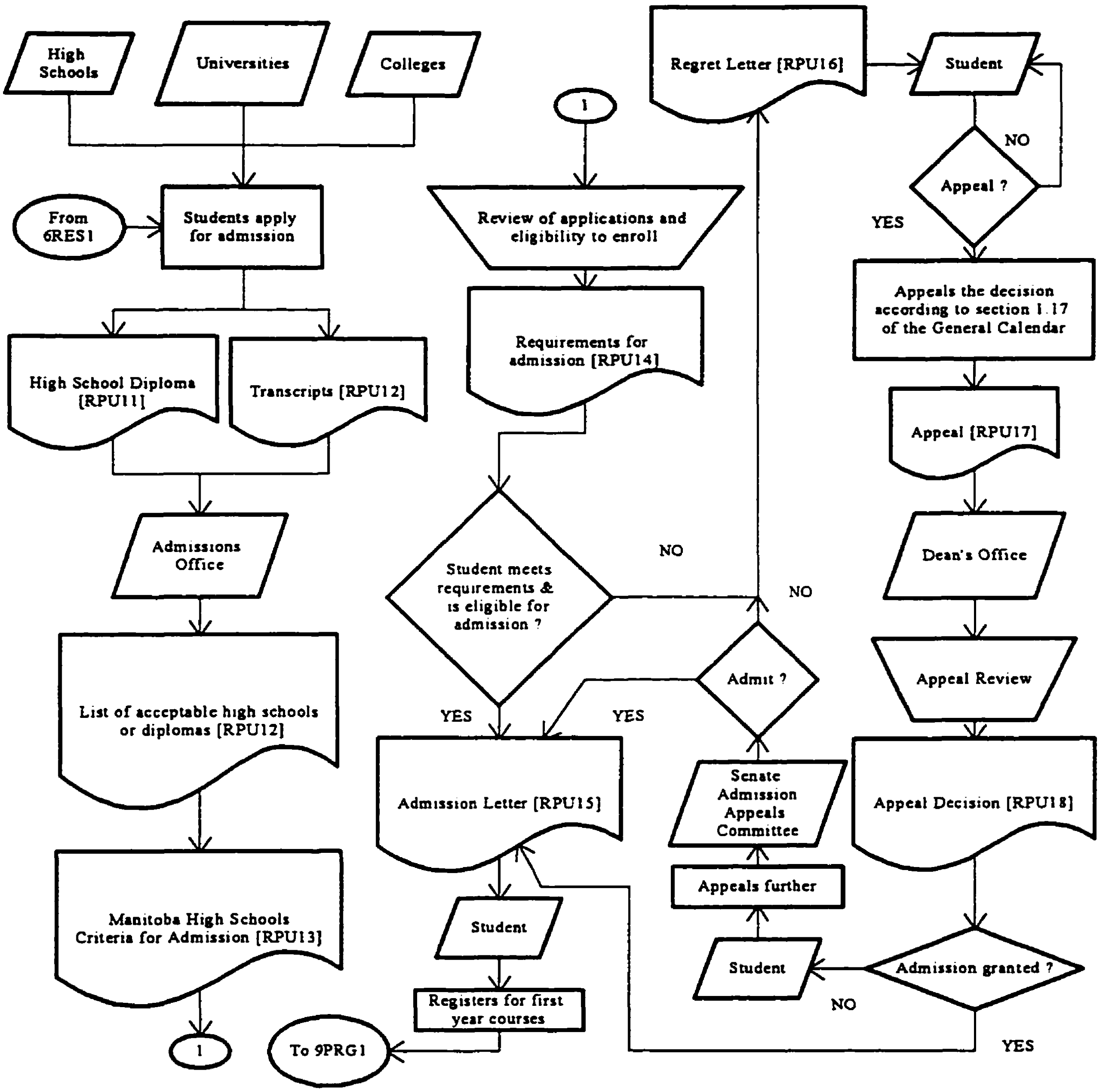
University of Manitoba *Faculty of Engineering* Industrial Engineering	Title: **PURCHASING PROCEDURE**	Status & Issue No: DRAFT 2 Date of Issue: April 17, 1997 Page 5 of 11 Code : PPU-1
CONTROLLED COPY # DO NOT DUPLICATE	Compliance with ISO 9001: 4.6 Purchasing	

APPOINTMENT OF TEACHING ASSISTANTS (6PRG2)



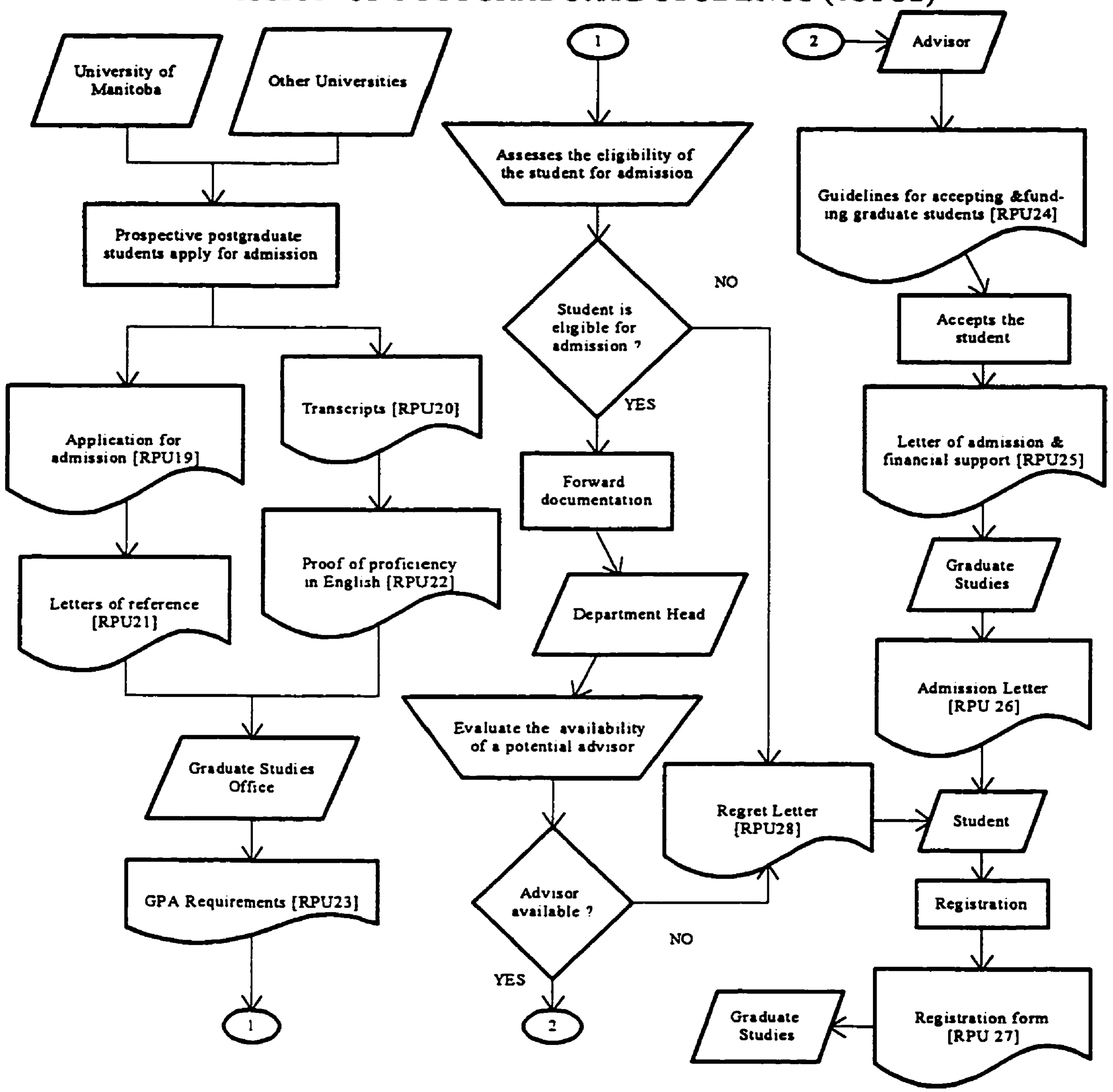
	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

ADMISSION OF UNDERGRADUATE STUDENTS (6STU1)



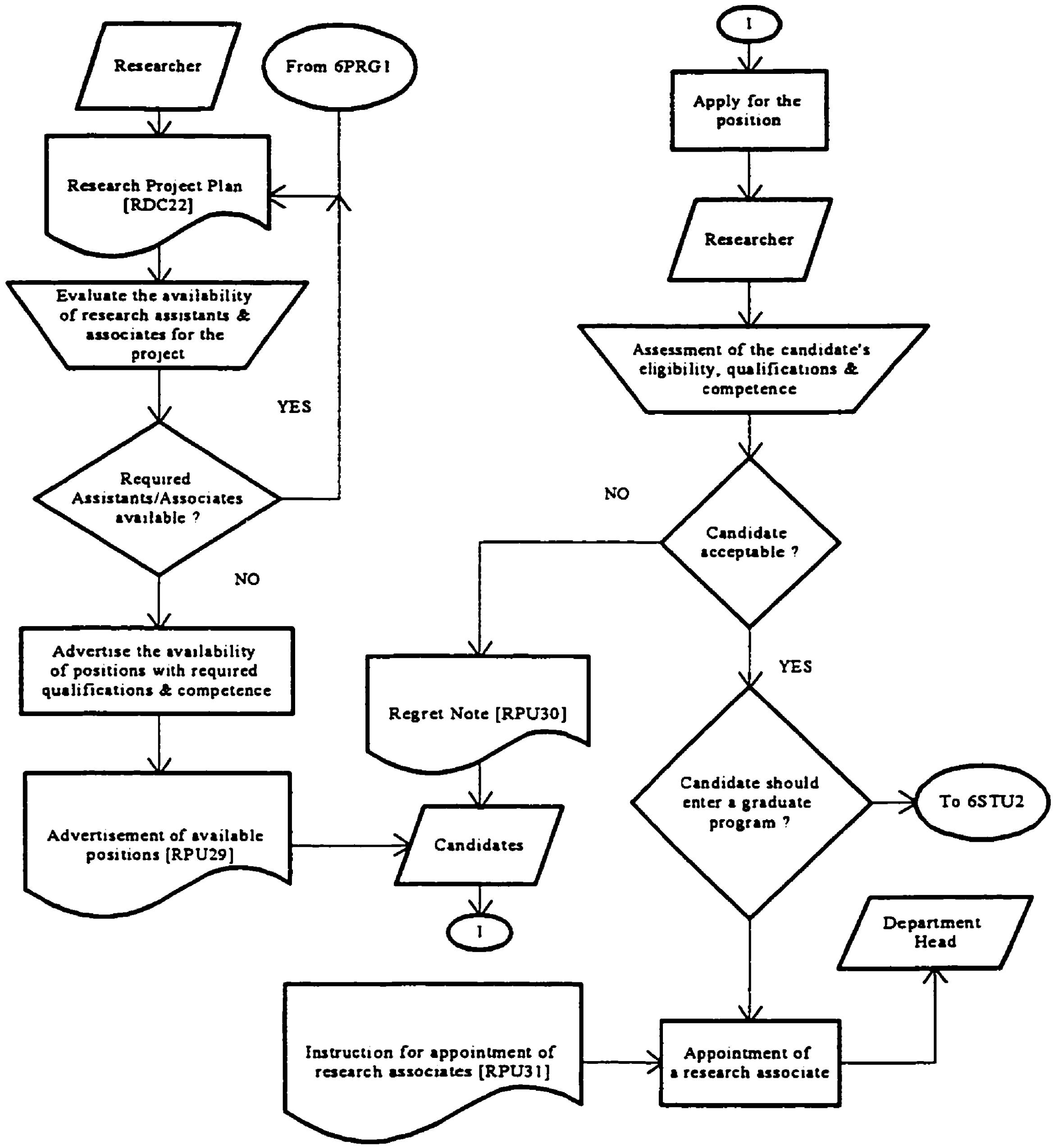
	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

ADMISSION OF POSTGRADUATE STUDENTS (6STU2)



	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

ADMISSION OF RESEARCH ASSISTANTS & ASSOCIATES (6RES1)



	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

4.3 Responsibility Matrix

FUNCTIONS RESPONSIBLE					
PROCESS	Faculty (Profs)	Department's Purchasing Secretary	Team for TA evaluation	Dean's Office	Admissions Office
6PRG1 Evaluation of material suppliers	in-charge				
Selection of the supplier	in-charge				
Inspection of received goods	in-charge				
Authorize payment and file records		in-charge			
6PRG2 Assess the need for a teaching assistant	in-charge				
Request teaching assistants	in-charge				
Review of applicants qualifications and competence and appointment			in-charge		
6STU1 Review of applications and qualifications					in-charge
Appeal review				in-charge	
6STU2 Evaluation of student's qualifications and competence to enroll in graduate studies	in-charge				
6RES1 Evaluation of applicants qualifications and competence for research	in-charge				

4.4 Output Elements

OUTPUT ELEMENTS			CUSTOMERS
Process	Name	Ref.	
6PRG1	1. Packing Slip	[RPU5]	General Office File
	2. Record of discrepancy	[RPU6]	Material Supplier & File
6PRG2	1. List of teaching assistants	[RPU9]	Teaching Assistants
	2. Regret letter	[RPU9]	Candidates for TAs
6STU1	1. Regret Letter	[RPU16]	Applicants
	2. Admission Letter	[RPU15]	

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

OUTPUT ELEMENTS			CUSTOMERS
Process	Name	Ref.	
6STU2	1. Letter of Admission	[RPU26]	Students
	2. Regret Letter	[RPU28]	Applicants
6RES1	1. Regret Note	[RPU30]	Applicants

6. REFERENCE DOCUMENTS

CODE	NAME (Records)	PLACE
[RDC11]	Course Plan (25.229 Manufacturing Engineering)	Dr. Cahoon
[RDC22]	Research Project Plan	Not Yet Available
[RPU1]	List of qualified suppliers	Not Yet Available
[RPU2]	Records of evaluation	Not Yet Available
[RPU3]	Purchase requisition Form	General Office
[RPU4]	Pink Confirmation Form	
[RPU5]	Packing Slip	Courier
[RPU6]	Announcement of Teaching Assistant Positions	General Office
[RPU7]	Applications for Positions	
[RPU9]	Regret Letter	Stan (326)
[RPU10]	Policy of assigning hours to teaching assistants	General Office
[RPU11]	High-School Diploma	Not Yet Available
[RPU12]	Transcripts	
[RPU13]	Manitoba High Schools Criteria for Admission	Admissions Office
[RPU14]	Requirements for Admission	
[RPU15]	Admission Letter	Not Yet Available
[RPU16]	Regret Letter	
[RPU17]	Appeal	Dean's Office
[RPU18]	Appeal Decision	
[RPU19]	Application for Admission	Graduate Studies
[RPU20]	Transcripts	
[RPU21]	Letters of Reference	
[RPU22]	Proof of Proficiency in English	
[RPU23]	GPA Requirements	

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

CODE	NAME (Records)	PLACE
[RPU24]	Guidelines for accepting & funding graduate students	General Office
[RPU25]	Letter of admission and financial support	
[RPU26]	Admission Letter	
[RPU27]	Registration Form	
[RPU28]	Regret Letter	
[RPU29]	Advertisement for available research positions	Not Yet Available
[RPU30]	Regret Note	
[RPU31]	Record of discrepancy	
[RPU32]	List of acceptable high schools and diplomas	Admissions Office

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Revised by:		
Approved by:		

APPENDIX III

25.476 ENGINEERING OPERATIONS RESEARCH II
January 1998

Text: "Operations Research: Applications and Algorithms" by Wayne L. Winston, Third Edition, Duxbury Press, Wadsworth Publishing Company, Belmont California, 1994.

Class Times: Monday, Wednesday, Friday 9:30 - 10:20 a.m.

Room: 448 Engineering

Instructor:	A.S. Alfa *Room #:* 246A Eng. Bldg. *Phone #:* 474-9173 *E-mail:* alfa@cc.umanitoba.ca	S. Karapetrovic *Room #:* 428 Eng. *Phone #:* 474-6052 *E-mail:* laki@asqnet.org
Consultation Times:	**Wednesday** **10:30 a.m. - 12:30 p.m.**	**Monday, Wednesday, Friday** **10:30 a.m. - 12:30 p.m.**
Teaching Assistants:	Xu Xiaoyi Room 428	Li-Xia Wen Room 429

Grading Scheme:

3 tests @15% each *	=	45%
Final Exam	=	55%
Total	=	100%

Test Dates:

January 28, 1998
February 11, 1998
March 11, 1998
March 25, 1998

* NOTE: There will be four (4) tests. The results of best three (3) will be counted for the final grade, i.e. the minimum mark received from the four tests will not count. Therefore, a student is allowed to miss one test only.

COURSE OUTLINE[μ]

Title	Chapter.Section
1. Nonlinear Programming (NLP)	12
• Introductory concepts	12.1
• Convex and concave functions	12.2
• Solving NLPs with one variable	12.3
• Golden section search	12.4
• Unconstrained NLP with several variables	12.5
• Method of steepest ascent	12.6
• Lagrange multipliers	12.7
• The Kuhn-Tucker Conditions	12.8
2. Deterministic Dynamic Programming (DP)	20
• Network problems	20.2
• Inventory problems	20.3
• Resource allocation problems	20.4
• Equipment replacement problems	20.5
• Formulating DP recursions	20.6
• Using spreadsheets to solve DP	20.9
3. Network Models	8
• Basic definitions	8.1
• Shortest path problems	8.2
• Maximum flow problems	8.3
• CPM and PERT	8.4
• Minimum spanning tree problems	8.6
4. Markov Chains and Processes	19
• What is a Stochastic Process?	19.1
• What is a Markov Chain?	19.2
• What is a Markov Process?	19.2
• N-step transition probabilities	19.3
• Classification of states	19.4
• Steady state probabilities	19.5
• Mean first passage times	19.5
• Absorbing chains	19.6
Title	**Chapter.Section**

[μ] Course information, including the outline and a list of assignments are also available on: http://home.cc.umanitoba.ca/~umkarape/25476.html

* To be covered if time permits

APPENDIX IV

1. Purpose

The purpose of these notes is to provide guidelines to a teaching assistant for conducting Mechanical Engineering Thermodynamics Laboratory (METL) 306 - Sargent Gas Calorimeter.

2. Guidelines

2.1 Input Elements

WHAT IS GIVEN TO ME		PROVIDED BY:	
1.	Laboratory Schedule	1.	Professor
2.	Laboratory Notes		
3.	List of Students		
4.	Student's Laboratory Reports	2.	General Office
5.	Atmospheric Pressure Reading	3.	Technician

2.2 Output Elements

WHAT I GIVE		GIVEN TO:	
1.	Marked Students Reports	1.	Professor

2.3 Work Instructions

2.3.1 Preparation

The professor will provide the teaching assistant with a list of students, laboratory notes and necessary additional documents. Teaching assistant will subsequently, in coordination with the technician, familiarize with the equipment required for the laboratory and conduct a trial experiment. Any technical difficulties in the course of the term will be resolved in coordination with the laboratory technician and the professor.

2.3.2 Execution

Ten to twenty minutes prior to resuming the laboratory session, teaching assistant shall start the flow of cooling water and then **purge any unburned gas** out of the combustion chamber of the calorimeter with the air. The air hose shall be provided by the technician prior to the trial experiment. This precaution **must be followed. Failure to do so could result in an explosion.** Subsequently, teaching assistant will start the flow of gas, light the burner and install it in the centre of the calorimeter. When the gas flow and temperatures at the calorimeter are stabilized, the experiment may be started.

At the start of the session, teaching assistant will check student attendance. Consequently, he/she will firstly describe the laboratory requirements. Secondly, the teaching assistant will describe the apparatus and the experimental method. The following table illustrates the parameters to be measured and corresponding instruments:

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Approved by:		

Parameter	Instrument
Gas Volume	Wet Gas Meter
Gas Temperature	Gas Meter Thermometer
Time Required for a Unit of Gas Volume	Stop Watch
Relative Gas Pressure (to atmospheric)	Water Manometer
Atmospheric Pressure	Barometer (provided by the technician)
Temperature at Barometer	Thermometer (provided by the technician)
Humidity (Enthalpies for A.H.C)	Psychrometer
Temperature of Products of Combustion	Thermometer (at the back of calorimeter)
Mass of Water (collected in the buckets)	Scale
Volume of Condensated Water	Glass Test Tubes
Inlet Water Temperature	Inlet Water Thermometer
Outlet Water Temperature	Outlet Water Thermometer

The instruments are illustrated in section 2.4 Apparatus.

Each student in the group should be assigned with a responsibility to measure one or more specific properties. For example, one student can measure gas volume, gas temperature and time, the second can observe and record relative gas pressure and so forth. Two tenths of a cubit foot of gas are to be burned in the first test, and the same amount in the second test for the purpose of verifying the original results. *(For the purpose of the trial experiment, the same procedure is followed. After the trial experiment, teaching assistant shall review the results obtained and apply any corrective actions required in coordination with the technician and the professor)*

Subsequently, when all the parameters have been measured, the students will gather in a group and fill the "Test Record", provided in the laboratory notes. The teaching assistant will conclude the session by informing the student on his/her office hours for consultations on the report.

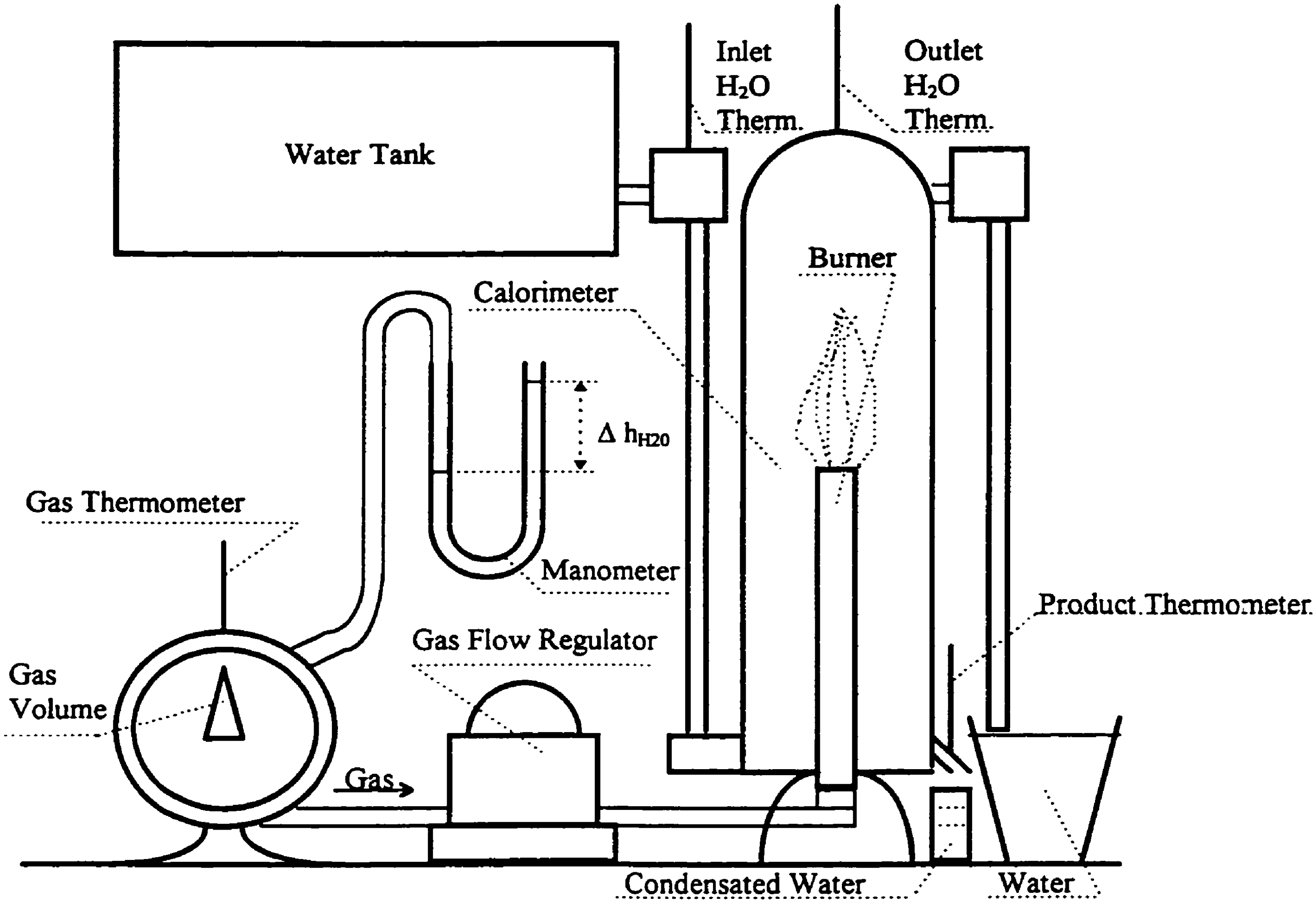
2.3.3 Marking

The marking should be based on the written report and participation (optional).The following is the suggested marking scheme for the written laboratory report:

Requirement	Marks	Comment
Complete Calculations	4	The emphasis is on the conceptual understanding not calculation errors. For example, subtract 0.5 points for an error in relative gas pressure calculation, if wrong density is used
Label Apparatus	1	Subtract 0.1 point for each device not labeled
Compare the Recommended to Calculated Heating Values, Relative Error	1	
Explain the difference between Higher and Lower Heating Value	1	
Subsequent Six Questions	0.5 each	
TOTAL	10	

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Approved by:		

2.4 Apparatus



3. Reference Documents

[1] Messersmith, C.W., Warner, C.F., 1959, *Mechanical Engineering Laboratory*, John Wiley & Sons
[2] American Society for Testing Materials, *Standard method of Test for Calorific Value of Gaseous Fuels by the Water Flow Calorimeter* (ASTM Designation D: 900-55)
[3] Cengel, Y.A., Boles, M.A., 1994, *Thermodynamics: An Engineering Approach*, (2nd ed.), McGraw-Hill
[4] Lab Notes for Sargent Gas Calorimeter Experiment

	Name:	Signature:
Prepared by:	Stanislav Karapetrovic	
Approved by:		

University of Manitoba Mechanical & Industrial Engineering	INSTRUCTION FOR ENROLLING IN COURSES WITH TIME CLASH	Status & Issue Number : D1
		Date of Issue: July 16, 1996
		Page 1 of 2
CONTROLLED COPY DO NOT DUPLICATE		Procedure Code : RDC-16
	Compliance with ISO 9001: 4.13 Nonconforming Product	

1.0 Purpose

The purpose of this instruction is to provide guidelines for granting permission ('the permission' in the text) to students to enroll in courses with a time-table conflict.

2.0 Scope

This instruction addresses:

(a) collecting the necessary information on the student requesting enrollment in two courses with a time-table conflict

(b) ruling a decision on whether enrollment is permitted or not

(c) keeping the records of student's requests and corresponding decisions

3.0 Application

This instruction assists the following:

(a) The Undergraduate Program secretary

(b) Faculty (professors) who decide to give the permission

(c) The Department Head

4.0 Definitions and Principles

Not Applicable

5.0 Responsibility

ACTIVITIES	Secretary, Undergraduate Program	Professors	Department Head	The Student
Collecting information on students	√	√		
Granting permission		√		
Granting permission in extraordinary circumstances		√	√	
Keeping records	√			
Obtaining signatures				√

	Function:	Name:	Signature:
Prepared by:			
Revised by:			
Approved by:			

6.0 Instruction

(a) A student who wishes to enroll in two courses with the same time-slot must fill in a formal request (Record RTC-50). The request must contain the reason, and the two courses he/she wishes to attend simultaneously. It is the student's responsibility to get the signatures.

(b) The Undergraduate Program Secretary or the professors shall retrieve the student's file if additional information is required.

(c) Both professors shall assess if there is enough grounds to permit the student to attend his/her course. The following are possible situations:

- The student is in good academic standing, there is evidence that the student performance is satisfactory, and he/she is unable to take a sufficient number of courses to remain a full-time student, or
- The student needs only these two courses to graduate, or
- The student will be hit by the 8- year rule, or
- The student has taken one, or both courses already and he/she is not on probation or suspension
- The student who is on probation or suspension will not be given a permission unless the Department Head rules otherwise. In this case, professors' permission is required as well.

Note: The professors can deny the request for all or any of the above reason(s).

(d) If both professors grant the permission, they will sign the record RTC-50. The record shall also be signed by the student.

7.0 Reference Documents

(a) Record RDC 50

	Function:	Name:	Signature:
Prepared by:			
Revised by:			
Approved by:			

THE UNIVERSITY OF MANITOBA

Intra-Departmental Correspondence

DATE: ___________

TO: Bev Dunlop, Secretary, Undergraduate Program

FROM: Prof. ______________________________ (_____)
COURSE 1

and Prof. ______________________________ (_____)
COURSE 2

STUDENT: ______________________________ ______________
NAME STUDENT NUMBER

REASON: ______________________________

I understand that this permission has been granted under unusual circumstances and that I am fully responsible for learning the course material and taking all required examinations. Any impact this may have on my grades is my responsibility only.

______________________ ______________________
DATE SIGNATURE

COURSE 1.

I give my permission for the above named student, to enroll in the course ________, not withstanding the timetable conflict with the course ____________.

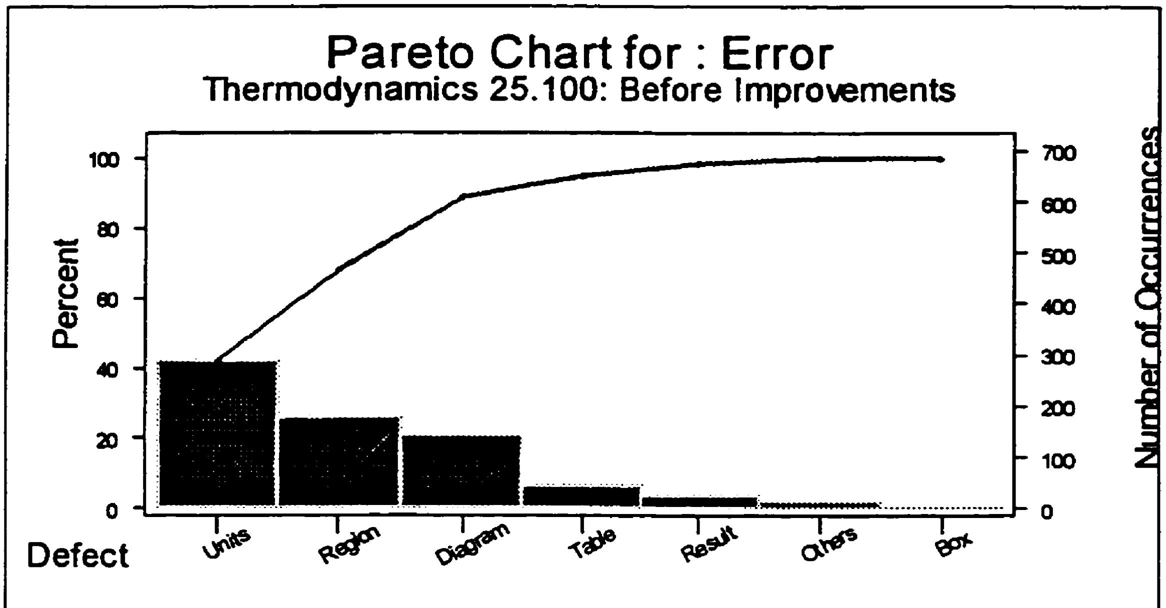
____

COURSE 2.

I give my permission for the above named student, to enroll in the course ________, not withstanding the timetable conflict with the course ____________.

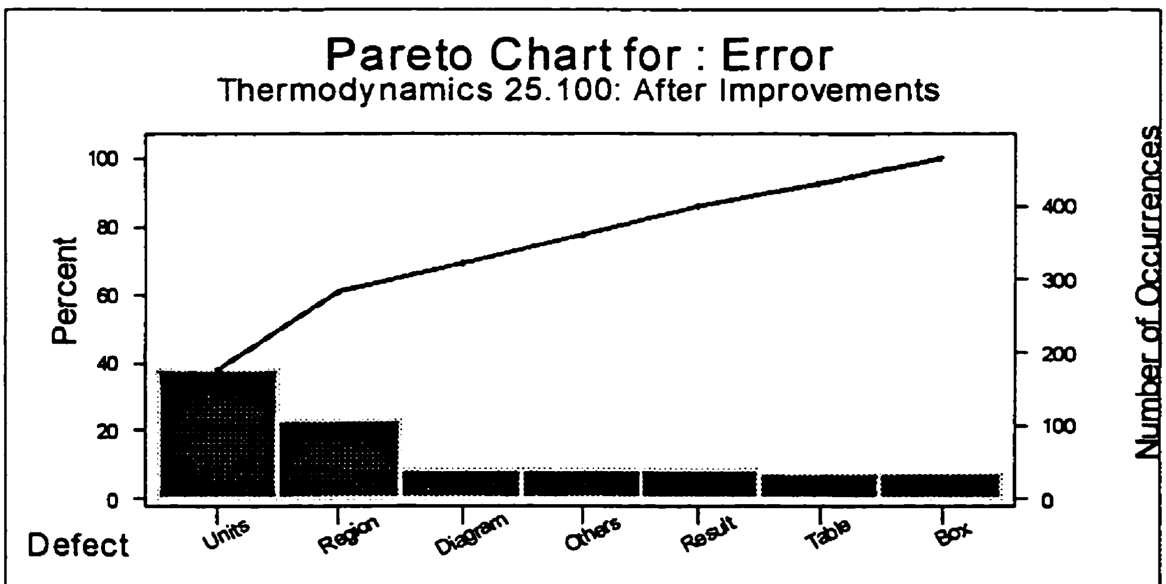
____

APPENDIX V



	Units	Region	Diagram	Table	Result	Others	Box
Count	288	177	141	43	24	10	1
Percent	42.1	25.9	20.6	6.3	3.5	1.5	0.1
Cum %	42.1	68.0	88.6	94.9	98.4	99.9	100.0

Quality Records: Assignment Errors Before and After a Quality Improvement



	Units	Region	Diagram	Others	Result	Table	Box
Count	177	105	39	39	38	33	33
Percent	38.1	22.6	8.4	8.4	8.2	7.1	7.1
Cum %	38.1	60.8	69.2	77.6	85.8	92.9	100.0

APPENDIX VI

Node: 0

Compare the relative PREFERENCE with respect to: GOAL

	THRUPUT	OUTPUT
INPUT	1.9	(1.2)
THRUPUT		(1.4)

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Student's Education
INPUT	Input
THRUPUT	Thruput
OUTPUT	output

APPENDIX VII

TO: Prof. ______________________

Department of Mechanical and Industrial Engineering

FROM: Stanislav (Stan) Karapetrovic

DATE: October 29, 1997.

RE: Scheduled Meeting

Dear Sir / Madame,

Quality assurance of education and research activities is increasingly becoming one of the most important issues in engineering education. As a part of the ISO 9001 quality system development exercise in the Department of Mechanical and Industrial Engineering, we have developed a hierarchical set of product quality characteristics, with the purpose of improved understanding and assurance of quality. This has been done with the assistance of Dr. Douglas Ruth, the Associate Dean of Engineering.

The next step in this analysis is to weigh product quality characteristics according to their importance, as judged by the faculty members. The weighting will be done using a decision analysis technique called the "Analytic Hierarchy Process" (AHP). AHP is a technique that applies pairwise comparisons of hierarchically presented characteristics. With coordination from the Dean's office, a meeting has been scheduled for ______________________. At the meeting, I will further explain the AHP technique, and with your kind help, I will conduct the scaling.

Thank you in advance for your cooperation.

With best regards,

Stanislav Karapetrovic (Stan)

e-mail: laki@asqnet.org

AHP Pairwise Comparison Matrices

Decision Maker #____, Date and Time: _________

How much more important is the characteristic from the i-th row compared to the characteristic from the j-th column ?

The value of relative importance is written as the $A_{i,j}$ of the matrix A, and can take the following values:

VALUE OF $A_{i,j}$	INTERPRETATION
1	Characteristic "i" is EQUALLY IMPORTANT as "j"
2	
3	Characteristic "i" is WEAKLY MORE IMPORTANT than "j"
4	
5	Characteristic "i" is STRONGLY MORE IMPORTANT than "j"
6	
7	Characteristic "i" is VERY STRONGLY MORE IMPORTANT than "j"
8	
9	Characteristic "i" is ABSOLUTELY MORE IMPORTANT than "j"

Characteristic	First Column	....	j-th Column	....
First Row				
....				
i-th Row			$A_{i,j}$	
....				

Example:

A decision maker judges that characteristic 'INPUT' is weakly less important than 'PROCESS' (Value = 1/3), 'INPUT' is equally important as 'OUTPUT' (Value = 1), and that 'PROCESS' is weakly more important than "OUTPUT' (Value = 3).

Characteristic	INPUT	PROCESS	OUTPUT
INPUT	1	1/3	1
PROCESS		1	3
OUTPUT			1

AHP Pairwise Comparison Matrices

Decision Maker #____

Department Characteristics	Research	Courses & Program	Student's Education
Research	1		
Courses & Program		1	
Student's Education			1

Research	Research Training	Research Productivity
Research Training	1	
Research Productivity		1

Research Training (RT)	Input	Throughput	Output
Input	1		
Throughput		1	
Output			1

RT: Input	Grant money	Equip. money	Stud/prof ratio	Committees	Student selection
Grant money	1				
Equip. money		1			
Stud/prof ratio			1		
Committees				1	
Student selection					1

RT: Throughput	Lead time to graduate	Lead time to candidacy	Student evaluation
Lead time to graduate	1		
Lead time to candidacy		1	
Student evaluation			1

RT: Output	Employability of grad. students	Publications of grad. students
Employability of grad. students	1	
Publications of grad. students		1

Research Productivity (RP)	Input	Throughput	Output
Input	1		
Throughput		1	
Output			1

RP: Input	Research proposals	Equipment proposals	Number of grad. students
Research proposals	1		
Equipment proposals		1	
Number of grad. students			1

AHP Pairwise Comparison Matrices

Decision Maker #____

Research proposals	Written and submitted	Funded
Written and submitted	1	
Funded		1

Equipment proposals	Written and submitted	Funded
Written and submitted	1	
Funded		1

RP: Throughput	Working & submitted papers	Research reports
Working & submitted papers	1	
Research reports		1

RP: Output	Publications	Reputation	Innovation
Publications	1		
Reputation		1	
Innovation			1

Publications	Journals	Conferences
Journals	1	
Conferences		1

Reputation	Invited/Keynote presentations	Editorial & referee duties
Invited/Keynote presentations	1	
Editorial & referee duties		1

Innovation	Patents	New laboratories and methods
Patents	1	
New laboratories and methods		1

Courses / Program	Input	Throughput	Output
Input	1		
Throughput		1	
Output			1

Courses/program: Input	Attractiveness to students	Educational material	Certification
Attractiveness to students	1		
Educational material		1	
Course certification			1

AHP Pairwise Comparison Matrices

Decision Maker #___

Educational material	Textbooks & CD ROMs	Lab Manuals	Audio-Visuals
Textbooks & CD ROMs	1		
Lab Manuals		1	
Audio-Visuals			1

Courses/Program: Throughput	Scheduling and topic cover	Classroom effectiveness
Scheduling and topic cover	1	
Classroom effectiveness		1

CP: Output	Teaching awards	Failure rate	EE initiatives	Course evaluation	Conformance
Teaching awards	1				
Failure rate		1			
EE initiatives			1		
Course evaluation				1	
Conformance					1

Engineering Education initiatives	EE publications	EE presentations	EE referee/editorial duties
EE publications	1		
EE presentations		1	
EE referee/editorial duties			1

Course evaluation	Students' evaluation	Peer & outside evaluation
Students' evaluation	1	
Peer & outside evaluation		1

Student's education	Input	Throughput	Output
Input	1		
Throughput		1	
Output			1

Education: Input	Student selection	Stud/prof ratio	Stud/TA&tech ratio	Resources/student
Student selection	1			
Stud./prof. ratio		1		
Stud./TA&tech ratio			1	
Resources/student				1

Resources per student	Expenses per student	Equipment per student
Expenses per student	1	
Equipment per student		1

AHP Pairwise Comparison Matrices

Decision Maker #___

Education: Thruput	Failures & repetitions	Program attrition	Student awards	Student success
Failures & repetitions	1			
Program attrition		1		
Student awards			1	
Student success				1

Student awards	National / International	Internal
National / International	1	
Internal		1

Student success	Design projects	Competitions
Design projects	1	
Competitions		1

Education: Output	Student employability	Reputation of graduates
Student employability	1	
Reputation of graduates		1

Student employability	Percentage employed in eng. jobs	Starting sallary
Percentage employed in eng. jobs	1	
Starting sallary		1

Reputation of graduates	Graduate schools	Professionals
Graduate schools	1	
Professionals		1

Suggestions on other characteristics and/or indicators that, in your opinion, would be useful (Please indicate where in the hierarchy you would like to see those):

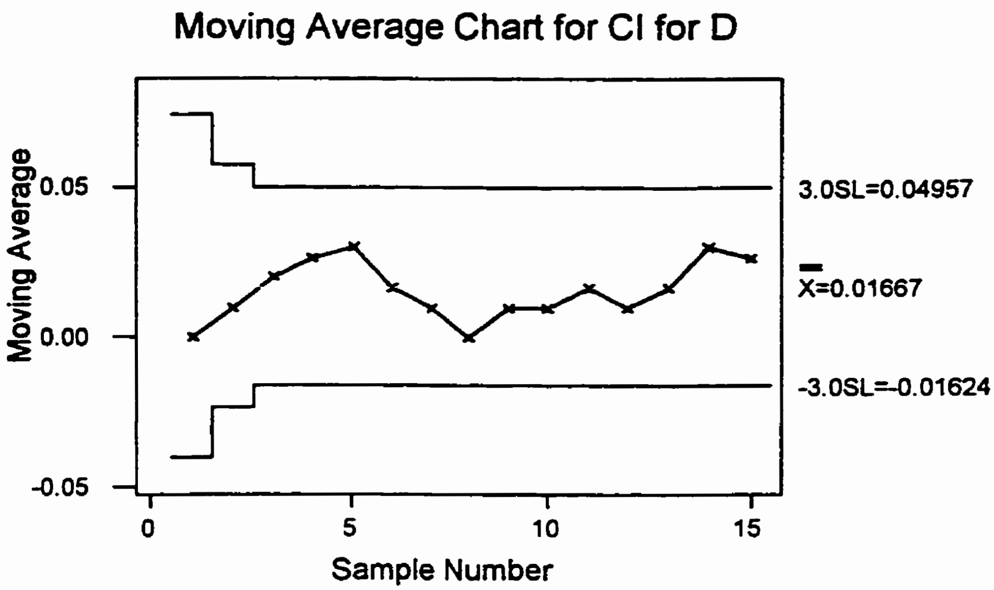
____

____

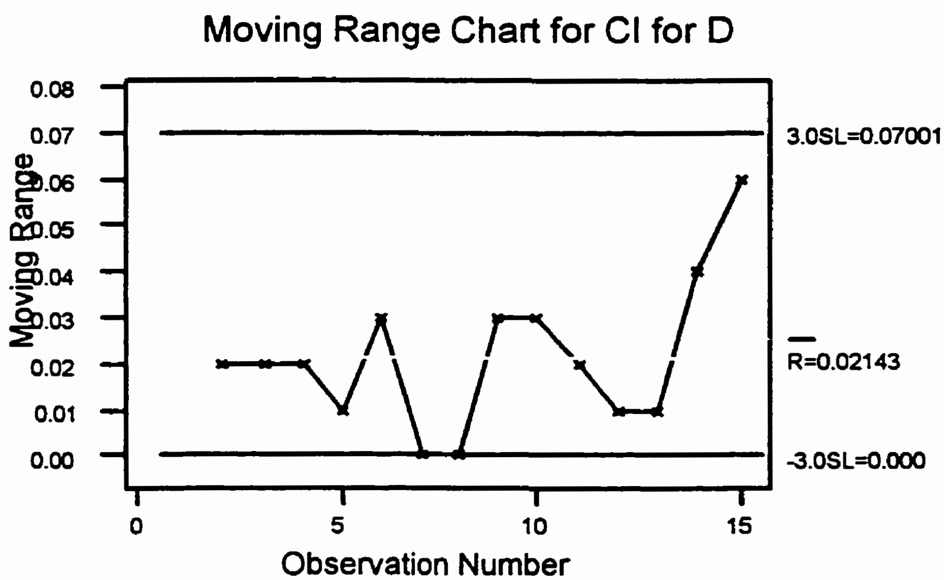
____

____

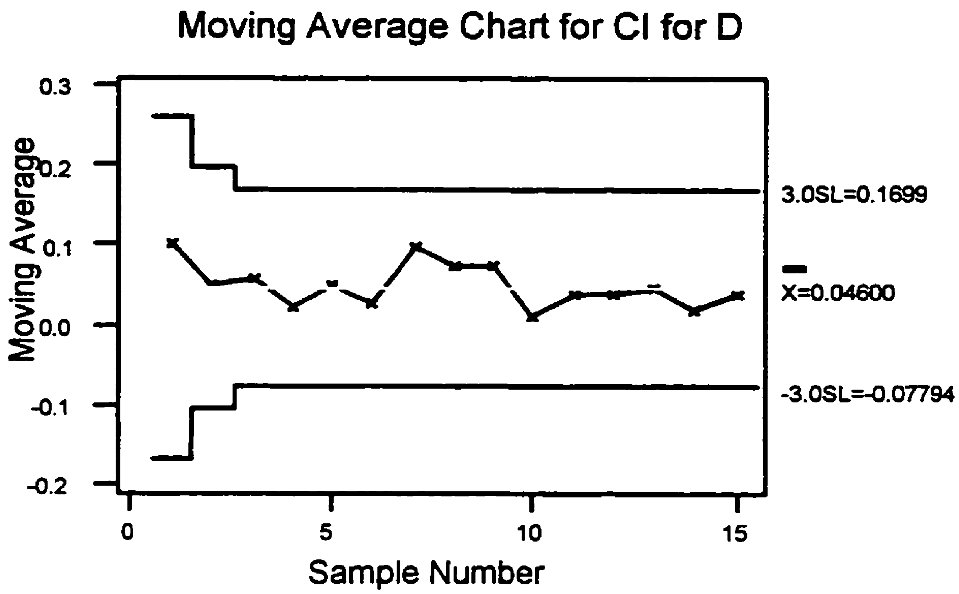
THANK YOU VERY MUCH
FOR YOUR TIME AND COOPERATION !



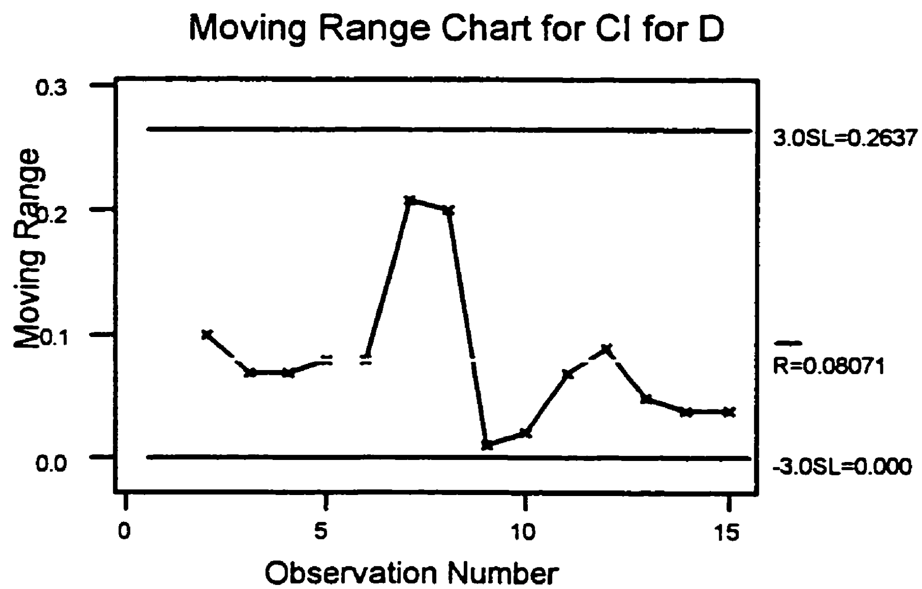
Moving Average Chart for DM #1



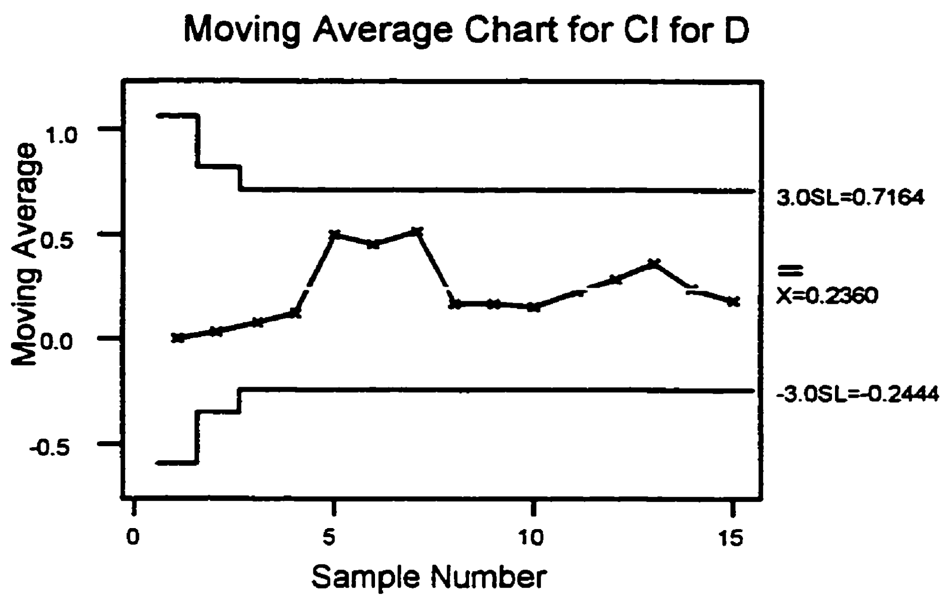
Moving Range Chart for DM #1



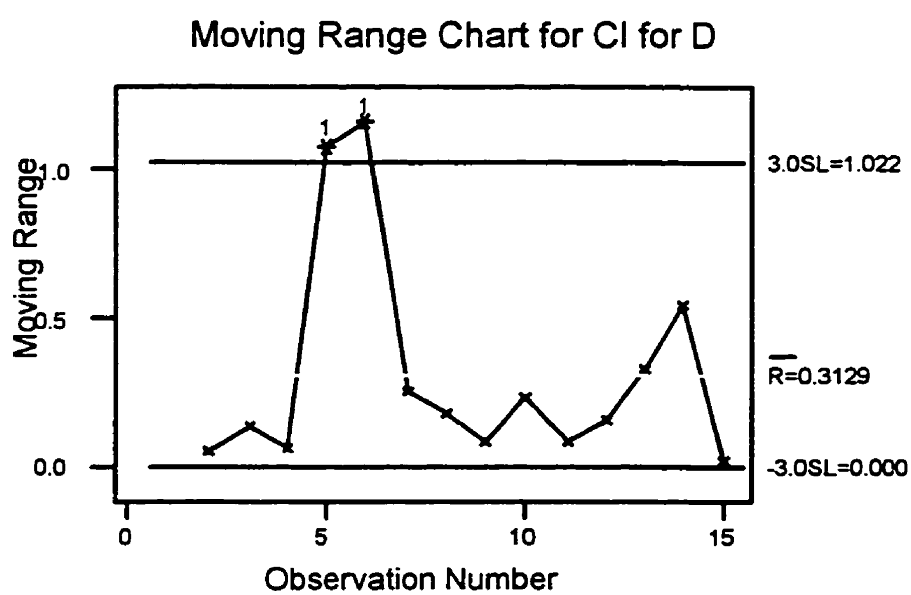
Moving Average Chart for DM #2



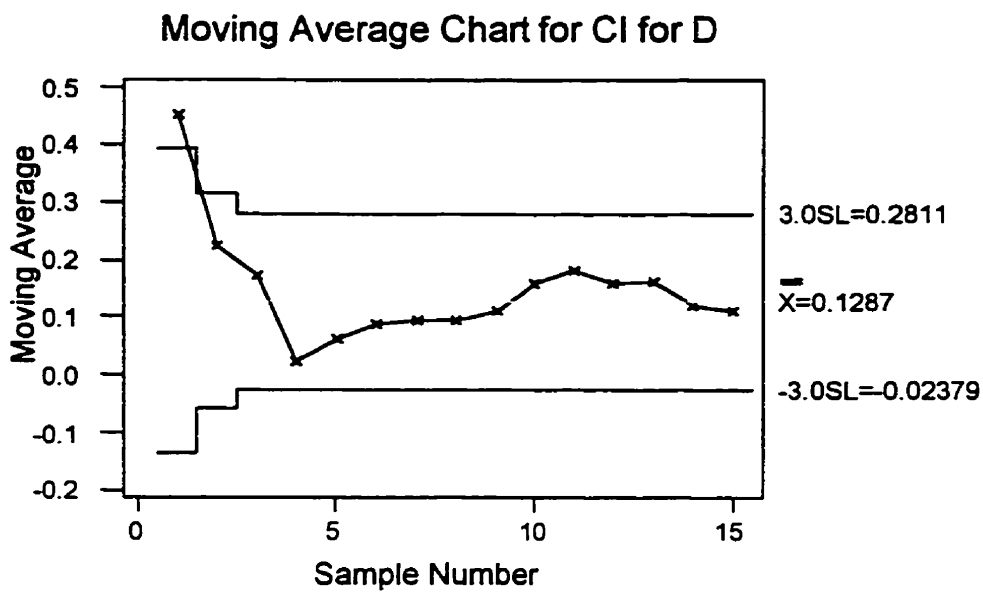
Moving Range Chart for DM #2



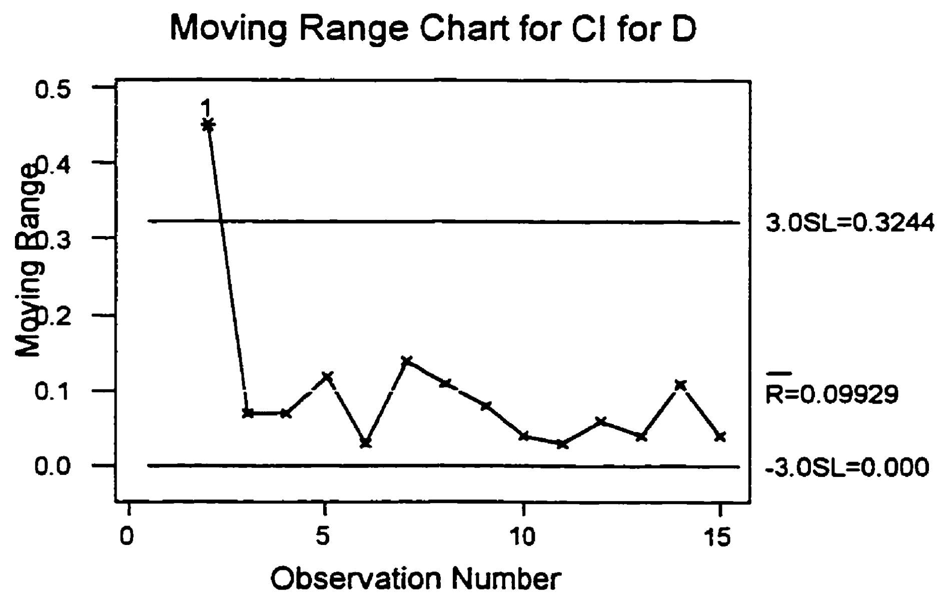
Moving Average Chart for DM #3



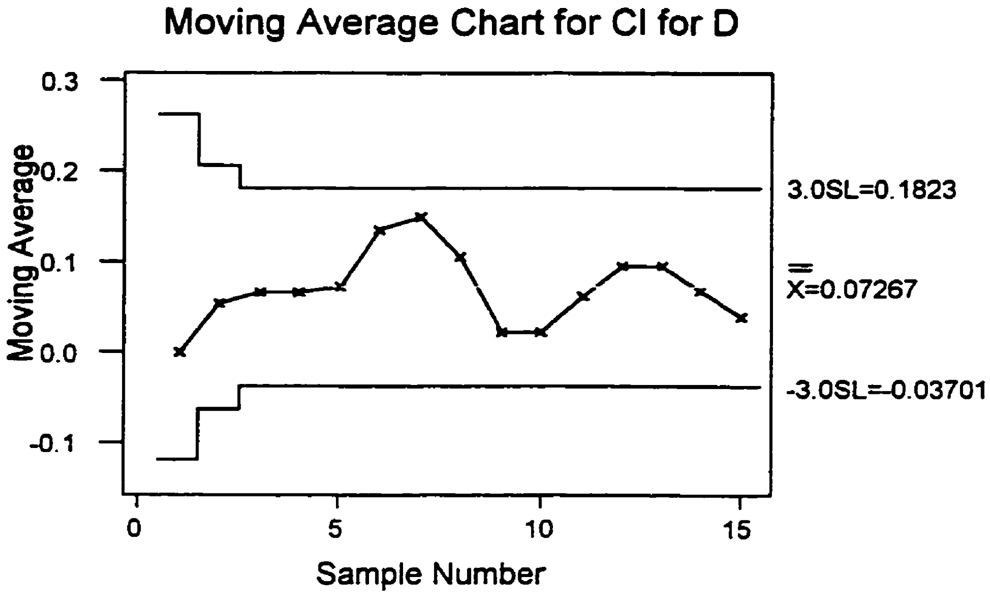
Moving Range Chart for DM #3



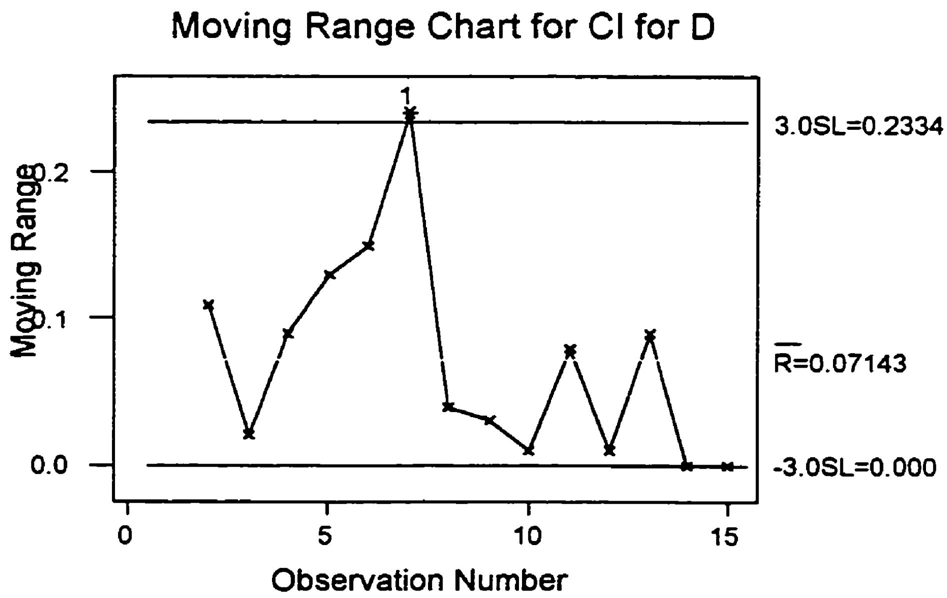
Moving Average Chart for DM #4



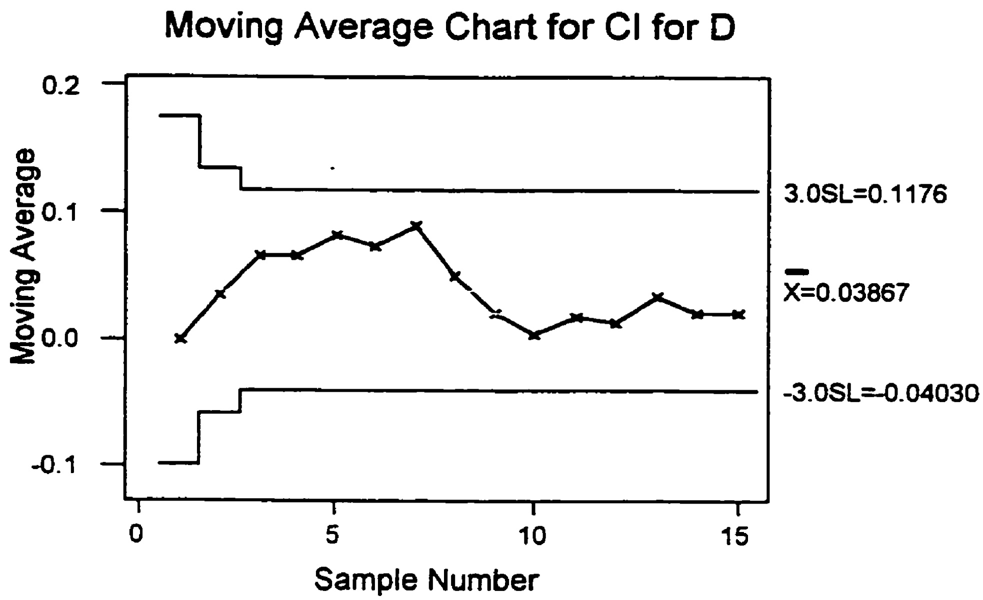
Moving Range Chart for DM #4



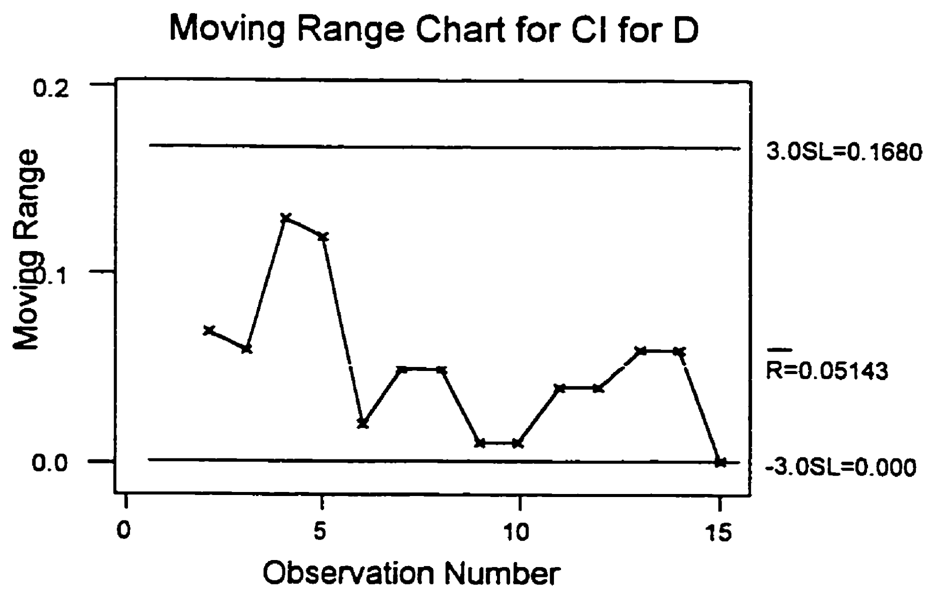
Moving Average Chart for DM #5



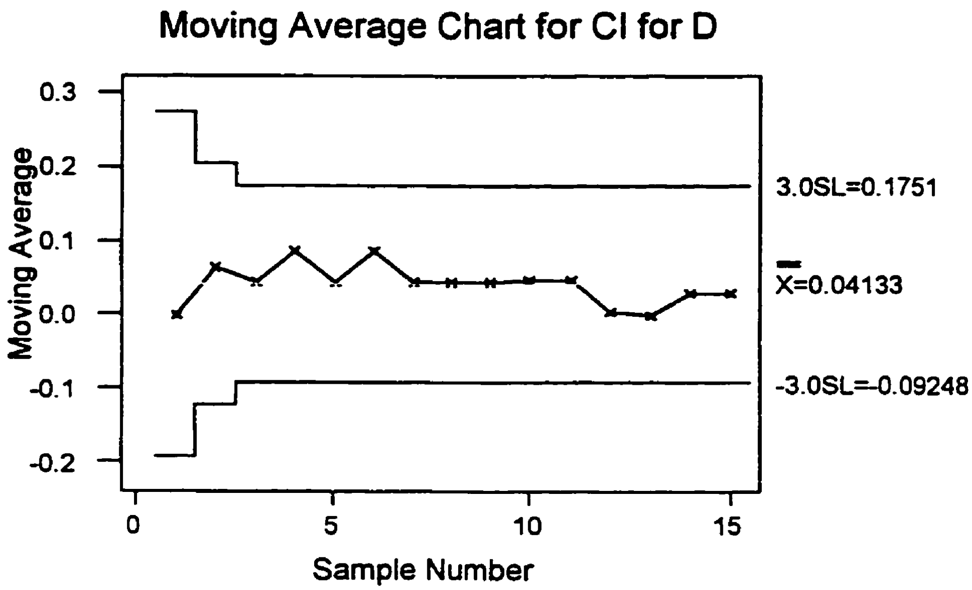
Moving Range Chart for DM #5



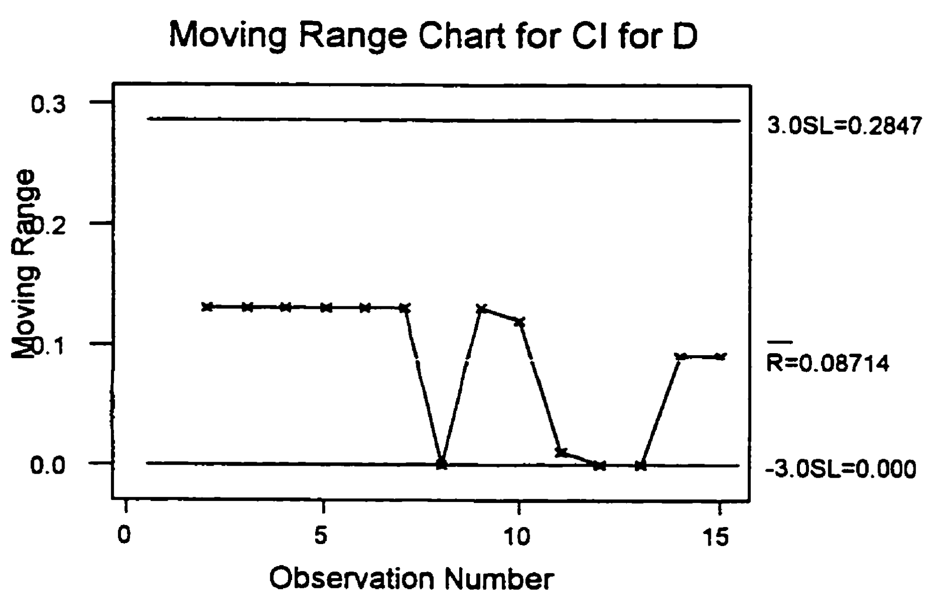
Moving Average Chart for DM #6



Moving Range Chart for DM #7



Moving Average Chart for DM #7



Moving Range Chart for DM #7

APPENDIX VIII

THERMODYNAMICS 25.220: Sargent Gas Calorimeter Experiment #306

1. The lower heating value accounts for the heat:	ANSWER
(a) added to the unsaturated air to saturate it, due to the air humidity	
(b) released by the condensated water vapour	Before:
(c) released by the combustion of CO_2	
(d) absorbed by the calorimeter	After:
(e) I don't know	87/98 (88.8%)

2. The heating value can be expressed in the following units:	ANSWER
(a) BTU/ft^3 [British Thermal Units per cubic foot]	
(b) kJ [kilo-Joules]	Before:
(c) kJ/(kgK) [kilo-Joules per kilogram and Kelvin]	
(d) BTU/lb [British Thermal Units per pound]	After:
(e) I don't know	94/98 (95.9%)

3. You have two manometers available: one with water, the other with mercury. You are using them to measure the same relative pressure. You have the following data available: Density of water = 1,000 kg/m^3, Density of mercury = 13.6 g/cm^3, Specific heat for water = 4,182 J/kgK, Specific heat for mercury = 0.1373 J/gK. Atmospheric pressure = 101,000 Pa. The water manometer reading is 6.8 inches. What is the reading of the mercury manometer?	ANSWER
(a) 102,666 Pa	
(b) 1 inch	Before:
(c) 2 inches	
(d) 0.5 inches	After:
(e) I don't know	85/98 (86.7%)

4. The mass of water circulated is directly used in the calculation of:	ANSWER
(a) lower heating value	
(b) higher heating value	Before:
(c) observed heating value	
(d) pressure of water vapour	After:
(e) I don't know	80/98 (81.6%)

5. Reduction factor accounts for:	ANSWER
(a) heat added to the unsaturated air to saturate it	
(b) heat released by the condensated water vapour	Before:
(c) compressibility of natural gas	
(d) moisture in the air	After:
(e) I don't know	72/98 (73.5%)

6. The "wet gas meter" measures:	ANSWER
(a) humidity of air	
(b) pressure of natural gas	Before:
(c) mass flow rate of natural gas	
(d) volume of natural gas	After:
(e) I don't know	92/98 (93.8%)

7. The calorimeter method used in the experiment is:	ANSWER
(a) oxygen-bomb	
(b) continuous flow	Before:
(c) natural gas bomb	
(d) discrete flow	After:
(e) I don't know	92/98 (93.8%)

Appendix 8-1: Questionnaire for Sargent Gas Calorimeter Experiment

THERMODYNAMICS 25.220

Vapour Compression Refrigeration System #214

GROUP #________DATE: __________

1. In a household refrigerator, the coils behind the refrigerator serve as the:	ANSWER
(a) evaporator (b) condenser (c) compressor (d) exhaust (e) I don't know	Before: After:

2. You have a refrigerator that is removing the heat from its food compartment at a rate of 360 kJ/min. If the food is maintained at 4°C and the required power input to the refrigerator is 2 kW, the coefficient of performance for this refrigerator is:	ANSWER
(a) 1.5 (b) 1.8 (c) 1/3 (d) 3 (e) I don't know	Before: After:

3. If an air conditioner is used as a heat pump, and its coefficient of performance as a refrigerator is COP_R, the corresponding coefficient of performance as a heat pump COP_{HP} is:	ANSWER
(a) $COP_R + 1$ (b) $COP_R - 1$ (c) COP^2 (d) COP_R (e) I don't know	Before: After:

4. In the course of the vapour compression cycle experiment, refrigerant reaches the flowmeter (and the evaporator) as:	ANSWER
(a) superheated vapour (b) saturated mixture (c) saturated vapour (d) subcooled liquid (e) I don't know	Before: After:

5. Which of the following statements is true:	ANSWER
(a) COP for a refrigerator can be greater than one (b) COP for a heat pump cannot be greater than one (c) $COP_{HP} = COP_R - 1$ (d) both "a" and "b" are correct (e) I don't know	Before: After:

6. Pressure gauges (part of the apparatus) measure:	ANSWER
(a) the absolute pressure of air (b) the absolute pressure of the refrigerant (c) relative pressure of refrigerant (d) hydrodynamic pressure of water (e) I don't know	Before: After:

7. Water in the experiment is used as a:	ANSWER
(a) heat source (b) heat sink (c) evaporator (d) both "a" and "b" (e) I don't know	Before: After:

Appendix 8-2: Questionnaire for Vapour Compression Refrigeration Experiment

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6″

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989