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INDUSTRIAL AND SYSTEMS ENGINEERING FOR THE 21st CENTURY: DISCOVERING AND ASSESSING THE MULTIFACETED NEEDS OF INDUSTRY

By

Gary W. Foster, Ph.D.

The Ohio State University, 2000

Professor Jerald Brevick, Adviser

Although industrial and systems engineers possess broad skill mixes and play diverse roles working in industry, it is hypothesized that industrial and systems engineers have unique fundamental core competencies and associated knowledge that distinguish themselves from other related disciplines. This study was intended to discover from an industry viewpoint what these core competencies and associated knowledge are and how or whether they change according to different key sample subgroups.

The researcher suspects that industry's perception of what constitutes key competencies to produce ideal industrial and systems engineers may not be identical to what key competencies industry is actually utilizing. Therefore, this study was designed to discover if any differences exist along these two different dimensions by analyzing incumbents' responses.

To accomplish this, the researcher developed a knowledge based survey instrument to identify what specific industrial and systems engineering (ISE) knowledge items (KIs) are being applied in industry jobs. In addition, this instrument also asked

incumbents to rate these 350 KIs to determine how much educational emphasis should be placed on each of them for undergraduate education curriculum development.

Based on the researcher's literature review, this project was the first ever to investigate these issues on such a comprehensive level of data collection and analysis for the ISE community. These results can be used by ISE institutions to help validate their respective curriculums. The survey instrument can also provide a framework methodology that can be altered to fit specific needs for different institutions. It can be duplicated in future years to track how industry's needs are changing over time. This provides a valuable tool for universities to use to ensure their respective curriculums keep pace with an ever-changing industry. The Ohio State University's (OSU) Industrial, Welding, and Systems Engineering (IW&SE) department will examine the resulting data to ensure its undergraduates are ready for industry's demands for the 21st century. However, the principle findings indicate the need for a diverse, well-rounded education that can be tailored to specific specialties. A detailed discussion is also provided regarding the results and implications for the total sample and each of the identified subgroups.

INDUSTRIAL AND SYSTEMS ENGINEERING FOR THE 21st CENTURY: DISCOVERING AND ASSESSING THE MULTIFACETED NEEDS OF INDUSTRY

DISSERTATION

Presented in Partial Fulfillment of the Requirement for

the Degree Doctor of Philosophy in the Graduate

School of The Ohio State University

By

Gary W. Foster, B.S., M.S.

*****

The Ohio State University
2000

Dissertation Committee:

Professor Jerald Brevick, Adviser

Professor G. Keong Leong

Professor R. Allen Miller

Approved by

Adviser

Department of Industrial,
Welding, and Systems
Engineering

ABSTRACT

Although industrial and systems engineers possess broad skill mixes and play diverse roles working in industry, it is hypothesized that industrial and systems engineers have unique fundamental core competencies and associated knowledge that distinguish themselves from other related disciplines. This study was intended to discover from an industry viewpoint what these core competencies and associated knowledge are and how or whether they change according to different key sample subgroups.

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Dedicated to my loving and beautiful wife, Colleen, and daughter, Cailin Renee; and my parents, Gary and Linda

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VITA

July 31, 1968 .... Born - Fairfield, Iowa, USA.

1990 .... B.S. Engineering Psychology - Human Factors Engineering, United States Air Force Academy, Colorado Springs, Colorado, USA.

1990 .... Commissioned *Second Lieutenant*, United States Air Force.

1990 - 1992 .... *Officer in Charge Test Construction Team*, *Test Psychologist*, United States Air Force, Air Education and Training Command, Occupational Measurement Squadron, Randolph Air Force Base, San Antonio, Texas, USA.

1992 .... Commissioned *First Lieutenant*, United States Air Force.

1992 - 1994 .... *Occupational Analyst*, United States Air Force, Air Education and Training Command, Occupational Measurement Squadron, Randolph Air Force Base, San Antonio, Texas, USA.

1993 .... M.S. - Industrial Engineering, St. Mary's University, San Antonio, Texas, USA.

1994 .... Commissioned *Captain*, United States Air Force.

1994 - 1995 .... *Education With Industry Fellow* - United States Air Force, Human Factors Engineer, Industrial Engineer, Software Quality Assurance Engineer, Lockheed-Martin, Government Electronics Systems, Moorestown, New Jersey, USA.

1995 - 1997 .... *Chief, C-130 Manufacturing*, United States Air Force, Aeronautical Systems Center, C-130 Systems Program Office, Wright-Patterson Air Force Base, Dayton, Ohio, USA.

1995 - Present .... *Ph.D. Student* - The Ohio State University, United States Air Force, Air Force Institute of Technology, Columbus, Ohio, USA.

1999 – Present .... *Integration Technical/Program Management Lead;*
Chief, Quality Assurance Evaluator - Cheyenne Mountain Complex Mission Support Software;
Deputy, Fixed Evolutionary Development;
Chief, Cheyenne Mountain Command and Control Software;
Integrated Space Command and Control Transition Lead, Electronic Systems Center, Strategic Nuclear Deterrence Command and Control Systems Program Office, Peterson Air Force Base, Colorado Springs, Colorado, USA.

FIELDS OF STUDY

Major Field: Industrial and Systems Engineering

Studies in: Manufacturing Systems
Operation Manufacturing Management
Manufacturing Ergonomics/Safety

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CHAPTER 1

INTRODUCTION

"To furnish the means of acquiring knowledge is ... the greatest benefit that can be conferred on mankind." - John Quincy Adams[1]

Like the chicken and the egg conundrum, a push-pull relationship exists between technological change and global competition. Global competition fuels technological change. Technological change then fuels more global competition as companies search to gain a competitive market advantage. Those companies that adapt survive while those that do not fail. Indeed, "Those who join the revolution will become the survivors, while those who prefer the status quo will become the causalities" (Reid, 1990).

1.1 Significance of Discovering and Assessing the Multifaceted Needs of Industry from an Educational Perspective

Education provides the very foundation needed to support an ever-changing environment because at the heart of every system lies an individual who is the agent of change. The challenge facing engineering is multifaceted and dichotomous. Clearly, to be effective in today's world one must possess a broad range of skills that need to be constantly updated. According to Dr. Joseph Bordogna, acting director of the National Science Foundation, "Expertise in a single discipline or technology is no longer the Holy

Grail for either a rewarded or rewarding engineering career. The modern engineer needs to be educated to thrive through change, else the engineer will become a commodity on the global market instead of that market's enabler of wealth creation. The former is bought cheaply; the latter is more dearly valued" (1999). On the contrary, however, due to the enormous complexity of most systems, a high demand will still exist for specialized and technologically advanced professionals in all aspects and types of specific system processes. This suggests both a broad and dynamic range exists for educational institutions. This dichotomous problem is especially pronounced for industrial and systems engineers whose goal is to effectively and efficiently utilize man, machine, and materials across a broad spectrum of operations for the long-term benefit of organizations. Not only must industrial and systems engineers be technically competent in specific technologies, they must also flourish in the growing need for systems solutions.

Undergraduate curricula must then continuously evolve because industry and industrial practices and their associated systems continue to change rapidly. According to the Society of Manufacturing Engineer's 2nd International Conference on "Manufacturing Education for the 21st Century" held in San Diego, CA during October 1998, "... education is being driven by requirements of the customer, which is industry, and by competition and the global marketplace." According to this conference, the future will call for true renaissance engineers with allied skills in business, communications, teamwork, and leadership to be developed. The conference further proclaimed, "... education must be tailored to develop students capable of contributing as employees in the newly predominant industries and also for careers that are difficult to forecast today." Thus, if the industrial and systems engineering (ISE) community wants to excel in this environment and to be respected as an interdisciplinary area, it must address state-of-the-art topics and ideas using state-of-the-art technologies and approaches. A challenge is then set for educators to develop and apply more effective methods for teaching and learning. However, before this step is taken, one should evaluate what knowledge items (KIs) should be taught from an academic and industrial perspective before the process of conveying information to students takes place. "By examining engineering education and exploring innovations based on integrative and holistic approaches, we can shed light on a host of key issues facing the entire science and engineering enterprise as we move into a remarkable era ... " (Bordogna, 1999).

1.2 Problem Statement

Based on the prevalent literature and the difficulties associated with forecasting and assessment technologies, very few comprehensive empirical measures exist to evaluate what specific KIs should be taught to students. This study explored this problem by developing a comprehensive measurement instrument to solicit and collect feedback from industry. Almost all other studies have relied upon a small panel of senior educators and/or senior management engineers to identify which broad area KIs are more and less important. Although this approach is efficient in its execution, it provides a more restricted viewpoint and does not provide nearly as much detail as the approach taken in this study.

1.3 Research Objectives and Expected Contributions

This study develops a repeatable methodology to be used as a continuous process improvement tool by providing objective data based on the dimensional criteria of alumni responses. Unlike most previous studies which approached this problem in a more simplistic, cursory manner, this study seeks inputs on specific KIs from a very large, diverse ISE population base to gain a more comprehensive assessment of the needs of industry.

The study's main objective is to discover and help determine, using advanced statistical procedures, what KIs are the most and least salient in industry and what level of undergraduate ISE education emphasis should be placed on each KI from an industry viewpoint. In addition, this study also helps to determine what industry incumbents believe are core competencies for industrial engineers. The resulting data can then serve as a curriculum-planning tool. It can be cross referenced with current curriculums to map which KIs are being covered by what faculty members to ultimately increase instruction effectiveness by identifying duplications and knowledge gaps.

Since the executed methodology is repeatable and not discipline specific, it can be applied to other fields and can also be duplicated in future years to track how industry's needs are changing over time. This provides a valuable metric for universities to use to ensure their respective curriculums keep pace with an ever-changing industry. Ultimately, this study provides objective information for educators to use to make better curriculum decisions to meet the changing needs of industry because,

"... there comes a time when for every addition of knowledge you forget something that you knew before. It is of the highest importance, therefore, not to have useless facts elbowing out the useful ones." - Sir Arthur Conan Doyle[2]

CHAPTER 2

TECHNICAL DISCUSSION AND LITERATURE REVIEW

"Knowledge is what we get when an observer, preferably a scientifically trained observer, provides us with a copy of reality that we can all recognize."

- Christopher Lasch[3]

2.1 Previous Studies Regarding Engineering Education

In a June 1998 Industrial Engineering Solutions article entitled, "IE2, The Curriculum Revisited: Developing a New Undergraduate Program at the Texas A&M University," the authors (Kuo and Deuermeyer) state a variety of sources have been sending the message to the ISE academic community that its students are not adequately prepared, and the ISE discipline is declining despite a good job market.

> Both industry and our engineering peers in other disciplines have repeatedly questioned the content of the ISE curriculum in recent years on the grounds that it lacks both technical rigor and relevance to contemporary industry. By ignoring undergraduate curriculum issues for several decades, ISE faculties have done little to deflect these charges. Junior faculty members have failed to focus on undergraduate education because it does not contribute to their own academic career advancement as effectively as concentrating on research and graduate education. Senior faculty members have been guilty of perpetuating a curriculum in which they no longer believe in failing to bring their own latest research findings into their undergraduate courses.

To summarize the authors' findings, they have identified five limits to the traditional ISE curriculum listed below.

1. The traditional curriculum is characterized by an emphasis on tools rather than on engineering problems,
2. The traditional curriculum is characterized by poor vertical integration of fundamental ISE concepts,
3. Much of the traditional ISE educational experience is based on a misdirected role of the industrial engineer,
4. The traditional curriculum places a gap between industrial engineering training and graduate programs, and
5. The traditional curriculum fails to address the needs of today's industry.

This dissertation touched on all of these issues, but will primarily address issues three and five by developing a comprehensive survey instrument to identify and quantify these needs. Specifically, the survey instrument will ascertain what role industrial engineers are performing in industry by soliciting feedback directly from these incumbents.

As further proof illustrating this preparation disparity between education and industry, a 1997 Society of Manufacturing Engineers (SME) survey asked respondents if they believe graduating engineers are prepared for real world engineering applications. Sixty-one of 70 respondents answered, "No." A follow-on question asked if this lack of competency was due to a gap between education and real-world application. Fifty-eight of the 60 respondents answered, "Yes." Clearly, these results indicate a problem exists between the needs of post educational environments and the curriculum of most schools. Whether this competency gap actually exists is debatable, but one can not argue that at least the perception of this gap exists. This perception is not limited to a specific occupation. Respondents of the SME survey came from the automotive (n=6), aerospace (n=9), electronics (n=4), machine tools (n=5), heavy equipment (n=3), consumer products and process industries (n=9), education (n=14), students (n=4), and other fields (n=14).

Fentiman, Britton, and Meyers (1994) conducted a survey of 900 recent engineering graduates from The Ohio State University (OSU) to determine whether the core-engineering curriculum provided them with the basic engineering skills necessary for their jobs. Four categories of skills were formed for this study. The skills included: 1) basic engineering skills, 2) basic graphics skills, 3) computer skills, and 4) communication and problem solving skills. The survey instrument had graduates rate a total of 26 different items on a one to five scale within these four categories. Graduates rated items with regard to two dimensions: 1) item relevance to their jobs, and 2) whether the graduates were adequately prepared in each item. Four hundred graduates completed the survey instrument.

The results pertinent to this dissertation related mainly to categories: 1) basic engineering, and 4) communication and problem solving skills. With regard to relative importance, the results yielded (from low to high) an average rating of 2.1 for differential equations, and 2.4 for chemistry. Thermodynamics, fields and electricity, calculus, and dynamics all scored between 2.5 and 2.9. Strengths, electronics, and statistics all scored between 3.0 and 3.1. The most important skills were mechanics, statics, materials, and economics all scoring between 3.2 and 3.3. Interestingly, graduates rated communication skills to be more important to job performance relative to all of the basic engineering skills. This fact indicates that although technical skills are the core of an engineer's knowledge base, skills unrelated to technology should not be overlooked (Owen, 1999).

Most graduates believe they were prepared in most basic engineering elements (except statistics, economics, and electronics), but felt less prepared in the communication and problem solving skills.

These results indicate that economics, statistics, electronics, materials, and especially communication and problem solving skills should receive heavier emphasis in engineering curriculums. Results from the SME education survey (1997) also stress the need for improved communication and problem solving skills.

Another study sanctioned by the SME's Ad Hoc Committee on Lifelong Learning examined the differing perceptions of a group of manufacturing engineers (n=603) versus a group of managers (n=652). The results were published in April 1999's edition of Manufacturing Engineering. Briefly, the results summarized in Table 2.1.1 shows how engineers rate themselves and how managers rate their engineers in the following technical and non-technical areas. The percentage indicates the numbers of respondents reporting the need for some or much improvement.

Technical Skills	Engineers	Managers
Computers and information technology	1.78%	2.96%
Manufacturing systems and controls	2.63%	3.93%
Manufacturing processes	3.62%	1.97%
Design and concurrent engineering	4.61%	4.92%
Materials	5.58%	7.87%
Quality control techniques	6.57%	4.92%
Human Factors and Ergonomics	7.53%	6.88%
Environment, health and safety	8.50%	8.82%
Legal and regulatory requirements	9.48%	10.3%
Statistics and mathematics	10.47%	8.82%
Non-technical Skills	**Engineers**	**Managers**
People and project management	1.65%	1.96%
Business skills	2.61%	10.89%
Leadership and change management	3.60%	2.94%
Oral communication	4.58%	4.92%
Supervisory skills	5.57%	8.90%
Negotiation and conflict resolution	6.56%	10.89%
Productivity and time management	7.55%	7.91%
Teaching and mentoring	8.54%	8.90%
Teamwork skills	9.52%	2.94%
Analytical and problem-solving	10.51%	4.92%
Writing skills	11.48%	4.92%

Percent reporting some or much improvement needed
Some data interpolated from original bar charts found in Manufacturing Engineer (April 1999)

Table 2.1.1: SME's ad hoc committee on lifelong learning survey with percentage indicating the number of respondents reporting the need for some or much improvement

Although these general results can be applied to most engineering curriculums, actually making decisions regarding what specific KIs within an area to emphasize and de-emphasize remains speculative. The SME education plan and the articles in the Industrial Engineering Solutions and Manufacturing Engineering do not provide much more detail than simply identifying broad areas of study. All of these sources approach their goals from differing approaches. The SME education plan and the article in Industrial Engineering Solutions had different industry panels composed of senior management engineers identify competency gaps while the Manufacturing Engineering article had respondents indicate where they believe improvements were needed. However, neither relative importance of these items to each other nor how often these items were used was specified.

This dissertation used a large population diverse, detailed, discipline specific, survey instrument to address the needs of ISE in distinguishing relative importance and how often specific KIs are utilized relative to one another within and between broad areas of study. With the use of a specialized computer software program, for the first time a much more detailed analysis was accomplished than performed in "typical" surveys. This work represents the most comprehensive, state-of-the-art analysis performed on this discipline to date in uncovering the needs of industry.

2.2 Job Analysis Defined

According to Mitchell and Driskill (1996), "The US military service has pioneered the development of several job and occupational analysis methods and the application of these technologies ... there is potential for considerable general utility to the country as a whole in military and civilian use ... for the study of jobs, occupations, and organizations."

The military's impact on the study of jobs has been immense. In fact, three of six major job analysis systems in the US (Critical Incidents, McCormick's Position Analysis Questionnaire, and Comprehensive Occupational Data Analysis Program (CODAP)) were developed in military-funded analysis research (Mitchell, 1988). This project will focus on one of these job analysis systems, a form of CODAP. Before discussing CODAP, the term and process of job analysis should be defined.

McCormick and Tiffin (1974) define job analysis as, "The collection and analysis of any type of job-related information by any method for any purpose." Job analysis essentially collects information in an empirical, quantifiable manner to describe verifiable job behaviors and activities. However, it should not be used to denote the wide assortment of procedures that make inferences about people such as to infer personality traits that might be necessary for successful job performance (Harvey, 1991). Similarly, Primoff and Fine (1988) observed, "The history of job analysis is essentially a history of individuals undertaking to satisfy certain needs for information about jobs in order to deal with practical personnel problems."

2.3 Challenges Facing Job Analysis

Although job analysis has been around for at least 50 years, this process is only slowly evolving and making progress. But, according to Schmidt (1987), significant gaps abound in the job analysis research base, consequently, practical prescriptions for collecting and using job analysis data are often based on little or no empirical justification. Prien (1977) notes that, "Research on job analysis had approximated little more than a pilot effort." In sharp contrast, whole disciplines have evolved focusing on attitudes, values, performance, style, and motivation in relation to the work people do with only the slightest suggestion that understanding what the individuals do is at all salient (Prien and Ronan, 1971). Harvey (1991) concludes, "Much additional research must be conducted to remedy current gaps in the literature, especially regarding the information processing aspects of the job analysis rating process."

The process of job analysis is also suffering from an image problem. Prien (1977) observed, "Although job analysis is an essential feature of almost every activity … the subject is treated in textbooks in a manner which suggests any fool can do it and thus, it is a task which can be delegated to the lowest level technician. This is quite contrary to the position taken … in the Equal Employment Opportunity Commission Selection Guidelines." Furthermore, Cunningham (1989) notes, "Job analytic research is time consuming, and laborious. It is sometimes difficult to publish, and does not seem to hold a strong attraction to students. In short, job analysis might be characterized as the Rodney Dangerfield of Industrial and Organizational psychology; it does not get a lot of respect."

Harvey (1991) draws a distinction between job analysis and other types of personnel analysis such as knowledge, and skills versus ability analysis. However, as Harvey (1991) notes the link is very close. "Clearly, there are large differences in the size of the inferential leap necessary to conclude each of these … . This definition distinction, although important, routinely causes confusion. Developing a knowledge or skill based job specification involves much less of a logical leap (than ability and others). However, it still requires some degree of translation, restating, or abstraction from the behaviorally oriented information contained in the job analysis itself." In a knowledge or skills approach this translation is left to the individual incumbents to apply in their individual jobs when accomplishing the survey. In a task-based approach, the data can be collected and broken down into the necessary required knowledge and skills once all the task-based data has been collected at the aggregate.

According to Cornelius and Lyness (1980), making overall judgments about the nature of jobs is a complex cognitive process. The literature suggests that to improve judgments of this sort, the overall decision should be decomposed into component parts. Therefore, improved information about workers requirements should be produced when workers rate requirements of individual tasks rather than the job at a holistic level. However, Harvey (1994) suggests that if knowledge based requirements are to be used rather than skills based knowledge requirements, it is extremely important to distinguish between specific, (such as the knowledge necessary to actually define runner dimensions of a die), versus more abstract knowledge requirements (such as understanding general die design principles and theories).

2.4 Job Analysis Process, Survey Design, and Data Collection Issues and Concerns

According to the Creative Research System's (1998) user manual and tutorials for the Survey System, there are seven steps in a survey project. These include:

1. Establish the goals of the project (See Section 1.3, Research objectives)
2. Determine your sample size (All ISE undergraduate alumni with US mailing addresses, 1,100)
3. Choose interviewing methodology (Direct interview with ISE faculty, industry alumni, and other subject matter experts)
4. Create questionnaire (Paper version of survey is attached in Appendix A)
5. Pre-test the questionnaire (Mail trial questionnaire on disk to a handful of ISE alumni)
6. Conduct interviews and enter data (Interview trial sample to solicit feedback, mail survey disk to population)
7. Analyze the data (Using atCODAP)

Each of these steps was followed in this project.

The goal of the project is specified in Section 1.3, Research Objectives and Expected Contributions, of study. Regarding sample size, the larger the sample, the more precise the yielded results. However, interestingly, the rate of improvement in precision for larger sample sizes decreases as the sample size increases. In fact, to increase the sample size from 1,000 to 4,000 requires four times as many people but only doubles the precision. The Handbook of Survey Research (1983) states that most national surveys, regardless of subject matter, typically have samples of 1000 or more depending on the number of subgroups formed for analysis. For an average number of subgroups, the recommended sample size is 1500-2000 for a national survey and 500-1000 for a regional or special survey. Nonetheless, researchers should not assume job descriptions based on a broad range of data are accurate even if the ratings are obtained from the entire population of job incumbents (Green and Stutzman, 1986). (This issue will be further addressed later in the dissertation.)

Citing Creative Research Systems (1998), there are three types of questions normally used in surveys. They include: 1) multiple choice, 2) numeric open-end, and 3) text open-end. Rating scales and agreement scales are sometimes treated as multiple choice types while other researchers treat them as numeric open-end questions. Regardless of classification, they serve the same function. Rossi, Wright, and Anderson (1983) believe closed questions are usually a more satisfactory method of creating data because:

1. The respondents can perform the task of answering the question when response alternatives are given,
2. The researcher can perform more reliably the task of interpreting the meaning of answers when the alternatives are given to the respondent (Schuman and Presser, 1981), and
3. When a completely open-end question is asked, many people give relatively rare answers that are not analytically useful. Providing respondents with a constrained number of categories increases the likelihood that there will be enough people in any given category to be analytically interesting.

Nonetheless, the optimum questionnaire technique of describing jobs remains an unanswered question (Prien and Ronan, 1971). An effective questionnaire should ultimately: 1) meet the objectives of the research, 2) obtain the most complete and accurate information possible, and 3) do this within the limits of available time and resources (Rossi, Wright, and Anderson, 1983).

Some common errors should be avoided when writing questions for surveys. These include providing: 1) double-barreled questions - single questions that ask for opinions about two different things, 2) questions based on false premises, 3) questions based on vague or ambiguous words, 4) overlapping alternatives, 5) double negatives, and 6) questions that ask for future intentions (Rossi, Wright, and Anderson, 1983). A good idea in survey construction is to also allow respondents the opportunity to write-in a response if the responses given do not adequately give a proper choice for the incumbent.

Another important characteristic of survey construction is its method of administration. Mail surveys possess advantages and disadvantages. Advantages include: 1) cost - generally the least expensive type, 2) less required amount of information needed - no telephone numbers are required only names and addresses, and

3) convenience to incumbents - it allows respondents to answer questions at their leisure making the survey less obtrusive. Disadvantages include: 1) time consuming administration, 2) misread or misinterpreted instructions especially from less educated respondents, and 3) low response rates. According to Creative Research (1998), even in a well-educated population, response rates vary from as low as 3% up to 90%. As a rule of thumb, the best response levels are achieved from highly educated incumbents and people with a particular interest in the subject (such as being a former ISE alumni). Dillman in The Handbook of Survey Research (1983) states, response rates of over 90% have been obtained from university alumni in mail and other self-administered questionnaires. As one way to improve response rates, Creative Research suggests mailing a postcard to the sample explaining the project and asking them to watch out for the survey in the next week or two. After a couple of weeks from mailing the questionnaire, a follow-up postcard can also be sent asking them to return the survey. Another method is to use an incentive such as money or a prize drawing. Lastly, a summary of the results of the project could also be offered to be mailed to those incumbents who responded to the survey instrument. According to Creative Research (1998), "Any of these techniques will increase the response rates."

Harvey (1990) concluded that questionnaires are an effective data collection technique when a number of jobs are being analyzed or when there are a large number of incumbents in a job. In fact, Prien and Ronan (1971) note, "The use of psychometric questionnaires in the future of describing jobs and to aid our understanding of work appears to be certain." The task inventory approach, used by the military, analyzes a number of jobs at once using a single questionnaire. This variant uses a questionnaire approach to describe jobs in terms of their involvement with a number of task statements. In this approach, only a subset of the total listings will likely apply to any given job, as the inventory contains all tasks thought to be a part of any job included in the study (Harvey, 1991). According to Harvey (1991), "The task inventory approach has achieved popularity among some of the larger private sector employers; given the amount of labor and cost involved in developing custom task inventories, however, it is infrequently seen in smaller or less well funded organizations." McCormick's (1976) research evidence suggests that incumbents can make reliable and valid ratings of this sort.

Questions still arise as to how many task or knowledge statements the survey should contain and what level of detail these statements should possess. Many task and knowledge statements can be subdivided into a number of more specific units. This is frequently encountered using the task-based approach. Prien and Ronan (1971) believe the degree of specificity of task elements depends to a degree on the purpose of the analysis. If the purpose concerns the development of performance criteria or training, the analysis may have to be extremely detailed. According to Harvey (1991), "The number of items in an inventory must be kept within certain limits (e.g., less than 1,000 statements). Thus, when the number of jobs covered by an … inventory increases, the tasks become shorter, more general, and less technologically specific … " simply for the reason of practicality.

Despite these shortcomings, the process of job and knowledge analysis share many similar processes especially for this research project. In fact, a number of variations of these inventories have been developed with the essential common feature being a comprehensive set of statements. The statements are general enough to be applicable to related job families yet specific enough to differentiate jobs (Prien and Ronan, 1971). Gagne (1963) summarizes the pragmatic purposes of this type of analysis as: 1) identifying job families, 2) defining education and training objectives, 3) measuring performance, and 4) designing training and instructional methods.

The analysis process itself entails subdividing a domain into elements through the application of a formalized, systematic procedure for data collection, analysis and synthesis (McCormick, 1976). This strategy entails systematically gathering the opinions of experts to develop a comprehensive inventory. To be effective, this system must meet several operational requirements as defined by Fleishman (1975).

1. Operational definition of terms must be understood by a broad range of people,
2. As a minimum, the descriptors employed in the differentiation and classification must permit nominal scaling to determine if a descriptor applies or does not apply to the particular item being examined,
3. Descriptors must be defined and treated within a system so they can be reliably evaluated,
4. All classes within the system must be mutually exhaustive and exclusive along with the classification scheme having to make a match between specific categories and behavioral effects, and
5. The taxonomy must promote communications among its users whether or not they are in different fields or specialists who must use the research findings in applied settings.

According to Phalen and Mitchell (1993), "The responses for individual job incumbents are the lifeblood of occupational analysis and research." However, relatively little attention has been paid to the provider of the information, the incumbent (McCormick, 1976). Since a study's validity is dependent on the accuracy of the information obtained through the incumbent, it is worthy of more attention (Green and Stutzman, 1986). Perhaps the most critical step in the course of the job analysis process is determining who will provide the ratings.

According to Thompson and Thompson (1982), the safest strategy is to collect information from as many informed sources as possible having the most direct, up-to-date experiences. However, some analysts will assume, often implicitly, that any errors in the data would be random and averaging across a large number of incumbents, these errors will essentially cancel out. The validity of this assumption is questionable because using incumbents does have its drawbacks (Green and Stutzman, 1986). For instance, newly hired and probationary employees are not good choices because they lack proper job experience. Some job incumbents may not have the appropriate memory, verbal, or comprehension skills necessary to understand directions or make adequate comparisons. Some incumbents may lack the proper motivation to adequately fill out the instrument or may possess disruptive motives in conflict with the goals of the study. Differences in incumbents' characteristics also impact a study's validity. For instance, studies conducted in realistic settings on the basis or race, sex, job tenure, performance level, and other factors have impacted data results. Thus, it is important to provide methods to identify poor respondents so they can be excluded from the sample.

Green and Stutzman, (1986) cite a few practitioners using a method to identify poor respondents based on their ratings. Respondents that produce ratings that have a low or negative correlation with the mean ratings are considered poor raters. The data from these incumbents are then eliminated and the means recomputed. The military and state governments use this method in their calculations (Christal and Weissmuller, 1975; Trattner, 1979). It presumes the mean ratings based on the entire population are relatively accurate. However, one must be careful not to eliminate these respondents if their ratings represent true differences. These differences could be the result of specific small subgroups possessing common characteristics. Thus, it is imperative to form subgroups to investigate these kinds of problems.

Other problems in survey construction need to be addressed. The first problem points to exactly what literature exists in estimating the test-retest reliability of inventory items. Wilson, Harvey, and Macy (1990) state, "Little is known about the test-retest reliability of task inventories." These authors examined this issue by looking at a specific variant of the most popular method, (Very similar to the method employed in this study) in which 1) a number of jobs are analyzed by using a single inventory, 2) incumbents rate the tasks as they apply to their individual jobs, and 3) a sizable number (if not all) of each job's tasks are surveyed. Their main concern was to answer two questions. First, what effect does the inclusion of data from inconsistent respondents have on reliability? Second, is the reliability of individual tasks rating scales affected when they are part of a multi scale inventory?

Wilson, Harvey and Macy (1990) provide evidence that the exclusion of inconsistent respondents may indeed inflate estimates of reliability relative to an unselected sample. Secondly, their data also provides no evidence to indicate the repeated-item correlation for individual scales decrease or increase when multiple scales are used. Their findings suggest reliabilities were roughly equivalent. This pattern seems to be upheld regardless of what calculation was used to compute the statistic. Nevertheless, the authors remain cautious because of some experimental design constraints citing Gael (1993), "From a practical standpoint, when several rating scales are used in an inventory, reliability may decrease for subsequent rating scales; if such a phenomenon occurs, it would have serious practical repercussions for multi scale inventories." Harvey (1991) agrees by stating, "Beyond a certain point, adding more scales makes completing the inventory unmanageable. Thus, researchers need to know the minimum number or rating scales that can be used to provide sufficient data to drive a variety of personnel functions. ... (Ultimately), additional research addressing the question of why there are such large differences in rating scale use is needed to resolve this issue."

Wilson, Harvey, and Macy (1990) also found in their work that inter-rater reliabilities were slightly lower (.70s to .80s) than those reported in previous studies (.90s). They concluded that by repeating a portion of the inventory with a very small test-retest interval, rater motivation would not be seriously effected, and job changes in job content could also be ruled out as a determinant of results. Thus, from a practical standpoint the authors believe that the use of repeated items in a task inventory is an advisable procedure to allow careless respondents to be removed or be subjected to further scrutiny for validity checking purposes.

Green and Stutzman (1986) used a similar method to assess respondents carelessness in completing an inventory, except they included a small set of items completely unrelated to those items in the survey instrument. Their results yielded four general postulates:

1. Different selection measures yield somewhat different job-analysis respondents,
2. Respondents are not equally accurate and may be screened for the tendency to make errors using a carelessness index,
3. In some applications, the number of sampled respondents needs to be greater than three in order to obtain reliable results, and
4. To the degree that the job is ill defined and unstable, the selection of job-analysis respondents assumes greater importance and is riskier.

Suboptimal scaling procedures also impact the validity of the survey procedure. A key debate exists between using a relative versus absolute scale. Phalen and Mitchell (1993) point out, "As for absolute judgments of stimuli, errors of judgment are much more apparent than for comparative judgments ... because absolute time estimations have a tendency toward overestimation of total time spent across all tasks (items)." However, using a relative scale contains some drawbacks. They only reveal that for a given job a certain item has a relatively higher or lower rating than other items in the instrument. Thus, meaningful cross job comparisons can not be made. For example, respondents that have identical relative profiles can have drastically different absolute profiles and vice versa. Harvey (1991) also points out that using relativistic scale anchors greatly improves the defensibility and replicability of the item ratings given to such instruments.

Another scaling issue exists involving how many points to use on scale questions. The research in this area is divided. According to Creative Research (1998), many surveys use a 10-point scale, but there is considerable evidence to suggest that anything over a five-point scale is irrelevant. However, this depends partially on education.

Among university graduates, a 10-point scale will work well. Cornelius and Lyness's (1980) findings support this claim. Their findings indicate that the education level of the incumbent is directly related to success on the rating task.

Another decision needs to be made regarding whether to use a trained job analyst to perform the study. Because of their familiarity of the job analysis process, analysts should be able to produce the most cross-job-consistent and reliable ratings (Harvey, 1991). However, drawbacks such as cost and time do exist. Another problem may arise when the job analyst has no familiarity with the project's content, thus efforts must be made to educate the analyst. The partiality of the analyst must also be questioned to examine if any predisposed biases exist.

Thus, many problems must be overcome in conducting reliable and valid research in this area. The most salient ones were discussed above. However, meaningful data can be extracted from groups when attention is given to proper construct design. Phalen and Mitchell (1993) acknowledge this fact by stating, "Noisy data resulting from job inventories or varying size and quality, sub optimal scaling procedures, and uncontrolled conditions of self-administration has, nevertheless, yielded meaningful results when the data are aggregated into large groups of respondents."

2.5 Discussion of Author/OASurv, Comprehensive Data Analysis Program (CODAP) and Anchored to CODAP (atCODAP) Systems

The data was collected using a new developmental product called Author/OASurv, which includes a windows-based front end for authoring a survey and a robust survey engine (OASurv) which actually administers the surveys in MS-DOS.

Since a Cooperative Research and Development Agreement has not been signed between the appropriate parties (Sensible Systems, Inc. and the US Air Force), special permission to use Author/OASurv was obtained from the US Air Force Human Research Laboratory at Brooks Air Force Base (AFB), San Antonio, Texas.

The data was analyzed on a personal computer using Sensible Systems, Inc. atCODAP (anchored to CODAP) made available in 1992. According to Metrica, Inc. (1998), the main frame version of CODAP consists of 100 to 400 different computer programs designed to serve as a tool to process, summarize, and display extensive sets and subsets of complex data. Originally, developed in the 1960s for the US Air Force Human Resource Laboratory, various versions are being used by the Army, Navy, and Air Force. The largest user of this program is the Air Education and Training Command's Occupational Measurement Squadron located at Randolph AFB, San Antonio, Texas. The CODAP system is now used by all US and many allied services, as well as a number of other government agencies, academic institutions, and some private industries (Christal and Weissmuller 1988; Mitchell, 1988).

According to Mitchell and Driskill (1996), the advantage offered by the inventory system is the use of CODAP-based programs. CODAP has the capability for obtaining and analyzing detailed information for large numbers of job incumbents. McCormick (1967) adds,

> The pioneering work of the (USAF) Personnel Research laboratory ... is particularly noteworthy. They have developed and used job inventories, consisting of job tasks in a given career field, as a means of mass collection of job information from incumbents. This technique, in combination with certain statistical procedures (which they have developed), has made it possible to describe jobs in quantitative terms to express job relationships.

In essence, CODAP is a theoretic approach that stresses the quantification and empirical testing over a custom-developed and carefully defined set of inventory items. These items, along with background questions, are used to form clusters or groups, define categories and produce prioritized lists of meaningful information to decision makers. CODAP transforms ratings from their original metric into a percentage based metric by dividing each rating by the sum of the ratings given to that specific position or job. Typical products produced by CODAP include composite cluster descriptions, group difference descriptions, variable summaries or cross tab reports, and ordered factor summaries (Metrica, Inc., 1998). Data analysis techniques used to produced these products include: 1) hierarchical clustering (used to define empirical subdivisions of a given area), 2) inter-rater reliability measures, and 3) regression analysis.

Hierarchical clustering "is an accretive clustering process in which individual objects are stepwise collected into groups based on their similarity. Once assigned to a group, an object remains in that group from that point forward. The two objects which have the best overlap at each step are merged (collapsed) and a secondary metric reports the homogeneity within the merged group" (Sensible Systems Inc. (SSI), 1999). Two types of hierarchical clustering normally exist: 1) task or knowledge clustering, and 2) case clustering. "Task (or knowledge clustering) is a process in which the similarity between tasks is measured in some manner and then used to form groups of tasks (or KIs) with similar profiles" (SSI, 1999). On the other hand, case clustering is "a process by which similarity between people is measured in some manner and then used to form groups of cases with similar profiles" (SSI, 1999). As stated earlier, this similarity is based on the overlap and magnitude of incumbent's ratings. This grouping technique is called, "collapsing the matrix" or "hierarchical grouping." It involves repeated searching for those individuals or partially formed clusters that have the highest remaining similarity. The standard CODAP method is accomplished by executing two different programs. The first program computes a similarity measure between every pair of cases contained in the data file. This measure is computed for each pair of cases by comparing the corresponding responses for all KIs. The output file is a similarity matrix. It then proceeds to group similar jobs into clusters. The vectors of similarity values for the clusters being merged are combined according to a specified mathematical algorithm to form an integrated cluster. The collapsing process continues until a single group has formed which contains all cases in a study (Christal, 1974). It can then print out a description of work performed by individuals in each cluster. The program is iterative and may evaluate well over a billion alternative solutions in arriving at the best definition of job types and clusters (Christal, 1974). Actually, another program performs the clustering process by using the similarity matrix as its input, and creating an output cluster solution file that records the details of the clustering process. Its output shows the groups that merged at each stage of the clustering process. The presentation of the sequence base can be altered based on the average value of a specified variable without altering the clustering solution. It merely creates a new presentation sequence. The primary variable is used to execute a sort. Secondary and tertiary variables are used to break ties (Metrica, Inc., 1998).

The primary output of the hierarchical clustering shows the major points in the clustering process, and has flexibility with respect to the level of detail reported. The final output report is a tree structure, clustering similar incumbents together. The size of the output can be adjusted by manipulating variables such as: 1) designating the minimum starter group size, 2) specifying a restricted range, and 3) changing a minimum average between requirements.

For demonstration purposes, the following example adapted from Archer (1966) is provided. Incumbents are asked to check the KIs utilized as part of their job. Next, incumbents are required to rate the relative importance of each KI as it relates to all other KIs on a one to nine scale. A rating of one indicates job applicability is extremely low. Likewise, a rating of nine indicates job applicability is extremely high. Table 2.5.1 shows the relative job applicability importance entered by 10 incumbents.

CASE NUMBER

KI	**99**	**13**	**1**	**21**	**44**	**78**	**3**	**34**	**10**	**12**
A8 Task demand analysis				1				8	7	
A10 Workplace design								2	2	
B24 Machine guarding	1	1	1	4	1	1	1			
C39 Protocol analysis	4	8	7	5						
E53 Decision trees	3	7	5	4						
F55 3-D CAD	2	4	6	5	3	4	3			
F73 Spreadsheets					5	4	1			
J111 Central limit theory			1	1	1	1	8		1	1
M172 Target costing							7			
Q231 Design for assembly										9
TOTAL	10	20	20	20	10	10	20	10	10	10

Table 2.5.1: Relative job applicability ratings entered by 10 incumbents

For comparison purposes across specific KIs, these relative ratings are converted to percentage values. It is assumed that the total of each incumbent's raw ratings represents 100% of his job knowledge. Each raw rating can then be expressed as a percentage of the total where r_i is the rating provided by the incumbent.

$$\frac{r_i}{\sum_{i=1}^{n} r_i} \times 100$$

Table 2.5.2 provides the estimated job applicability percentage by each incumbent on each task. This may be regarded as the KI job description of the incumbents identified at the top of the column, since it shows how their job applicability knowledge is distributed over the KIs performed.

CASE NUMBER

KI	99	13	1	21	44	78	3	34	10	12
A8 Task demand analysis				5				80	70	
A10 Workplace design								20	20	
B24 Machine guarding	10	5	5	20	10	10	5			
C39 Protocol analysis	40	40	35	25						
E53 Decision trees	30	35	25	20						
F55 3-D CAD	20	20	30	30	30	40	15			
F73 Spreadsheets					50	40	5			
J111 Central limit theory			5		10	10	40		10	10
M172 Target costing							35			
Q231 Design for assembly										90
TOTAL	100	100	100	100	100	100	100	100	100	100

Table 2.5.2: Knowledge level job descriptions of 10 incumbents

Duty level descriptions can also be obtained by summing the percentage of job applicability ratings on all KIs within a KI subheading area. For example, under KI subheading area A, Biomechanics, KIs A8 and A10 would sum to 90% for case 10. This would indicate that incumbent 10 applies a large portion of biomechanics knowledge in job performance. A summary in Table 2.5.3 is provided depicting duty level descriptions for all 10 incumbents.

KI	99	13	1	21	44	78	3	34	10	12
					CASE NUMBER					
A. Biomechanics				5				100	90	
B. Safety	10	5	5	20	10	10	5			
C. Cognitive Science	40	40	35	25						
E. Decision Analysis	30	35	25	20						
F. Scientific Computation and Modeling	20	20	30	30	30	80	20			
J. Engineering Statistics and Quality Control			5		10	10	40		10	10
M. Cost Analysis							35			
Q. Manufacturing Processes and System Design										90
TOTAL	100	100	100	100	100	100	100	100	100	100

Table 2.5.3: Knowledge sub-heading job descriptions of 10 incumbents

Additional useful statistics that aid in describing the data include: percent members performing (PMP), average percent job applicability by members performing, average percent of job applicability by all members, and cumulative sum of average job applicability by all members. Using the data from Table 2.5.4, the following information reports these statistics.

KI	PMP	Avg % JA by Member Performing	Avg JA for all members	Cum sum of avg JA for all members
A8 Task demand analysis	30.00	51.67	15.50	15.50
A10 Workplace design	20.00	20.00	4.00	19.50
B24 Machine guarding	70.00	9.29	6.50	26.00
C39 Protocol analysis	40.00	35.00	14.00	40.00
E53 Decision trees	40.00	27.50	11.00	51.00
F55 3-D CAD	70.00	26.43	18.50	69.50
F73 Spreadsheets	30.00	31.67	9.50	79.00
J111 Central limit theory	60.00	14.87	8.50	87.50
M172 Target costing	10.00	35.00	3.50	91.00
Q231 Design for assembly	10.00	90.00	9.00	100.00
TOTAL				100.00

Table 2.5.4: Additional useful statistics that aid in describing KI data

The hierarchical process entails maximizing the minimal overlap between cases. To demonstrate, from Table 2.5.2, incumbent with case 99 has a 20% job applicability (JA) with KI F55, 3-D CAD, on a relative basis. The overlap between case 99 and the total group on KI F55 is illustrated in Figure 2.5.1.

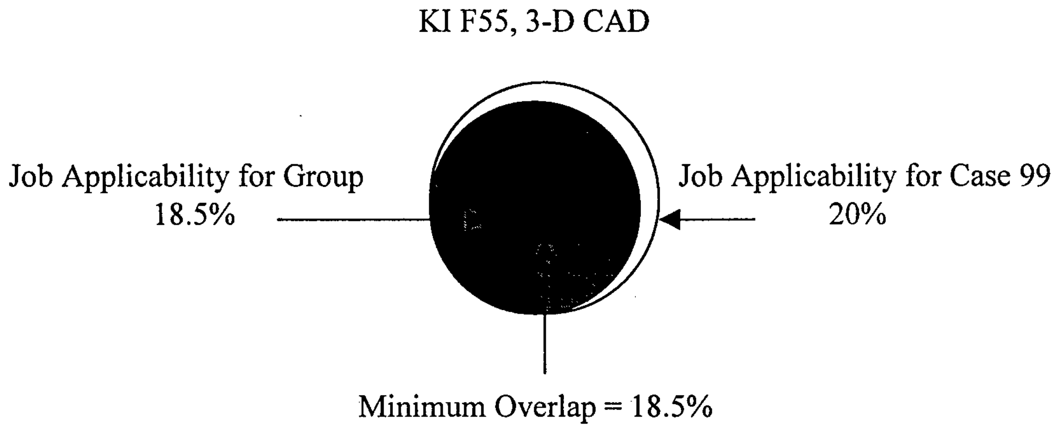

Figure 2.5.1: Overlap between case 99 and group on KI F55, 3-D CAD

The degree of overlap value is the smaller of the two job applicability percentages, 18.5%. Applying this procedure to all other group KIs with case 99 yields the following results.

	Percentage of Job Applicability		
KI	**Case 99**	**Group**	**Overlap**
A8 Task demand analysis		15.50	0.00
A10 Workplace design		4.00	0.00
B24 Machine guarding	10.00	6.50	6.50
C39 Protocol analysis	40.00	14.00	14.00
E53 Decision trees	30.00	11.00	11.00
F55 3-D CAD	20.00	18.50	18.50
F73 Spreadsheets		9.50	0.00
J111 Central limit theory		8.50	0.00
M172 Target costing		3.50	0.00
Q231 Design for assembly		9.00	0.00
TOTAL	100.00	100.00	50.00

Table 2.5.5: Computation of KI-level overlap between case 99 and the group job applicability ratings

A similar calculation can be accomplished at the KI sub-heading level to provide the amount of overlap at this higher level.

The automated hierarchical clustering process begins with the KI level descriptions of the N incumbents. The computer locates the two most similar of the N, KI descriptions, and groups them into a single cluster. The total number of available groups is then reduced by N-1. In the next stage the computer then locates and clusters the two most similar remaining N-1 groups. The program may add this individual to the existing group or combine two individuals to form a new group. The total number is then reduced to N-2. The computer continues in successive stages until all individuals are merged into one group and accounted for in the cluster diagram (Archer, 1966).

The basic identifying group used in the hierarchical structuring process is called the Job. When there is a substantial degree of similarity between jobs, they are grouped together and identified as a Cluster. Specialized jobs too dissimilar to fit a cluster are labeled Independent Jobs.

Inter-rater reliability measures the agreement of internal consistency among raters to the extent to which a test yields the same results for the same individual over time. It represents "a process in which a number of raters are cross-compared (correlated) to detect deviant raters" (SSI, 1999). This agreement is dependent upon systematic and random error. Examples of these types of errors result when a rater carelessly rates items, inadvertently inverts the scale, or when a group of raters generally agree on the ratings of some tasks, but disagree on others. A CODAP and atCODAP program (GRPREL) exists to automatically or manually remove divergent raters or items and then recompute the agreement when true differences among raters do not exist. Normally, a rater is considered to be unacceptably divergent when the respondent's correlation with the mean rating for all raters is not significantly greater than zero for a one-tailed test at alpha of .05 (Metrica, Inc., 1998). In addition the GRPREL program also computes a measure of the extent to which a representative sample of raters (with respect to what is being rated) produces a comparable set of ratings when rating a common set of items. It computes and evaluates the reliability of a single rater ($r_{1,1}$) or a composite of "K" raters ($r_{k,k}$) based on raw or adjusted ratings. $R_{k,k}$ is calculated using the Kuder-Richardson formula 21.

The Kuder-Richardson formula 21 (KR-21), a form of the KR-20 formula, is a split-half reliability coefficient used to measure the overall internal consistency or homogeneity in terms of how individuals responded to the instrument's items. KR-20 estimates the average correlation between halves of a test using all possible combinations of splitting the test in half from a single administration. A disadvantage of the KR-20 is that it can only be used if each answer to a test question is scored as either right or wrong. KR-21 is used as an estimate of KR-20. It is not as good a reliability estimate as the KR-20, but it can be calculated knowing only the mean, variance, and the number of questions on the instrument. It assumes that all items are of approximately the same difficulty. The general formula for calculating KR-21 is given below.

$$KR21 = \frac{k}{k-1}\left(1 - \frac{\bar{X}(k-\bar{X})}{k\sigma^2}\right)$$

Where:

$\bar{X}$ = the assessment mean
k = the number of items in the assessment
σ^2 = variance

A high reliability coefficient (.70 or higher) means the instrument device was accurately measuring some characteristic of the people taking the survey. It also means the individual items on the device were producing similar patterns of responding in different people. Therefore, a high correlation value means the device items are homogenous and therefore, valid (Bruning and Kintz, 1971).

The reliability of a single rater ($r_{1,1}$) is calculated using the Spearman-Brown formula. This formula is used to predict the reliability coefficient of different sizes. The general formula is given below.

$$r_{xx} = \frac{Nr}{1 + (N-1)r}$$

Where:

N = the number of times the test is to be increased or decreased
r = reliability of test

Reliability coefficients of well made standardized tests tend to have high reliability coefficients of .90 or higher. However, there are no hard and fast rules that state a reliability coefficient has to be a certain size before a measuring instrument can be considered valid. According to most textbooks, reliability measures remain relative and many instruments with reliability well below .90 are still considered to be useful. The more homogenous the sample the higher the reliability coefficient. The size of the reliability coefficient will differ when computations are based upon different sample sizes. Thus, no test has a single characteristic reliability coefficient. Based on 25 years of empirical research at the United States Air Force Occupational Measurement Squadron (USAF OMS) and now recently the Institute of Job Occupational Analysis, $r_{1,1} > .2$ and $r_{k,k} > .9$ provide research worthy results.

Returning to the GRPREL program discussion, it can accommodate various scales with raters not needing to rate all items. The rater mean adjusts to the sample mean to compensate for both rater and subset effects as well as rater leniency. The following variables can be specified by the user: 1) overall mean and standard deviation, 2) standardized knowledge means and standard deviations, and 3) number of iterations performed to remove divergent raters. As stated earlier as a rule of thumb, a reliability coefficient of .90 or greater for the rater composite is usually required for a test to be considered a reliable measuring instrument. A rater correlation table produced by the GRPREL program lists removal recommendations for raters whose probability or correlation values are considered too low or the user can set default minimums for these values to lower the number of raters that would be deleted (Metrica, Inc., 1998).

In addition to GRPREL reports, some other interesting reports that CODAP can produce include a consolidated description of: 1) work performed by any specified group of individuals, 2) the percent of group members performing each task, 3) the average percent of work spent on the task by those who perform it, 4) the percent of group time spent on each task, 5) the differences in work performed by any two specified groups of individuals, 6) individuals and for each individual in a specified group, 7) the amount of work time each worker spends on a given set of tasks, 8) two-way frequency distributions between background variables, 9) task lists and background variables, 10) widely and narrowly focused items, 11) item discrimination values, and 11) homogeneity indexes (Christal, 1974). An item is considered widely performed when its value is greater than two standard deviations above the mean. An item is considered to have a narrow focus when a few people use the knowledge, but it consumes a large portion of their time. It is calculated by subtracting the percent of time spent by all members from only those members using the KI in their job. An item discrimination value measures the average PMP difference from all other groups or stages for each core item. A core KI is a KI that has at least 66.66% PMP. The calculation is given below.

$$\frac{\text{Sq rt}\left((PMP^2)-\sum_{i=1}^{n}\overline{(PMP^2)}\right)}{n-1}$$

Item discrimination values are calculated because an item may be classified as core but it may not be discrimination. For example, KI 330, Teamwork Implementation is common for many stages which makes it less discriminating. On the other hand, KI 231, Design for Assembly is not common and is only a core KI for a handful of stages. Thus, this KI would have a high discrimination value as it is compared to all other stages. High positive numbers (>20) indicate a KI is being performed at a much higher level compared to all other stages. Conversely, high negative numbers (<-20) indicate a KI is being performed at a much lesser level compared to all other stages.

The core homogeneity index is calculated by multiplying the PMP by the average percent job applicability rating for all members. The sum of these cross products is divided by 100 to arrive at the core homogeneity index. This index concentrates on those KIs that most represent a specific group of members and the job applicability of these items to their job. As a rule of thumb, any value between 20 and 50 is considered a good core homogeneity value based on empirical findings from the analysis of various Air Force Specialties. Phalen and Weismuller's (1981) findings indicate, "groups having a core homogeneity index below 20 are not sufficiently homogenous to warrant being selected as job types."

At this point, the reader may be wondering why should CODAP be used instead of other statistical packages such as SPSS, SAS, BMDP, STATA, or SYSTAT? A 1985 U.S. Navy paper entitled, "Data Base Management Systems, Statistical Packages and Report Writers: Is CODAP Really Necessary?" demonstrated that SPSS could perform every computation that CODAP performs. Weismuller (1998) agrees, however, to mimic CODAP products would require 10 times the manpower on the part of the computer technicians and analysts to obtain the necessary and comparable products. In short, CODAP is hand-tailored to support occupational analysis while off-the-shelf products are not. Later the U.S. Navy issued another report in 1987 entitled, "NODAC Recants - SPSS as a Supplement to CODAP – Not a Replacement."

2.6 Task Analysis Using CODAP and atCODAP Compared To Other Job Analysis Methods

Typically, three different types of job analysis methods exist. These include: 1) high-specificity, or task-oriented methods, 2) moderate-specificity, or worker-oriented methods, and 3) low-specificity methods. High-specificity approaches to job analysis describe work in technologically and behaviorally explicit terms. Moderately-specificity approaches step up to the next higher level of behavioral abstraction by describing a collection of tasks that are similar in terms of having a common objective or focus. The idea behind this approach is that a relatively few general work behaviors exist, and all jobs can be described in terms of how much of each general work behavior they involve. They are conceptually more behaviorally abstract and less technologically specific than task statements (Harvey, 1991). However, the delineation of what constitutes worker-oriented behavior versus a task statement remains debatable. As a general test, worker-oriented behaviors can be further subdivided into more specific tasks (Harvey, 1991). Low-specificity approaches represent the highest level of behavioral abstraction. They describe jobs in terms of general constructs that have very low specificity and are used mainly to compare jobs that differ at a more behaviorally specific level of analysis (Harvey, 1991). These methods are not relevant for the purposes of this project and will not be discussed any further.

Examples of moderate-specificity or worker-oriented approaches include Threshold Trait Analysis (TTA), Abilities Requirements Scales (ARS), and Position Analysis Questionnaire (PAQ). TTA uses supervisors to directly rate the skills, job knowledge, specific abilities, abstract abilities, and personality traits they feel are required to perform a job (Harvey, 1991). It was created to provide a reliable, comprehensive, system for defining and establishing 33 traits of basic human attributes required to effectively perform a wide variety of jobs (Lopez, Kesselman, and Lopez, 1981). Essentially, this method is designed to describe general traits that are common and necessary in a specific job.

Fleishman's ARS were designed to identify general capabilities (such as perceptual motor ability requirements) of an individual to perform a variety of human tasks. Fleishman has been able to account for performance in terms of a relatively small number of abilities by investigating a wide range of several hundred different tasks.

PAQs is another and the most widely used worker-oriented approach to identify a relatively few work behaviors and how much of each general work behavior is involved on a scaling system. Ultimately, however, unlike high-specificity approaches, all of these moderate specificity methods do not yield the comprehensive data necessary to identify specific detailed KIs necessary for this study.

High-specificity or task-oriented approaches include Critical Incidence Technique (CIT), Job Element Method (JEM), Functional Job Analysis (FJA), Task Inventory/CODAP), and atCODAP. The CIT is a non-metric method, which does not collect quantitative ratings on job tasks nor produce listings of tasks that vary across the jobs being studied. The CIT is usually developed by having subject matter experts identify particularly effective or ineffective job behaviors they have witnessed or performed. This method is mainly used to develop a detailed picture of job performance used especially in job appraisals. It is of questionable desirability in serving as a general-purpose job analysis method (Harvey, 1991).

JEM is designed to effectively select the best worker from a group of workers able to perform a particular job. It is accomplished by analyzing the requirements of the job in terms of what makes employees superior and what causes trouble if ignored. According to Primoff (1975), "The essence of this method is that job elements are defined, subject matter of examinations prepared, and crediting plans developed by the people who have the most complete and direct experience with each job being analyzed. Research ... is directed towards ... representing the major structure of worker superiority on the job, and rating people accurately." Essentially, this method is directed towards developing performance criteria for specific jobs. This method is not really applicable for this project because this project is directed towards engineers performing a number of different jobs across a multitude of different occupational sectors. The project is also trying to identify KIs that are used, not how individuals perform using their knowledge.

FJA is a highly structured method similar to the task inventory approach. It is usually applied to one specific job at a time producing a listing of tasks tailored to each job. In contrast, the task inventory approach analyzes a number of jobs at once using a single questionnaire. Thus, unlike in the FJA method, only a smaller subset of tasks is expected to be performed by each job incumbent. The inventory in FJA includes all tasks expected to be performed in a single job, while in the task analysis approach all tasks are included that are thought to be part of any job included in the survey. Since this project is going to be applied to ISE graduates performing a diverse set of jobs, the task inventory method is the most suitable in providing the detailed information required for analysis and is the method of choice.

DACUM (**D**eveloping **a** **Cu**rriculu**m**) is a relatively new occupational analysis approach developed by the Center for Education and Training Employment (CETE) at The OSU. It is partly designed to determine at a relatively low cost the competencies or tasks that must be performed by persons employed in a specific job or occupational area. According to the CETE, DACUM analysis can be used for curriculum development, training needs assessment, student achievement records, worker performance evaluations, competency test development, and job descriptions. DACUM operates on three premises: 1) expert workers can describe and define their jobs more accurately than anyone else, 2) an effective way to describe jobs is to define tasks that expert workers perform, and 3) all tasks, demand certain knowledge, skills, and tools to be performed correctly. Some main differences between DACUM and TI/CODAP are the format of administration, number of tasks, and length of time to complete. DACUM sessions usually last two days using a small panel of experts to decide and rate relevant tasks. On average, DACUM charts contains between 50 and 200 tasks. (Currently, no DACUM research banks exist for ISE practitioners). On the other hand, the TI/CODAP process has much larger sample sizes, usually contains more tasks per inventory, and takes longer to administer. Thus, a trade-off exists between comprehensiveness of sample size and number of tasks versus cost.

From personal experience, I feel using such a small sample size yields less than optimum results. For example, as a Second Lieutenant in the USAF, I was in charge of leading subject matter experts in creating promotion specialty knowledge tests for enlisted career fields. At times, the group would come to a consensus that was in disagreement with the occupational survey data. After further discussions, the data almost always proved to be more correct than the opinions of subject matter experts. Although experts in their field, these individuals could not possibly contain the knowledge needed to make correct decisions regarding every aspect of their career field. In essence, the occupational survey data provides a more realistic, non biased, representation of responses because it includes the entire career field being surveyed.

To further demonstrate the benefits of the TI/CODAP approach, Levine, Ash, Hall, and Sistrunk (1983) asked 93 experienced job analysts to evaluate these seven different job analysis methods discussed above for 11 different job analysis purposes. These purposes included: 1) job description, 2) job classification, 3) job evaluation 4) job design, 5) personnel requirements/specifications, 6) performance appraisal, 7) worker training, 8) worker mobility, 9) efficiency/safety, 10) manpower/workforce planning, and 11) legal/quasi legal requirements. TI/CODAP scored the highest in categories 1), 2), 4), 7), 8), 10), and 11). Admittedly, the author acknowledges some lack of experimental controls, but the results indicate that TI/CODAP scored very well as a job analysis method. Although this method is task based and not knowledge based, it still indicates that this type of methodology is well accepted by experienced job analysts. The result of this work is given in Table 2.6.1 with the higher scores being more advantageous.

Purposes	Job Analysis Methods: Threshold Traits Analysis	Ability Requirements Scales	Position Analysis Questionnaire	Critical Incident Technique	Task Inventory/ CODAP	Functional Job Analysis	Job Elements Method	F^b	$p<$	η^2
Job description	2.95[c] (1.01)	2.15 (.97)	2.86[c] (1.09)	2.59[c] (1.15)	4.20[d] (.94)	4.07[d] (.97)	2.66[c] (1.03)	54.58	.0001	.32
Job classification	3.11[c] (1.00)	2.61[d] (1.07)	3.67[e] (.97)	2.19 (.95)	4.18[f] (1.00)	3.81[ef] (.97)	2.73[cd] (1.11)	50.82	.0001	.30
Job evaluation	2.80[c] (.93)	2.44[cd] (1.04)	3.70[e] (1.03)	2.37[d] (1.13)	3.46[e] (1.08)	3.52[e] (.90)	2.72[cd] (1.06)	26.91	.0001	.18
Job design	2.73[cd] (1.03)	2.28[e] (1.09)	2.99[c] (1.13)	2.52[de] (1.10)	3.72[f] (1.13)	3.64[f] (.99)	2.59[de] (1.08)	28.25	.0001	.18
Personnel requirements/specifications	3.68[c] (.87)	3.51[cd] (1.09)	3.36[cd] (1.03)	2.86[e] (.98)	3.19[de] (1.13)	3.58[c] (.94)	3.64[c] (1.19)	9.24	.0001	.07
Performance appraisal	2.80[cd] (1.11)	2.75[c] (1.14)	2.72[c] (1.06)	3.91[e] (1.12)	3.24[df] (1.15)	3.58[ef] (1.13)	3.07[cd] (1.12)	18.07	.0001	.13
Worker training	2.74[c] (1.13)	2.78[c] (1.13)	2.76[c] (1.03)	3.42[d] (.96)	3.65[d] (1.03)	3.63[d] (1.07)	3.33[d] (1.06)	16.03	.0001	.12
Worker mobility	2.67[c] (1.01)	2.47[cd] (1.05)	2.78[ce] (1.05)	2.20[d] (.96)	3.34[f] (1.09)	3.07[ef] (.94)	2.62[c] (.98)	18.60	.0001	.11
Efficiency/safety	2.34[cd] (1.02)	1.90[c] (.95)	2.46[de] (1.09)	3.08[f] (1.30)	2.79[ef] (1.05)	2.81[ef] (1.08)	2.30[cd] (1.07)	14.28	.0001	.10
Manpower/workforce planning	2.61[cd] (.98)	2.32[ce] (.93)	2.83[df] (1.06)	2.24[e] (.88)	3.41[g] (1.14)	3.11[fg] (1.06)	2.60[cde] (1.11)	20.65	.0001	.12
Legal/quasilegal requirements	2.65[cd] (1.06)	2.44[c] (1.13)	3.03[de] (1.06)	2.66[cd] (1.14)	3.67[f] (1.17)	3.38[ef] (1.09)	2.79[cd] (1.14)	17.45	.0001	.11

[a]Means are the top numbers. Standard deviations are the numbers in parentheses. The sample size ranges from 91 to 93.
[b]F-ratios, probability, and η^2 values are for the effect of the job analysis method, as derived from a two-way repeated measures ANOVA (job analysis method × organizational affiliation).
[cdefg]Means in each row with the same superscripts are not significantly different from each other.

Table 2.6.1: Ranking of job analysis methods as conducted by Levine, Ash, Hall, and Sistrunk (1983)

Sage conducted a similar study at The OSU in 1996, except atCODAP and DACUM were added to the list to be evaluated. TTA, ARS, and JEM were removed from the list. Sage (1996) compared the following six job analysis methods given in Table 2.6.2 by collecting data from experienced job analysts on 10 different dimensions. The following table depicts Sage's results with the higher scores again being more advantageous.

JA METHOD	PAQ	CIT	TI/CODAP	atCODAP	FJA	DACUM
Sample Size	(n=21)	(n=19)	(n=22)	(n=11)	(n=28)	(n=14)
Versatility/ Adaptability	4.14	4.00	4.22	4.18	3.86	2.64
Acceptability	3.38	2.71	3.39	3.45	3.00	.14
Amt. Of Training Required	2.81	2.57	2.13	3.36	2.68	1.86
Employee Sample Size	2.90	2.65	2.48	3.82	2.68	1.29
Reliability	3.57	2.81	4.00	4.27	2.96	1.86
Validity	2.86	1.67	4.00	4.36	2.46	1.21
Cost	2.57	2.62	1.74	3.91	2.61	4.01
Completion Time	2.57	1.86	2.00	3.64	2.61	3.86
AVERAGE SCORE	3.10	2.61	3.26	3.87	2.86	2.12

PAQ = Position Analysis Questionnaire
CIT = Critical Incident Technique
TI/CODAP = Task Inventory/Comprehensive Occupational Data Analysis Program
atCODAP = Anchored to CODAP
FJA = Functional Job Analysis
DACUM = Developing a Curriculum

Table 2.6.2: Ranking of job analysis methods as conducted by Sage (1996)

2.7 Use of Automated Surveys

A comparison by Weissmuller, Grimmes, Siem, and Kenny (1997), found that in two studies, automating data collection from diskettes was approximately 11.5 and 9.7 times, respectively, faster than manual data entry methods from paper and pencil surveys. This represents a substantial savings in manpower. Besides pure efficiency reasons, these researchers found that automated surveys possessed other advantages. These included: 1) ensuring all responses were answered and within valid parameters, which alleviated the problem data entry personnel faced when confronted with invalid responses, and 2) reducing data entry transcription errors. For these researchers, "It was clear that the automated survey provides a more valid reflection of respondent data."

CHAPTER 3

RESEARCH METHODOLOGY/APPROACH

"Science is a method that once applied to a problem will produce an answer, and when applied again will produce a comparable answer again, again, and again."
- Percy H. Hill[4]

The method section discusses the: 1) initial development of the survey, 2) survey instrument validation process, 3) survey return rate, 4) survey representation and response bias, 5) method used to collect the data which also discusses the format and composition of the survey instrument, 6) data analysis and interpretation methods, and 7) uses of the data.

3.1 Initial Development of Survey Instrument

The survey instrument was constructed using Author/OASurv developed by the Institute for Job and Occupational Analysis under contract (F4162296P1499) to the US Air Force and patterned off a published job inventory produced by Foster and Huguley (1993) entitled, "US Air Force Job Inventory – Test Pilots School Graduates." The Biographical, Background, and Knowledge Sections were developed after reviewing various literature and interviewing subject matter experts from industry, OSU, and OSU ISE graduates.

3.2 Survey Instrument Validation Process

The survey instrument was constructed by interviewing 15 OSU faculty and industry workers. The survey was then reviewed by former and current occupational analysts, who specialize in special management applications survey development, at the USAF OMS, Air Education and Training Command, Randolph Air Force Base, San Antonio, Texas. Next, trial surveys were given to 12 people representing current and former OSU students and industry members. The composition of industry members included industrial, computer science, manufacturing, and human factors engineers along with business managers. Follow-on interviews were conducted to refine the inventory and identify any problems. Finally, the survey was administered to the general survey population. As part of the survey, the incumbents were asked to comment on any KIs they believe were left out. Only three KIs were identified: enterprise resource planning (ERP), programmable logic control programming, and merger and acquisition strategy. The other 43 KIs identified were already contained in the survey. This serves as an indicator of the comprehensiveness of the survey instrument.

3.3 Survey Administration - Return Rate

Survey administration commenced in May and ran through September 1999. All 1983 – 1998 OSU ISE undergraduate alumni (n = 1,100) with US mailing addresses obtained from the OSU Alumni Association, including US territories and the District of Columbia, were administered the OSU Behavioral and Social Sciences Review Board approved computerized knowledge instrument by mail. Of the 1,100 eligible incumbents, 160 responded to the survey instrument. This represents a 13.6% return rate. Of the 13.6% that responded to the survey, 31 were eliminated from Knowledge Section I and 28 were eliminated from Knowledge Section II, respectively, due to the following reasons given below in Table 3.3.1.

Reasons for Survey Removal	**Count**
Corrupted Files – Physically unrecoverable	4
Divergent Raters	8,5
Homemaker	8
No Data	4
Not in job longer than six months	2
Student	1
Did not want to divulge information	1
No survey on outgoing disk (remailed)	1
Did not receive survey (remailed)	1
Damaged disk (remailed)	1
TOTAL	31,28

Table 3.3.1: Reasons for survey removal

Thus, the useable response rate was 129 respondents or 11.7% for Knowledge Section I and 132 respondents or 12% for Knowledge Section II of the total population. Although the response rate is in line with expectations, survey representation is robust and represents the total population well.

3.4 Survey Representation and Response Bias

Five different criteria were used to establish how well the sample represents the entire population. These included: 1) gender, 2) state of residence, 3) year of graduation, and 4) work sector involvement. The Chi-square Test for Goodness of Fit (x^2) was the statistical test used to determine how well the frequency distribution for the sample fits the entire population distribution that is specified by the null hypothesis. This test uses frequency data to test a hypothesis about a population distribution. The null hypothesis specifies the proportion of the population for each category on the scale of measurement. The test statistic (x^2) has degrees of freedom equal to the number of categories minus 1 (Gravetter and Wallnau, 1988).

$$x^2 = \Sigma (f_o - f_e)^2 / f_e$$

Where:

f_e = the expected frequency for each category if H_o is true
f_o= the observed frequency (data) for each category
H_o = there are no differences in the sample compared to the general population
H_i = there are differences in the sample compared to the general population

The first table shows how the sample represents the population gender.

Gender	Population	Sample	Sample as % of Population
Male	770	94	12.2
Female	330	38	11.5
TOTAL	1100	132	12.0

Table 3.4.1: Survey representation by gender

Since x^2 (1, n=132)=.14, p<.05 reject H_i, conclude H_o, there are no differences for each category. The sample is representative of the population distribution in terms of gender.

Tables 3.4.2 and 3.4.3 show how the sample represents the population's state of residence and year of graduation, respectively.

State	Population	Sample	Sample as % of Population
OH	705	86	12.2
CA	52	4	7.7
MI	40	7	17.5
TX	36	2	5.6
IL	20	2	10.0
IN	20	3	15.0
VA	20	4	20.0
PA	19	2	10.5
GA	18	0	0.0
FL	15	2	13.3
NC	14	2	14.3
AZ	13	3	23.1
TN	12	2	16.7
KY	11	3	27.3
WA	11	1	9.1
NY	10	2	20.0
SC	10	1	10.0
MO	9	2	22.2
NJ	7	0	0.0
MN	6	0	0.0
OR	6	1	16.7
CT	5	0	0.0
Other	45	3	0.0
TOTAL	1100	132	12.0

Table 3.4.2: Survey representation by state of residence

For computing x^2, two groups where used, (Ohio residence and all others) because a chi square test should not be performed when the expected frequency of any cell is less than five. The chi square statistic can be distorted when f_e is very small (Gravetter and Wallnau, 1988). Also, according to Lind and Mason (1994), "For more than two cells, x^2 should not be applied if more than 20% of the f_e cells have expected frequencies less than five." Since x^2 (1, n=132)=.065, p<.05 reject H_i, conclude H_o, there are no differences for each category. The sample is representative of the population distribution in terms of the population's state of residence .

Class	Population	Sample	Sample as % of Population
1983	68	6	8.8
1984	76	10	13.2
1985	82	9	11.0
1986	81	8	9.9
1987	89	10	11.2
1988	77	15	19.5
1989	65	9	13.8
1990	66	6	9.1
1991	55	5	9.1
1992	56	4	7.1
1993	40	4	10.0
1994	40	3	7.5
1995	62	12	19.4
1996	74	12	16.2
1997	91	10	11.0
1998	78	9	11.5
TOTAL	1100	132	12

Table 3.4.3: Survey representation by year of graduation

For Table 3.4.3, not more than 20% of the f_e cells for year of graduation have expected frequencies less than five. The Chi Square Goodness of Fit test remains valid. Since x^2 (15, n=132)=11.60, p<.05 reject H_i, conclude H_o, there are no differences for each category. The sample is representative of the population distribution in terms of year of graduation.

Finally, Tables 3.4.4 and 3.4.5 show how well the sample represents the population by occupational title and involvement with specific work sectors, respectively.

Reported Job Title	Population	Sample	% of Pop vs. Sample
Industrial Engineer	102	19	18.6
Manager	65	25	38.5
Engineer	60	11	18.3
Consultant	46	10	21.7
Manufacturing Engineer	28	6	21.4
Quality Assurance	25	9	36.0
Sales	22	1	4.5
Analyst	21	6	28.6
Project Engineer	21	5	23.8
Systems Engineer	18	5	27.8
Staff Engineer	16	4	25.0
Process Engineer	17	6	35.3
Military	11	1	9.1
Operations	11	4	36.4
Vice President	10	4	40.0
Grad Student	9	0	0.0
Production Engineer	8	4	50.0
Ergo/Loss Prevention	8	2	25.0
Facilities Engineer	8	1	12.5
Cost Estimator	7	3	42.9
CEO/CFO	6	1	16.7
Marketing Rep	5	3	60.0
Lawyer	5	2	40.0
Environmental Engineer	4	0	0.0
Professor/Teacher	4	1	25.0
Material Handler	4	1	25.0
Software Engineer	4	0	0.0
Homemaker	4	0	0.0
Sales Planner	3	1	33.3
Other	42	3	7.1
TOTAL	594	138	23.2

Some job titles were classified into multiple categories

Table 3.4.4: Survey representation by job title

Because at least 20% of the cells in the Table 3.4.4 had frequencies less than five, sales, staff engineering, and military through other were combined into one cell. Since x^2 (10, n=132)=.227, p<.05 reject H_i, conclude H_o, there are no differences for each category. The sample is representative of the population distribution in terms of reported job title.

Work Sector	Population	Sample	Sample as % of Population
Consumer Products and Process Industries	110	32	29.1
Electronics	61	17	27.9
Auto	60	20	33.3
Medical	33	10	30.3
Defense	32	10	31.3
Heavy Equipment	31	8	25.8
Aerospace	26	7	26.9
Warehousing and Distribution	16	6	37.5
Education	13	3	23.1
Machine Tools	11	3	27.3
Government	10	3	30.0
Retail	7	3	42.9
Transportation	4	2	50.0
Other	24	8	33.3
TOTAL	438	132	30.1

Of the 1100 total population, 438 reported their work sector involvement from the OSU Alumni Association

Table 3.4.5: Survey representation by work sector involvement

Because 20% of the cells in the above table had frequencies less than five, education, machine tools, government, retail, and transportation were combined into one cell. Since x^2 (9, n=132)=1.03, p<.05 reject H_i, conclude H_o, there are no differences for each category. The sample is representative of the population distribution in terms of involvement with a specific work sector.

3.5 Method Used to Collect Data

(Paper Survey is attached in Appendix A. The diskette version could not be attached due to limitations in the dissertation publishing process)

The survey instrument contained a cover letter and a single scale knowledge based inventory. A cover letter, endorsed by the department head, was included to briefly:

1. Introduce the study,
2. Explain the purpose of the study and what the information will be used for,
3. Solicit subjects' help,
4. Provide software installation requirements and instructions,
5. Provide a point of contact for administrative questions and mailing address, and
6. Thank the subjects for their participation.

The actual knowledge based inventory was prefaced by:

1. An introduction,
2. General instructions,
3. Voluntary disclosure and privacy statements,
4. Survey taking hints, and
5. Approximate completion time.

The actual knowledge based survey consisted of three parts:

1. A BIOGRAPHICAL SECTION for general information relevant to the study about subjects,
2. A BACKGROUND SECTION for information about various pertinent questions, and
3. KNOWLEDGE SECTIONS to rate: 1) the level of applicability of the KIs in the subject's own current job, and 2) to identify overall undergraduate educational emphasis of the different KIs in ISE.

For the first knowledge section (job applicability), each incumbent first checked whether or not each KI was being applied in his or her job. After checking all KIs used, each member then rated each of the used KIs on a 9-point scale.

For the second knowledge section (overall educational emphasis), all KIs were rated on an identical 9-point scale.

For both knowledge sections the 9-point scale used shows relative importance as compared to all other KIs. This scale is given below which is used to determine relative importance for each item rated by a respondent.

9. Extremely High
8. Very High
7. High
6. Above Average
5. Average
4. Below Average
3. Low
2. Very Low
1. Extremely Low

All of the incumbent's ratings are assumed to account for 100% of his or her job applicability knowledge usage and overall educational knowledge emphasis in producing the most qualified industrial and systems engineer. This procedure provides a basis for comparing KIs in terms of both of these dimensions.

To qualify for this survey, incumbents must have:

1. Been an undergraduate alumnus of The OSU's ISE Department,
2. Been working at their present job for at least six months, and
3. Have access to an IBM compatible personal computer or able to access a text file paper version that was also included.

Thus, in summary, the resulting knowledge survey contained: 1) a cover page that included an introduction and instructions, 2) biographical, and 3) background sections, and a 4) two-part knowledge section. Each of these knowledge sections contained a comprehensive identical listing of 350 KIs grouped under the following 20 subheadings. The parentheses after each subheading denote the number of KIs in each area.

KI SUB-HEADINGS

1. BIOMECHANICS (12)
2. SAFETY (19)
3. COGNITIVE SCIENCE (9)
4. INFORMATION SYSTEM DESIGN (7)
5. DECISION ANALYSIS (4)
6. SCIENTIFIC COMPUTATIONS AND MODELING (21)
7. MATHEMATICAL OPTIMIZATION AND MODELING (9)
8. SIMULATION (11)
9. DESIGN OF EXPERIMENTS (16)
10. ENGINEERING STATISTICS AND QUALITY CONTROL (19)
11. QUALITY AND CONTINUOUS IMPROVEMENT (14)
12. ENGINEERING ECONOMICS (16)
13. COST ANALYSIS (14)
14. PRODUCTIVITY, WORK MEASUREMENT, AND METHODS (12)
15. PRODUCTION PLANNING, SCHEDULING, AND CONTROL (15)
16. FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING (21)
17. MANUFACTURING PROCESSESS AND SYSTEM DESIGN (60)
18. MANAGEMENT (24)
19. PERSONAL AND PROFESSIONAL SKILLS (31)
20. DISCIPLINES (16).

Table 3.5.1: Listing of KI subheadings

3.6 Data Analysis and Interpretation Methods

For the first time ever, ISE related data was collected using Author/OASurv and analyzed using atCODAP. Data analysis methods included: 1) hierarchical clustering techniques, 2) inter-rater reliability measures, and 3) regression analysis. These methods were discussed in Section 2.5. A method called job typing was used during the hierarchical clustering process. Each individual in the sample utilizes a set of KIs in a job. For the purpose of organizing individual jobs into similar units of knowledge utilization, an automated clustering program is used. Job typing essentially entails analyzing the cluster groupings produced by atCODAP. Each individual job description (all the KIs utilized by that individual and the relative job applicability and overall ideal emphasis) in the sample is compared to every other job description in terms of KIs utilized and the relative emphasis on each item in the inventory. The automated system is designed to locate the two job descriptions with the most similar KIs utilized and the relative emphasis ratings and combine them to form a composite job description. In successive stages, new members are added to this initial group.

The basic identifying group used in the hierarchical job structuring process is the Job. When there is a substantial degree of similarity between jobs, they are grouped together and identified as a Cluster. Specialized job types too dissimilar to fit within a cluster are labeled Independent Jobs. The analyst then looks for similarities and differences in responses between and within cluster groups to apply a generic title for descriptive purposes to each cohesive subgroup. For example, one might expect graduates who specialized in biomechanics to be applying similar KIs in their respective biomechanic type of jobs. Thus, their responses should, in theory, be similar. AtCODAP would form a cluster that contains these similar responses. Simply stated, the researcher's job is to decipher the hierarchical cluster tree. The researcher draws valid conclusions from the data based on KIs results and on computed statistics such as between and within group reliability and regression analysis techniques. Variable summaries and group difference reports were also created and analyzed for content and significance. Sensible Systems, Inc., provided access to the software necessary (atCODAP and Author/OASurv) to perform the data analysis.

3.7 Uses of Data

Besides helping to explain the main hypotheses of identifying ISE core competencies, the resulting data served a variety of other uses. It was used to identify what should be included in basic engineering courses for the composition of core and electives for curriculum development. Furthermore, since the data was provided at the knowledge level, each KI was subsequently mapped to courses to identify gaps and duplications in OSU's ISE curriculum. The KIs were also used to determine what KIs between and within competencies should receive emphasis and de-emphasis.

CHAPTER 4

RESULTS AND ANALYSIS

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you can not (or do not) measure it, when you can not express it in numbers, your knowledge is of a meager and unsatisfactory kind."
– Lord Kelvin[5]

4.1 Background Results for Total Sample

All survey incumbents met the prerequisite survey requirements of being an undergraduate of OSU's ISE department and have been working at their present job for at least six months. The results of the background statistics are given below. Each statistic is self-explanatory except the Time Spent on Survey statistic. Because this was an automated survey, the software program tracked and reported the total start and stop times and computed a net time to complete statistic.

Statistic	Mean	Median	Mode	Standard Deviation	Min	Max
Time Spent on Survey(min)	78.9	54	51	71.8	21	554
Age (years)	31.8	32	35	5.0	21	52
Number of People Supervised	22	1	0	69.1	0	550
Number of People at Site	1946	700	5000	2825	0	9999

Table 4.1.1: Survey administration background statistics

The researcher thought the time to complete this survey would take approximately 30-45 minutes to complete based on trial observations. However, the mean time to actually complete this survey was 78.9 minutes with a median and mode or 54 and 51 minutes, respectively, with a standard deviation of 21 minutes. This result indicates that survey respondents spent more time than the researcher thought necessary to accomplish this survey in a timely, but thorough manner.

The average age of the survey respondent was 31.8 with a median and mode of 32 and 35, respectively, with a standard deviation of five years. Not surprisingly, the ages ranged from 21 to 52 years of age considering the survey population came from graduates between the years of 1983 to 1998.

Since the survey respondents graduated in the last 15 years, it is also not surprising that the number of people supervised averaged 22 with a median and mode of 1 and 0, respectively. However, the range was quite broad from 0 to 550 people supervised. This helps to explain the high standard deviation of 69.1. Of the seven people who supervise over 100 people, the average age was 34.6 and average graduation year was 1987. These graduates worked for heavy machinery, printing, automotive, and consulting companies. As one would expect, as ISE graduates become more senior their supervisory responsibilities also increase. Typically, recent graduates do not normally have very many supervisory responsibilities.

The average number of workers at an ISE graduate's work site is 1,946 with a median and mode of 700 and 5000, respectively. Incumbents work in all sizes of organizations as the range of 0-9999 indicates.

Overall, the majority of incumbents believe their job utilized their training very well to fairly little as depicted in Table 4.1.2. The extremes of extremely well and very little received only five and eight responses, respectively. Reasons given for their job not utilizing their training include: being a home-based business not requiring specific IE skills, or not being an ISE type of job like sales and ministry. Interestingly, incumbents responded more favorably, as depicted in Table 4.1.2, when asked about the usefulness of OSU's ISE education in their current job. Only 94 participants responded in the very well to so-so range for the first question while 120 incumbents responded in the same range regarding usefulness of OSU's ISE education.

Survey Question	EW	VW	FW	So-So	FL	VL	NAA
1. Job utilizes education? If FL or less why?	5	21	42	30	15	8	1
3. Usefulness of OSU's ISE education in current job? If FL or less why?	6	37	62	20	4	3	0

Extremely Well (EW) / Very Well (VW) / Fairly Well (FW) / So-So (So-So) / Fairly Little (FL) / Very Little (VL) / Not At All (NAA)

Table 4.1.2: Amount job utilizes training and usefulness of OSU ISE education statistics

Examples of comments as to why incumbents believe the usefulness of OSU's ISE education was fairly little to very little include:

1. "I chose some electives in ergonomics and wish that I had also gotten some in manufacturing … I really could have used some more mechanical engineering courses."
2. "Although surveys say that the manufacturing sector is shrinking and the service sector is increasing, there is still an incredible demand for education to prepare engineers to be ready for many 'hands-on' engineering opportunities in manufacturing plants. An IE program such as OSU's has an incredible opportunity to tap into that need."
3. "OSU ISE education does a good job at preparing you to be a teacher, but not a very good job of preparing for industry. During my first job, I worked at a plant that was unionized. Because of the contract with the workers, engineers were not able to have any hands on experience but were expected to give hands on direction. As you could imagine, this is a poor combination."
4. "OSU ISE education is too theoretical – did not focus on practical application."

In order to gauge how satisfied ISE graduates are with their current job, the following question given in Table 4.1.3 was asked. Overwhelmingly, 110 out of 133 respondents were very to slightly satisfied with their current job. The next largest response category was extremely satisfied, thus the data indicates that most incumbents are satisfied with what they accomplish in their current job positions.

Survey Question	ES	VS	SS	NSND	SD	VD	ED
2. Sense of accomplishment from job	12	79	30	2	9	0	0

Extremely Satisfied (ES) / Very Satisfied (VS) / Slightly Satisfied (SS) / Neither Satisfied Nor Dissatisfied (NSND) / Slightly Dissatisfied (SD) / Very Dissatisfied (VD) / Extremely Dissatisfied (ED), Why?

Table 4.1.3: Sense of accomplishment from job statistics

Examples of comments as to why incumbents are slightly dissatisfied include:

1. "I feel I am still looked at as the time study person when I would like to be known as a project engineer."
2. "I am not fully utilizing my ISE education. I went to OSU to become an IE and I am now a computer consultant; consulting on manufacturing systems."
3. "The job requires my soul to be sold to the company; I am not willing to do this."
4. "Because I have not been given the opportunity that I had expected when I first started the job, I have a sense of feeling that my ISE education is not being utilized."
5. The IE is given the task of improving processes, but is not given the resources to properly do the job, or the authority. The major military contractor that I work for is also a top-heavy company with not enough emphasis on production. Rather than committing to doing the job right they believe that outsourcing (passing the buck) is an acceptable way to do a job. It may be fun for the manages to take trips all over the country to "solve" problems at a supplier, but it is more cost efficient to do it right in house."

Surprisingly, a very small amount of survey respondents further their ISE education through formal graduate work. In fact, only 17 out of the 133 respondents (13%) have received Master's or Doctoral degrees in ISE. Of the 59 post bachelor degree holders, 71% of them report their highest level of education as not being in ISE. Other areas of study where degrees were held include: languages, economics, ministry, occupational health, business administration, and industrial technology.

Survey Question	Bach	Bach+	2Bach+	M	M+	2M+	DL	Other
4. Highest level of ISE Education	114	6	1	8	0	0	3	0
5. Highest level of Education	73	21	0	32	3	0	3	0

Bachelor's degree (Bach) / Bachelor's Plus, but no Master's degree (Bach +) / More than one Bachelor's degree (2Bach+) / Master's degree (M) / Master's degree plus (M+) / More than one Master's degree (2M+) / Doctoral Level (DL) / Other – Explain (Other)

Table 4.1.4: Highest level of ISE education and all education statistics

As a whole most (74%) of ISE graduates work with 10 or less other degreed practicing IEs at their work site. However, at the opposite end of the scale, 17 respondents (14%) reported working with 25 or more IEs at their work facility. Upon further investigation, these ISE graduates work for very large Fortune 500 companies with an average number of people at the work site being 6,864 compared to the entire sample average of 1,946. The same trend holds true for the number of non-degreed IEs working in each incumbent's work facility except smaller numbers are reported between the range of 6 to 25 + and more reported in the 1 to 5 category.

Survey Question	1-5	6-10	11-15	16-20	21-25	25 +	Unknown
9. # of degreed practicing IEs in your work facility	77	12	6	4	3	17	12
10. # of non-degreed practicing IEs in your facility	93	5	2	1	2	10	19

Table 4.1.5: Number of degreed practicing and non-degreed IEs in work facility

Survey Question	Yes	No
11. Does your facility have a separate ISE department?	26	106
- If no, where do they reside?		
12. Does your facility have a separate manufacturing eng department?	49	83
- If no, where do they reside?		
15. Did OSU's ISE program adequately prepare you for your 1st job?	113	19
- If no, why?		
17. Does a real-world application gap exist between education and industry in ISE? - If yes, why?	83	49

Table 4.1.6: Survey results regarding IE and ME facilities, adequacy of OSU ISE program preparing undergraduates for first job, and whether a real-world application gap exists between industry and ISE education

Of the 17 individuals who work in IE organizations of 25 or more, only 7 out of the 17 reported their facility as actually having a separate IE department. Almost all large organizations reporting a separate IE department were in automotive or aerospace related businesses. IEs can be found working in numerous other locations to include:

1. consulting (4),
2. cost analysis (1),
3. distribution (1),
4. ergonomics (2),
5. engineering (6),
6. facilities and maintenance (4),
7. finance (1),
8. industrial design, (1),
9. logistics (4),
10. loss prevention (1),
11. manufacturing (18),
12. management information systems/computer information systems (4),
13. material management (1),
14. marketing (2),
15. organizational development (1),
16. operations planning (6),
17. process optimization (3),
18. product engineering (4),
19. production (3),
20. project management (2),
21. quality (6),
22. research (1),
23. safety (1),
24. simulation and modeling (1),
25. software development (1), and
26. technical (1).

It is almost twice as common to see separate ME departments than IE departments. However, 20 out of the 26 facilities employing separate IE departments also had separate ME departments. The remaining six organizations were not in manufacturing intensive sectors. MEs can be found working in numerous other locations to include:

1. consulting (1),
2. engineering (7),
3. facilities and maintenance (2),
4. industrial engineering (3),
5. industrial design (1),
6. management (1),
7. manufacturing (3),
8. operations (3),
9. process engineering (1),
10. production (3),
11. production engineering (5),
12. quality (1),
13. research (1), and
14. test (2).

For those facilities that have separate ME departments, they tend to include smaller organizations in addition to the larger ones. This topic was of particular interest at the colloquium so the data is broken out and given in Table 4.1.7 for both separate IE and ME departments.

Size of Facility	Number of Separate IE and (ME) Departments
500 and less	4 (20)
501-1000	3 (5)
1001-1500	6 (3)
1501-2000	2 (1)
2001-2500	1 (1)
2501-3000	2 (2)
3001-3500	0 (0)
3501-4000	1 (1)
4001-4500	0 (0)
4501-5000	1 (5)
5001-5500	0 (0)
5501-6000	0 (0)
6001-6500	0 (0)
6501-7000	0 (0)
7001-7500	0 (0)
7501-8000	0 (2)
8001-8500	0 (0)
8501-9000	1 (1)
9001-9500	0 (0)
9501-9999	5 (8)
TOTAL	26 (49)

Table 4.1.7: Number of separate IE and ME departments by facility size

As for preparation for ISE jobs following graduation, 86% of the survey respondents believe OSU's ISE program adequately prepared them for their first job following graduation. Only 19 individuals felt they were not adequately prepared because of perceived lack of skills in:

1. blue print reading,
2. business law and regulatory compliance fundamentals,
3. business practices,
4. career development,
5. change management,
6. communication,
7. company culture,
8. configuration control,
9. cost, schedule and performance,
10. financial justification,
11. information technology,
12. leadership development,
13. management/supervisory training,
14. network training,
15. organizational structure,
16. people,
17. personal computer,
18. program management,
19. programming,
20. quality,
21. supplier relationship/purchasing negotiation,
22. time management, and
23. work ethic.

Compared to an earlier study conducted by the SME (1997), 63% of ISE graduates believe a real-world application gap exists between education and industry in ISE versus 97% (n=60) of SME surveyed engineers felt about engineering in general. Examples of reasons given by incumbents as to why a real-world application gap exists between education and industry in ISE include:

1. misconceptions of IEs roles and skill sets in organizations especially companies not seeing the value of work measurement and time studies,
2. lack of co-op/intern experiences,
3. challenges presented by social, political, and cultural aspects,
4. isolation of principles and theories with secondary emphasis on application,
5. lack of ability to duplicate real-world challenges in universities,
6. lack of professors with real-world experiences,
7. inability of universities to keep pace with ever changing industry requirements, and
8. not knowing.

4.2 Job Typing Process Based on Hierarchical Diagram, Clustering Process and Data Results

After completing the Biographical and Background sections, individual survey respondents were tasked to first determine whether they applied a list of 350 KIs in their current jobs by placing a check next to each identified item. They were then asked to rate these checked items on how often they applied these knowledges on a 1 to 9 relative scale. AtCodap was then used to organize these responses into similar units. Each individual's answers and their relative applicability ratings are then compared to every other respondent's answers in terms of job applicability and the relative score on each KI in the inventory. The automated system is designed to locate the two job descriptions with the most similar checked job applicability and ratings combining them to form a composite job description. In successive stages, new members are added to the initial groups. New groups are formed based on the similarity of job applicability and similar ratings in the individual job descriptions.

The results of the clustering process is depicted in the clustering diagram with job titles assigned to each subgroup identified as a homogenous group. One block, manufacturing managers, taken from the cluster diagram is also provided to explain what the numbers represent.

Manufacturing Managers

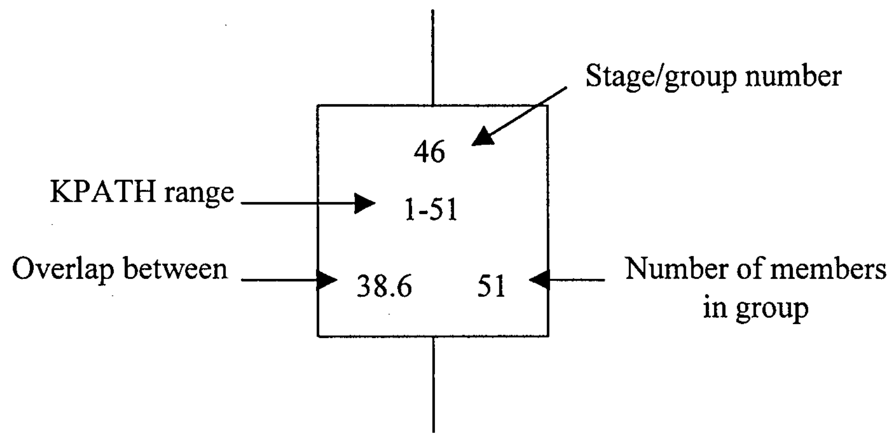

Figure 4.2.1: Explanation of one block of hierarchical cluster diagram

Stage/group number = the stage in the clustering process which this group was formed by merging of two similar groups. The stage number is also used to identify the group formed at this stage, i.e. stage 46 = group 46.

Number of members in the group = 51

KPATH range = the range of numbers that is used to identify the location of the 51 group member on the KPATH printout of case data. This range is referred to as the "KPATH range." It refers to the sequencing of cases and their related data after the cases have been hierarchically grouped.

Overlap between = 38.6 = the average percentage of overlap "between" members of the two subgroups that merged to form group 46, namely, group 49 and group 51. It represents the average percentage of overlap between all possible pairings of members in group 49 and group 51. (Phalen, 1973)

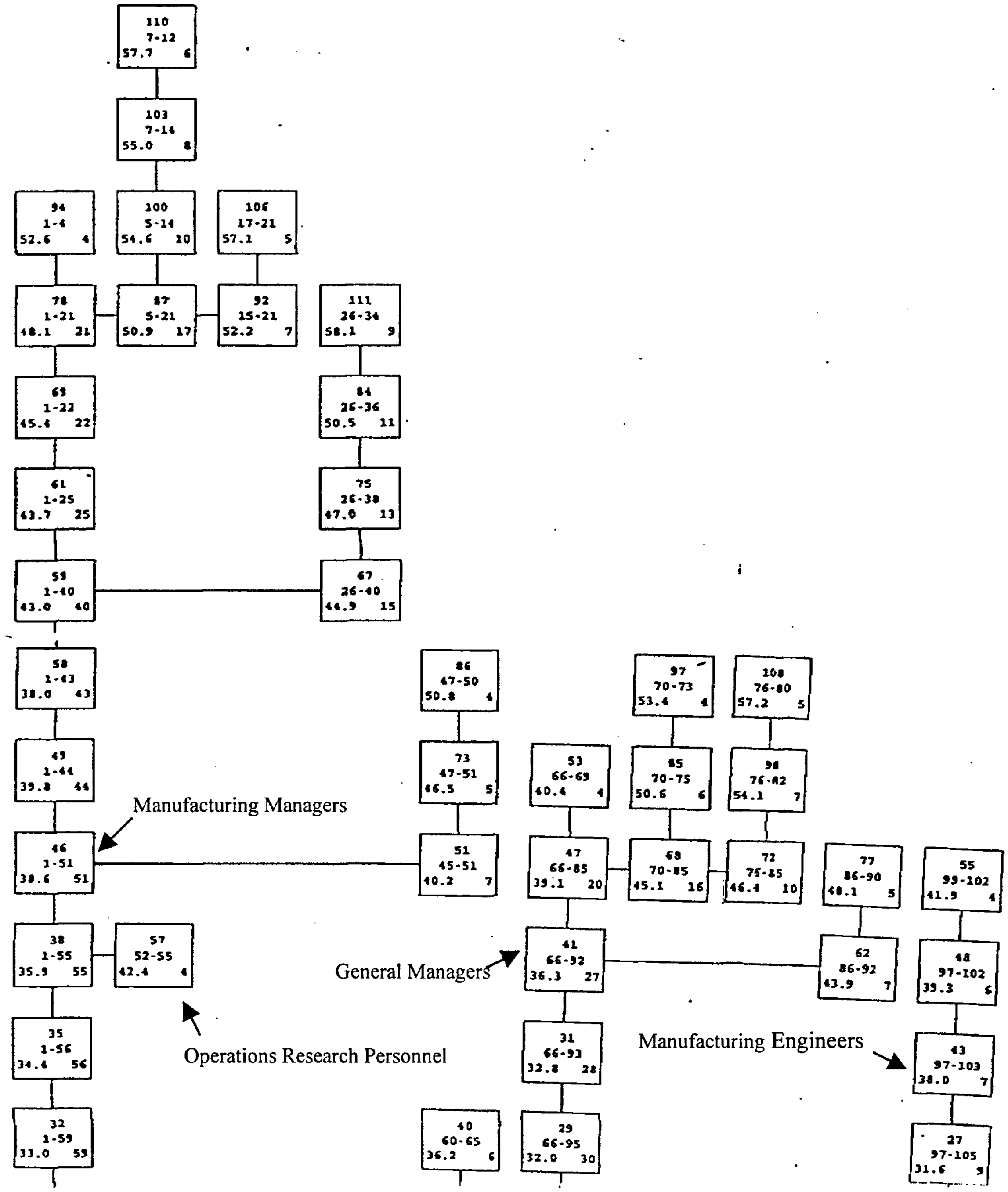

Figure 4.2.2: Hierarchical diagram depicting clustering process – top half

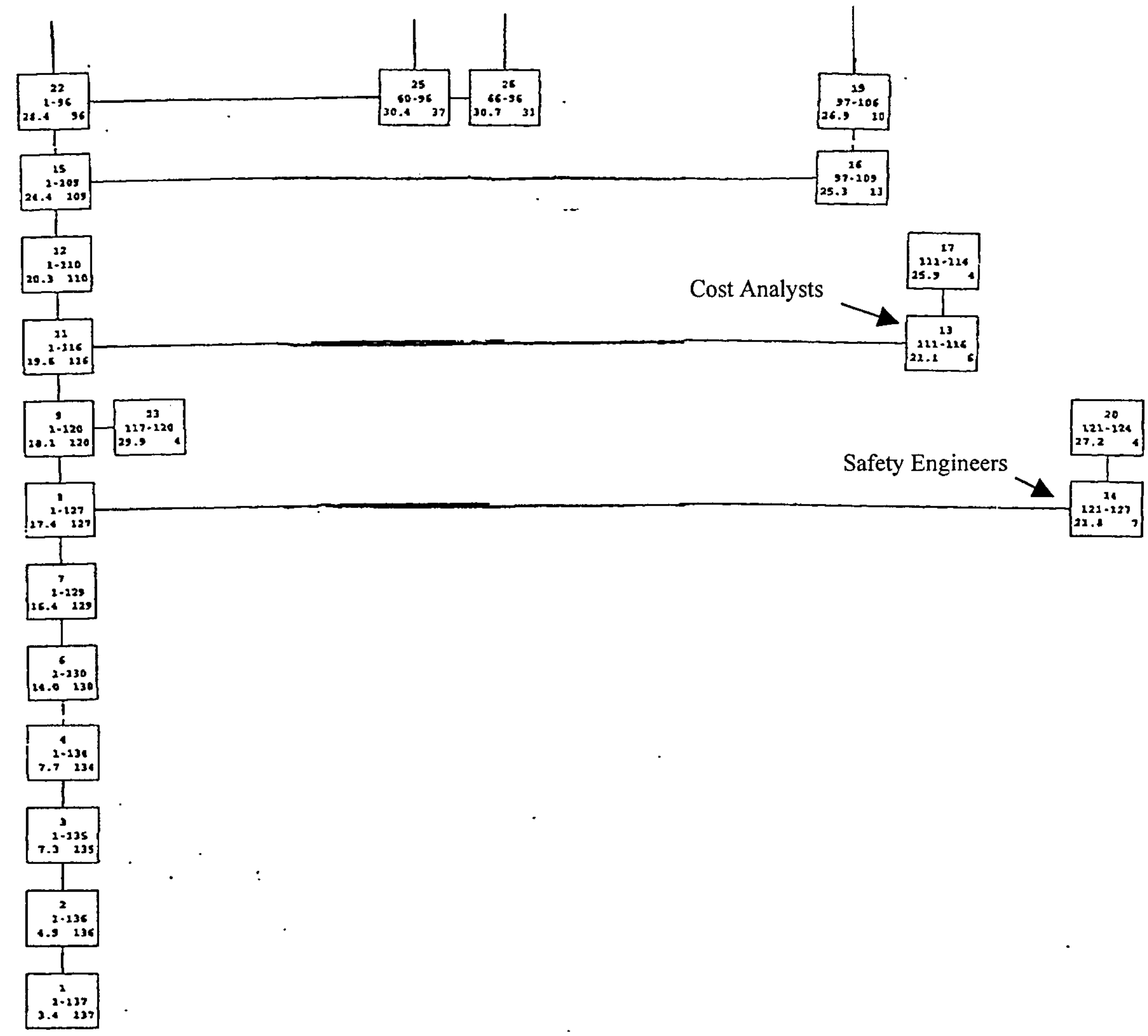

Figure 4.2.3: Hierarchical diagram depicting clustering process – bottom half

Six independent jobs pertaining to the job applicability knowledge section were identified with the pertinent overlap value, group sizes and $r_{(1,1)}$ and $r_{(k,k)}$ statistics given below in the following Table 4.2.1.

JOB ID	STAGE	NUMBER	R(1,1)	R(k,k)	OVERLAP VALUE	KPATH SEQ
Total Sample		132	0.2939	0.9278		
Manufacturing Managers	*46*	*51*	0.3329	0.9009	38.6	1-51
Manufacturing Engineers	*43*	*7*	0.3611	0.5915	38.0	97-103
Safety Engineers	*14*	*7*	0.4384	0.5935	21.8	121-127
Operations Research Personnel	*57*	*4*	0.5577	0.7208	42.4	52-55
Cost Analysts	*13*	*6*	0.4114	0.5546	21.1	111-116
General Managers	*41*	*27*	0.4286	0.8359	36.3	66-92

Table 4.2.1: Independent job typing identification statistics for job applicability

The next table depicts how these jobs responded to the ideal undergraduate recommendation section with the pertinent group sizes and $r_{(1,1)}$ and $r_{(k,k)}$ statistics given in Table 4.2.1. A cluster diagram is not applicable because this section asks respondents to rate each KI to produce the ISE ideal undergraduate regardless of their current job.

JOB ID	STAGE	NUMBER	R(1,1)	R(k,k)
Total Sample		129	0.2906	0.9825
Manufacturing Managers	*46*	*51*	0.3402	0.9634
Manufacturing Engineers	*43*	*7*	0.5538	0.8968
Safety Engineers	*14*	*7*	0.2123	0.6179
Operations Research Personnel	*57*	*4*	0.4638	0.7758
Cost Analysts	*13*	*6*	0.2620	0.6805
General Managers	*41*	*27*	0.3176	0.9263

Table 4.2.2: Independent job typing identification statistics for ideal emphasis

In order to apply titles to each of the stage numbers, numerous pieces of data were examined such as the background data and GRPREL reports. Examining the data at the subgroup knowledge level provides a good starting point in the job typing process. For example, Table 4.2.3 given below shows the relative PMP for stage 13 appropriately entitled, "Cost Analysts."

Cost Analysts STAGE 13 n=6	**PMP**
COST ANALYSIS	18.60
PERSONAL AND PROFESSIONAL SKILLS	16.21
ENGINEERING ECONOMICS	10.34
MANAGEMENT	9.89
ENGINEERING STATISTICS AND QUALITY CONTROL	7.08
QUALITY AND CONTINUOUS IMPROVEMENT	7.08
SCIENTIFIC COMPUTATIONS AND MODELING	6.22

Table 4.2.3: PMP performing for cost analysts subgroup

This group finds cost analysis KIs more applicable to their jobs on a frequency basis than any other KI subgroup. This provides a good starting point in providing a job title to this stage number. Other pieces of data such as background variables were examined to confirm this title. An important point to make is the atCODAP job analysis process places less emphasis on incumbents' self reported job titles than the actual KIs being reported as applicable to their current job. This is an important distinction to be made. Job titles can be misleading and can change frequently. However, this is not to say incumbent's job titles are not important, but these titles serve as another indicator in the job typing process. In fact, this report was one of the last reports to be generated so as not to unfairly bias the fundamental job typing process.

The other independent job stages, along with their job title name, based on their PMP information is given below. Only the top PMP scores for each group are given.

Operations Research Personnel STAGE 57 n=4	**PMP**
PERSONAL AND PROFESSIONAL SKILLS	22.27
ENGINEERING STATISTICS AND QUALITY CONTROL	11.43
SCIENTIFIC COMPUTATIONS AND MODELING	7.82
MANAGEMENT	6.34
QUALITY AND CONTINUOUS IMPROVEMENT	5.24
MATHEMATICAL OPTIMIZATION AND MODELING	5.04

Table 4.2.4: PMP for operations research personnel subgroup

Manufacturing Managers STAGE 46 n=51	**PMP**
PERSONAL AND PROFESSIONAL SKILLS	24.45
MANUFACTURING PROCESSES AND SYSTEM DESIGN	12.36
MANAGEMENT	8.60
QUALITY AND CONTINUOUS IMPROVEMENT	7.62
FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING	5.71
PRODUCTIVITY, WORK MEASUREMENT AND METHODS	4.39

Table 4.2.5: PMP for manufacturing managers subgroup

Manufacturing Engineers STAGE 43 n=7	PMP
MANUFACTURING PROCESSES AND SYSTEM DESIGN	16.69
FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING	15.64
PERSONAL AND PROFESSIONAL SKILLS	14.22
PRODUCTIVITY, WORK MEASUREMENT AND METHODS	9.42
MANAGEMENT	7.88
BIOMECHANICS	5.79

Table 4.2.6: PMP for manufacturing engineers subgroup

Safety Engineers STAGE 14 n=7	PMP
SAFETY	12.90
PERSONAL AND PROFESSIONAL SKILLS	10.08
MANUFACTURING PROCESSES AND SYSTEM DESIGN	9.02
INFORMATION SYSTEM DESIGN	8.52
BIOMECHANICS	8.28
COGNITIVE SCIENCE	6.56
DESIGN OF EXPERIMENTS	5.90
QUALITY AND CONTINUOUS IMPROVEMENT	4.98

Table 4.2.7: PMP for safety engineers subgroup

General Managers STAGE 41 n=27	PMP
PERSONAL AND PROFESSIONAL SKILLS	45.69
MANAGEMENT	11.77
QUALITY AND CONTINUOUS IMPROVEMENT	6.07
INFORMATION SYSTEM DESIGN	5.31

Table 4.2.8: PMP for general managers subgroup

Item discrimination values were the next piece of data to help confirm these job titles. As discussed earlier, an item discrimination value measures the average PMP difference from all other groups or stages for each core item. A core KI is a KI that has at least 66.66% PMP. Item discrimination values are calculated because an item may be classified as core, but it may not be discriminating. Each of the top discriminating KIs for each stage is given on Table 4.2.9.

Manufacturing Managers	**Manufacturing Engineers**	**Safety Engineers**
Core Item Discriminators	Core Item Discriminators	Core Item Discriminators
Labor/mgt relations	Design for assembly	Health/safety record keep process
Control charts	Space planning	Safety culture implementation
Cost of quality	Design for manufacturing	Human-computer interaction
Quality Standards - ISO, QS	Time studies	Workplace design
Flow chart interpretation	Calculation of time standards	Workstation design
Process empowerment	Types of mtl handling systems	Database - types, info, relational
Work breakdown	Design for cost	Statistics
Flow process charts	Jig and fixture designs	Design concepts-anthropometry
Number of machines/people rqt	Manual material handling	Task demand analysis
Bench marking	Workstation design	Fire safety
Supervision	Method improvements	Workplace air quality
Method improvements	Method analysis	Hazardous communication
Evaluation of layouts	2-D CAD	Physics
Capacity planning	Machine guarding	Human-information processing
Methods analysis	Line balancing techniques	Output analysis

Ops Research Personnel	**Cost Analysts**	**General Managers**
Core Item Discriminators	Core Item Discriminators	Core Item Discriminators
Taxes	Types of cost - labor, mtl, oh, marg	Resource identification
Continuous probability models	Cost estimation equations	Accountability
Discrete probability models	Labor computation	Teamwork implementation
Goodness of fit	Worth-present,future,expected	Values/ethics
Hypothesis testing	Database - types, info content, relational	Assessing performance
Reliability	Time value of money	Mentoring of personnel
Basic accounting	Breakdown of fixed costs	Empowerment
Depreciation	Capital budgeting	Social and culture awareness
Confidence intervals	Project management	Consensus building
Combinatorial optimization	Quote preparation	Time management
Sampling - distribution	"Black-box" approach	Conclusion drawing
Worth-present,future,expected	Target costing	Conflict resolution
Assignment algorithm	Non parametric analysis	Predict/anticipation of problems
Discrete event concepts	Factory and systems apps	Leadership implementation
Rate of return	Minimum cost analysis	Documentation

Table 4.2.9: Top core discriminating KIs for each independent job

4.3 Job Applicability Results – Total Sample Size (n=137)

The following paragraphs contain descriptions of the clusters and independent job types for the incumbents identified through the structure analysis process. Out of the 137 respondents, 129 responses where used to rate the "job applicability" section. The average number of raters per item = 30.87. The percent of possible responses rated was 24% with a mean rating of all ratings = 5.78. The GRPREL program identified the following raters as divergent based on the following statistics. As stated earlier, a rater is considered to be unacceptably divergent when the respondent's correlation with the mean rating for all raters is not significantly greater than zero for a one-tailed test at alpha of .05 (Metrica, Inc., 1998).

Rater #	**Items Rated**	**Sample Mean**	**Rater Mean**	**Rater Std Dev**	**Rater Coor.**
19	16	6.23	6.69	1.04	.0513
24	92	5.91	6.80	1.62	-.0347
37	43	4.99	5.30	1.11	-.0806
55	12	5.87	6.33	1.43	-.1157
70	9	6.81	7.67	0.82	-.7179
99	19	5.67	7.63	1.09	-.1875
105	80	5.68	7.41	1.29	.0854
120	48	5.54	6.13	1.98	-.2183

Table 4.3.1: Identification of divergent raters for job applicability

Overall, inter-rater agreement results were extremely high. The inter-rater reliability of a single rater $r_{(1,1)}$ = .2939. This measure computes and evaluates the reliability of a single rater based on raw or adjusted ratings. The composite of k raters $r_{(k,k)} = .9278$. This measure computes and evaluates the reliability of a composite number of raters based also on raw or adjusted ratings. For research purposes, the USAF OMS and Institute of Job Occupational Analysis recommend that to provide meaningful research value the $r_{(1,1)}$ should be greater than .2 and the $r_{(k,k)}$ value should be greater than .9. In this case, only 90 raters would be needed to reach this $r_{(k,k)}$ threshold. As a further projective statistic, the $r_{(k,k)}$ would equal .9258 for 30 raters. These results indicate ISE graduates are a very homogenous group in deciding what KIs are being applied in their current jobs. The following tables list the top 50 and bottom 25 items, sorted on number of raters rating and mean value, respectively, that graduates believe are the most and least job applicable KIs.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
73	Spreadsheets	109	7.71	0.85
332	Time management	107	7.45	0.91
320	Presentation	100	6.31	1.16
311	Documentation	98	7.05	1.08
316	Information gathering, researching, and organization	94	7.34	0.90
322	Process thinking	94	7.21	0.93
333	Values/ethics	94	7.07	1.11
321	Problem solution implementation	92	7.14	0.90
330	Teamwork implementation	91	7.11	0.93
305	Active listening	89	7.53	0.91
331	Technical communication	88	6.75	0.98
134	Customer focus	85	7.11	1.15
310	Creativity and innovation	84	7.23	0.90
317	Non-technical communication	84	7.10	1.02
313	Facilitation	80	6.92	1.04
309	Consensus building	78	6.79	1.15
146	Benefit cost analysis	78	5.74	1.21
318	Predictive/ anticipation of problems	77	6.69	1.08
312	Empowerment	76	6.64	1.12
308	Conflict resolution	75	6.45	1.22
177	Flow process charts	75	5.63	1.51
181	Method improvements	74	6.53	1.22
286	Financial justification	74	6.24	1.13
348	Statistics	74	5.95	1.17
173	Types of cost - labor, material, overhead, and marginal	74	5.74	1.33
307	Conclusion drawing	72	6.88	0.96
328	Supervision	72	6.79	1.21
42	Database - types, information content, relational	72	6.28	1.39
131	Benchmarking	72	5.31	1.36

Table 4.3.2: Top 50 KIs, sorted on number of raters rating, that graduates believe are the most job applicable (continued)

Table 4.3.2: (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
304	Accountability	71	7.34	0.98
299	Project management scheduling, Program Evaluation and Review Technique(PERT), Critical Path Method (CPM)	71	6.70	1.19
141	Process empowerment Quality circles, employee suggestions	71	5.89	1.51
137	Leadership implementation	69	6.75	1.15
306	Assessing performance	68	6.74	1.02
132	Change management	68	6.47	1.33
324	Risk management	67	6.00	1.19
293	Mentoring of personnel	66	6.39	1.42
142	Quality standards - ISO, QS	66	6.29	1.36
147	Capital budgeting	63	5.19	1.25
322	Resource identification	62	6.29	1.12
187	Capacity planning	62	6.19	1.25
133	Cost of quality	62	5.52	1.41
210	Number of machines/ people required	60	5.65	1.52
202	Evaluation of layouts	60	5.60	1.28
336	Computer Science	59	6.37	1.32
182	Methods analysis	59	6.36	1.33
163	Breakdown of fixed costs - fixed, variable, direct, and indirect labor and materials	59	5.92	1.24
11	Workplace design	58	4.84	1.42
63	Flow chart interpretations	57	5.30	1.48
166	Labor computation	56	5.86	1.26

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
267	Sensoring	6	4.17	1.42
39	Protocol analysis	6	3.83	1.11
21	Industrial toxicology	6	3.33	1.64
19	Heat stress	6	3.17	1.60
270	Surface integrity	5	5.60	1.24
6	Muscle performance	5	4.40	1.65
76	Calculus-based optimization	5	4.40	1.63
264	Powder metallurgy processes	5	4.40	1.05
56	Artificial intelligence(AI)	5	3.40	0.76
72	Solid modeling	5	3.20	2.15
297	Patent process	5	3.20	1.49
67	Mathematical programming	4	6.75	1.13
201	Distance metrics	4	6.25	0.53
217	Systematic Layout Planning(SLP)	4	6.25	0.53
106	Response plots	4	5.50	1.46
255	Machine tool elements design	4	4.75	0.65
78	Dynamic programming	4	4.50	1.77
7	Physiological control models	4	4.25	0.53
66	Markov models	4	4.25	1.43
339	Linguistics	3	6.33	0.38
334	Biological sciences	3	5.33	1.59
250	Kinematics of machine tools	3	4.33	0.96
344	Neuroscience	2	4.50	0.35
68	Neural networks	1	6.00	0.00
91	Surface search methods	1	5.00	0.00

Table 4.3.3: Bottom 25 KIs, sorted on raters rating, that graduates believe are the least job applicable

4.4 Ideal Undergraduate Emphasis – Total Sample Size (n=132)

Out of the 137 respondents, 132 responses where used to rate the "ideal undergraduate" section. The GRPREL program identified the following raters as divergent based on the following statistics.

Rater #	Items Rated	Sample Mean	Rater Mean	Rater Std Dev	Rater Coor.
37	350	5.1	5.33	.71	.0912
73	350	5.1	5.00	.00	.000
83	350	5.1	5.00	.00	.000
84	350	5.1	4.41	.49	-.1869
86	350	5.1	5.41	.49	-.0357

Table 4.4.1: Identification of divergent raters for ideal undergraduate emphasis

Raters 73 and 83 were eliminated because these respondents rated every item a 5.0 providing no discrimination among items. Similarly, raters 37, 84, and 86 were eliminated due to poor rater correlation with the sample. Overall, inter-rater agreement results were extremely high. The inter-rater reliability of a single rater $r_{(1,1)} = .2906$. The composite of k raters $r_{(k,k)} = .9825$. In this case, only 21 raters would be needed to reach this $r_{(k,k)}$ threshold. As a further projective statistic, the $r_{(k,k)}$ would equal .9248 for 30 raters. These results indicate ISE graduates are a very homogenous group in deciding what KIs an ideal undergraduate should know. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that graduates believe the ideal ISE graduate should possess.

Item	Description	Number Raters Rating	Sorted Mean Value	Standard Deviation
332	Time management	132	7.36	0.96
73	Spreadsheets	132	7.13	1.10
321	Problem solution implementation	132	6.97	1.06
320	Presentation	132	6.95	1.06
333	Values/ethics	132	6.92	1.14
322	Process thinking	132	6.90	1.05
330	Teamwork implementation	132	6.87	1.12
134	Customer focus	132	6.83	1.10
310	Creativity and innovation	132	6.80	1.11
331	Technical communication	132	6.73	1.04
316	Information gathering, researching, and organization	132	6.72	1.17
299	Project management scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	132	6.70	1.12
311	Documentation	132	6.63	1.13
348	Statistics	132	6.59	1.02
181	Method improvements	132	6.52	1.13
318	Non-technical communication	132	6.51	1.25
182	Methods analysis	132	6.45	1.10
317	Leadership implementation	132	6.44	1.21
319	Predictive/anticipation of problems	132	6.39	1.16
305	Active listening	132	6.39	1.32
286	Financial justification	132	6.35	1.12
133	Cost of quality	132	6.33	1.07
132	Change management	132	6.33	1.16
313	Facilitation	132	6.32	1.14
336	Computer Science	132	6.32	1.09
341	Mathematics	132	6.30	1.15
306	Assessing performance	132	6.25	1.23
309	Consensus building	132	6.25	1.21
329	System perspective	132	6.25	1.18
307	Conclusion drawing	132	6.21	1.27
177	Flow process charts	132	6.20	1.10
308	Conflict resolution	132	6.19	1.29
300	Proposal preparation	132	6.16	1.07
121	Process capability	132	6.12	1.17
138	Management and planning tools - SPC	132	6.11	1.12
312	Empowerment	132	6.11	1.33
253	Logistics	132	6.08	1.13
328	Supervision	132	6.08	1.25

Table 4.4.2: Top 50 KIs, sorted on mean value, that graduates believe the ideal ISE graduate should possess (continued)

Table 4.4.2: (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
278	Troubleshooting	132	6.06	1.30
143	Quality standards - ISO, QS	132	6.05	1.29
154	Rate of return	132	6.05	1.15
323	Resource identification	132	6.00	1.09
185	Work breakdown	132	5.98	1.24
251	Lean manufacturing implementation	132	5.98	1.37
324	Risk management	132	5.98	1.14
12	Workstation design	132	5.98	1.20
141	Process empowerment - Quality circles, employee suggestions	132	5.98	1.23
157	Time value of money	132	5.94	1.19
248	Just-in-time manufacturing implementation	132	5.94	1.18
252	Line balancing techniques	132	5.94	1.18

Item	Description	Number Raters Rating	Sorted Mean Value	Standard Deviation
29	Workplace air quality	132	3.86	1.27
2	Design concepts - anthropometry limits	132	3.85	1.35
22	Industrial ventilation	132	3.85	1.29
14	Electrical safety	132	3.84	1.31
18	Health and safety record keeping process	132	3.81	1.18
21	Industrial toxicology	132	3.81	1.15
66	Markov models	132	3.81	1.20
6	Muscle performance	132	3.80	1.13
335	Chemistry	132	3.77	1.14
70	Pseudocode	132	3.76	1.40
86	Initialization bias	132	3.73	1.08
31	Workplace violence control	132	3.70	1.24
16	Fire safety	132	3.67	1.28
23	Loss control program design	132	3.67	1.20
15	Fall hazard control	132	3.64	1.26
91	Surface search methods	132	3.63	1.06
344	Neuroscience	132	3.63	0.96
7	Physiological control models	132	3.61	1.18
68	Neural networks	132	3.61	1.19
345	Philosophy	132	3.61	1.15
92	Terminating versus non-terminating	132	3.58	1.08
3	Energy consumption measurement	132	3.49	1.28
19	Heat stress	132	3.35	1.18
334	Biological sciences	132	3.31	1.00
339	Linguistics	132	3.25	1.15

Table 4.4.3: Bottom 25 KIs, sorted on mean value, that graduates believe the ideal ISE undergraduate should possess

4.5 Widely Performed and Narrowly Focused KIs

As discussed earlier, an item is considered widely performed when its PMP value is greater than two standard deviations above the mean. Table 4.5.1 lists those items for the entire sample that are widely performed with PMP >= 57.44%.

KI Number	KI	PMP
73	Spreadsheets	83.94
332	Time Management	80.29
320	Presentation	74.45
311	Documentation	73.72
316	Information gathering, researching and organization	70.80
322	Process thinking	70.80
333	Values/ethics	70.07
321	Problem solution implementation	68.61
330	Teamwork implementation	68.61
331	Technical communication	67.15
305	Active listening	66.42
310	Creativity and innovation	63.50
134	Customer focus	62.77
318	Non-technical communication	62.77
146	Benefit cost analysis	58.39
313	Facilitation	58.39
309	Consensus building	57.66

Table 4.5.1: Widely performed KIs with PMP >= 57.44%

Not surprising these top 17 KIs comprise 21.52% of the total sample's knowledge utilization.

An item is considered to have a narrow focus when a few people use the knowledge, but it consumes a large portion of their time. In this case, a "highly focused" item cutoff is a z score of 4.35 and a percent difference between "all" and "performers" of 1.75. Only two items met this criteria and are given in Table 4.5.2.

KI Number	KI	PMP
64	High level computer languages – C, Pascal, Ada, etc.	18.98
46	Usability testing process	15.33

Table 4.5.2: Narrowly focused KIs with z-score of 4.35 or higher

4.6 Job Applicability Results – Manufacturing Managers (n=51)

Of all the job types identified, manufacturing managers is the largest with 51 members. The $r_{(1,1)}$ and $r_{(k,k)}$ values were .3329 and .9009, respectively. The average number of raters per item was 18.23 with 36% of possible responses rated. The mean rating per item was 5.68. Only 49 raters would have been needed to reach an $r_{(k,k)}$ of .90. As one would expect, this subgroup mainly consisted of a variety of manufacturing manager level jobs across different work sectors. Most engineering positions reported were at the senior level. The following tables list the top 50 and bottom 25 KIs, sorted on raters rating and mean value, respectively, that manufacturing managers believe the most and least job applicable KIs are to this subgroup.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
73	Spreadsheets	48	8.02	0.65
311	Documentation	48	6.71	1.16
320	Presentation	48	6.29	1.09
332	Time management	46	7.46	0.93
320	Problem solution implementation	46	7.17	0.92
322	Process thinking	45	7.44	0.80
330	Teamwork implementation	45	7.27	0.84
310	Creativity and innovation	45	7.18	0.96
333	Values/ethics	44	7.18	1.02
305	Active listening	43	7.40	0.95
316	Information gathering, researching, and organization	43	7.28	0.90
313	Facilitation	43	7.19	0.97
134	Customer focus	43	7.12	1.19
312	Empowerment	43	6.91	1.06
331	Technical communication	43	6.44	1.06
141	Process empowerment - Quality circles, employee suggestions, etc.	43	6.26	1.38
177	Flow process charts	42	5.79	1.24
181	Method improvements	41	6.63	1.18
143	Quality standards - ISO, QS	41	6.34	1.42
348	Statistics	41	6.22	1.11
133	Cost of quality	41	5.78	1.39
318	Non-technical communication	40	7.20	1.00
309	Consensus building	40	7.08	1.00
317	Leadership implementation	40	7.00	0.96
328	Supervision	40	6.67	1.22
308	Conflict resolution	40	6.55	1.22
173	Types of cost - labor, material, overhead, and marginal	40	5.85	1.37
114	Control charts	40	5.20	1.54
319	Predictive/anticipation of problems	37	6.76	1.04
146	Benefit cost analysis	37	6.11	1.05
131	Benchmarking	37	5.68	1.17
307	Conclusion drawing	36	7.31	0.83
132	Change management	36	7.28	1.02
293	Mentoring of personnel	36	6.69	1.33
286	Financial justification	36	6.53	0.96
166	Labor computation	36	6.22	1.13
202	Evaluation of layouts	36	5.58	1.33

Table 4.6.1: Top 50 KIs, sorted on raters rating, that manufacturing managers believe are the most job applicable to this subgroup (continued)

Table 4.6.1: (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
210	Number of machines/people required	36	5.50	1.55
63	Flow chart interpretations	36	5.14	1.27
304	Accountability	35	7.29	0.97
306	Assessing performance	35	6.97	0.96
290	Labor/management relations	35	6.60	1.23
187	Capacity planning	35	6.49	1.08
324	Risk management	35	5.83	0.98
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	34	6.74	1.19
323	Resource identification	34	6.68	0.93
185	Work breakdown	34	5.53	1.34
147	Capital budgeting	34	5.38	1.11
182	Methods analysis	33	6.42	1.31
200	Capacity planning	33	6.18	1.36

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
217	Systematic Layout Planning (SLP)	3	6.00	0.58
48	"Black-box" approach	3	5.33	1.54
102	Non parametric analysis	3	5.00	1.15
10	Work-rest cycles	3	4.33	0.54
112	Combinatorics - combinations, permutations, etc.	3	4.33	1.54
250	Kinematics of machine tools	3	4.33	0.96
19	Heat stress	3	3.67	1.92
81	Non-linear programming - setting up	3	3.67	0.27
267	Sensoring	3	3.67	1.35
39	Protocol analysis	3	3.33	0.96
6	Muscle performance	3	3.00	1.15
76	Calculus-based optimization	3	3.00	0.00
56	Artificial intelligence(AI)	3	2.67	0.27
23	Loss control program design	2	4.50	0.35
83	Transportation algorithm	2	4.50	1.06
75	Assignment algorithm	2	3.50	0.35
119	Point estimates	2	3.50	1.06
70	Pseudocode	2	2.50	1.06
66	Markov models	1	5.00	0.00
67	Mathematical programming	1	5.00	0.00
91	Surface search methods	1	5.00	0.00
7	Physiological control models	1	4.00	0.00
344	Neuroscience	1	4.00	0.00
77	Combinatorial optimization	1	2.00	0.00
334	Biological sciences	1	2.00	0.00

Table 4.6.2: Bottom 25 KIs, sorted on raters rating, that manufacturing managers believe are the least job applicable to this subgroup

4.7 Ideal Undergraduate Analysis – Manufacturing Managers (n=51)

The $r_{(1,1)}$ and $r_{(k,k)}$ values were .3402 and .9634, respectively. The average number of raters per item was 51 since all items were rated. The mean rating per item was 5.28. Only 17 raters would have been needed to reach an $r_{(k,k)}$ of .90. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that manufacturing managers believe the ideal ISE undergraduate should posses.

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
332	Time management	51	7.64	0.87
73	Spreadsheets	51	7.46	0.91
321	Problem solution implementation	51	7.16	1.03
322	Process thinking	51	7.14	0.98
333	Values/ethics	51	7.12	1.04
181	Method improvements	51	7.10	0.91
330	Teamwork implementation	51	7.10	1.04
134	Customer focus	51	7.08	0.95
320	Presentation	51	7.00	0.99
132	Change management	51	6.96	0.92
310	Creativity and innovation	51	6.96	1.03
182	Methods analysis	51	6.94	0.91
316	Information gathering, researching, and organization	51	6.94	1.11
133	Cost of quality	51	6.92	0.88
331	Technical communication	51	6.84	1.04
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	51	6.80	1.07
305	Active listening	51	6.80	1.20
311	Documentation	51	6.78	1.00
317	Leadership implementation	51	6.76	1.06
348	Statistics	51	6.76	1.01
177	Flow process charts	51	6.70	0.91
121	Process capability	51	6.68	0.92
309	Consensus building	51	6.62	1.04
307	Conclusion drawing	51	6.60	1.14
313	Facilitation	51	6.60	1.13
318	Non-technical communication	51	6.58	1.28
306	Assessing performance	51	6.56	1.13
114	Control charts	51	6.54	0.91
329	System perspective	51	6.52	1.04
320	Predictive/anticipation of problems	51	6.50	1.19
138	Management and planning tools - SPC	51	6.46	1.04
141	Process empowerment - Quality circles, employee suggestions, etc.	51	6.46	1.16
286	Financial justification	51	6.44	1.03

Table 4.7.1: Top 50 KIs, sorted on mean value, that manufacturing managers believe the ideal ISE undergraduate should possess (continued)

Table 4.7.1 (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
308	Conflict resolution	51	6.44	1.23
341	Mathematics	51	6.44	1.20
251	Lean manufacturing implementation	51	6.40	1.14
252	Line balancing techniques	51	6.40	0.95
312	Empowerment	51	6.40	1.21
185	Work breakdown	51	6.38	1.12
249	KANBAN/Pull versus CONWIP/Push	51	6.38	1.07
278	Troubleshooting	51	6.34	1.20
248	Just-in-time manufacturing implementation	51	6.30	1.04
108	Statistical software use	51	6.28	1.07
143	Quality standards - ISO, QS	51	6.26	1.34
12	Workstation design	51	6.24	1.04
63	Flow chart interpretations	51	6.20	0.97
183	Monitor methods	51	6.20	1.05
200	Capacity planning	51	6.20	1.15
300	Proposal preparation	51	6.20	1.08
131	Benchmarking	51	6.18	1.00

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
66	Markov models	51	4.00	1.04
67	Mathematical programming	51	4.00	1.04
274	Tool wear	51	4.00	1.19
21	Industrial toxicology	51	3.98	1.01
15	Fall hazard control	51	3.96	1.16
335	Chemistry	51	3.94	1.14
14	Electrical safety	51	3.92	1.26
22	Industrial ventilation	51	3.92	1.09
345	Philosophy	51	3.92	1.20
7	Physiological control models	51	3.90	1.22
16	Fire safety	51	3.90	1.14
31	Workplace violence control	51	3.90	1.21
91	Surface search methods	51	3.88	1.03
92	Terminating versus non-terminating	51	3.88	1.04
18	Health and safety record keeping process	51	3.84	1.00
297	Patent process	51	3.84	1.11
29	Workplace air quality	51	3.82	0.95
3	Energy consumption measurement	51	3.70	1.26
23	Loss control program design	51	3.68	1.22
68	Neural networks	51	3.62	0.99
70	Pseudocode	51	3.62	0.99
344	Neuroscience	51	3.62	0.97
339	Linguistics	51	3.42	1.22
19	Heat stress	51	3.34	1.06
334	Biological sciences	51	3.28	1.10

Table 4.7.2: Bottom 25 KIs, sorted on mean value, that manufacturing managers believe the ideal ISE undergraduate should possess

4.8 Unique Core KIs Discriminators Matched to Top Technical Ideal Undergraduate Recommendations – Manufacturing Managers

In order to simplify analysis, Table 4.8.1 is provided. It shows the KIs that were identified as unique core KIs from top to bottom in scoring for manufacturing managers, matched to top scoring technical ideal undergraduate recommendations made by this subgroup. The arrows help map between these variables.

Manufacturing Managers	*Stage 46, Homogeneity index=32.54*	*n=51*
Core Item Discriminators	Ideal Graduate Recommendation	Mean
Labor/mgt relations	Method improvements	7.04
Control charts	Methods analysis	6.88
Cost of quality	Statistics	6.73
Quality Standards - ISO, QS	Control charts	6.51
Flow chart interpretation	Mgt, planning tools - SPC	6.45
Process empowerment	Mathematics	6.43
Work breakdown	Lean manu implementation	6.41
Flow process charts	Line balancing techniques	6.41
Number of machines/people rqt	KANBAN/pull vs CONWIP/push	6.39
Bench marking	Work breakdown	6.33
Supervision	JIT manu implementation	6.31
Method improvements	Statistical software use	6.25
Evaluation of layouts	Quality standards - ISO, QS	6.25
Capacity planning	Workstation design	6.25
Methods analysis	Capacity planning	6.20

Table 4.8.1: Unique core KIs ranked from top to bottom in scoring matched to top scoring technical ideal undergraduate recommendations – manufacturing managers

4.9 Job Applicability Results – Manufacturing Engineers (n=7)

Although small, the manufacturing engineers were easy to job type based on the unique KIs that were applicable to this subgroup. The $r_{(1,1)}$ and $r_{(k,k)}$ values were .3611 and .5915, respectively. The average number of raters per item was 2.56 with 19% of possible responses rated. The mean rating per item was 5.31. Forty-four raters would have been needed to reach an $r_{(k,k)}$ of .90. The manufacturing engineer subgroup consisted of three manufacturing engineers, a staff engineer, production engineer, engineering coordinator, and a manger of IE and manufacturing. Table 4.9.1 lists the top 50 KIs, sorted on raters rating, that manufacturing engineers believe the most job applicable KIs are to this subgroup. The bottom 25 KIs that graduates believe had low job applicability is not reported due to the low sample size. There were 167 KIs that did not receive a rating from any of the raters. Therefore, no meaningful data can be easily summarized from this report.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
181	Method improvements	7	6.43	1.02
215	Space planning	7	6.29	0.99
11	Workplace design	7	6.14	1.09
176	Calculation of time standards - normal and standard time, allowances	7	5.86	1.23
12	Workstation design	7	5.43	1.50
184	Time studies	7	5.43	0.70
231	Design for assembly	7	5.43	1.50
235	Design for manufacturing	7	5.43	1.41
203	Expansion planning	6	6.50	0.91
187	Capacity planning	6	6.17	0.95
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	6	6.17	1.21
182	Methods analysis	6	6.00	1.22
177	Flow process charts	6	5.00	1.47
5	Manual materials handling	6	4.83	0.89
73	Spreadsheets	5	7.60	0.68
332	Time management	5	7.40	0.72
202	Evaluation of layouts	5	7.00	1.10
200	Capacity planning	5	6.60	0.70
252	Line balancing techniques	5	6.40	1.05
49	2-D computer aided design (CAD)	5	6.00	1.10
147	Capital budgeting	5	5.60	0.90
286	Financial justification	5	5.60	1.53
210	Number of machines/people required	5	5.40	1.37
214	Selection of material handling systems and equipment capabilities	5	5.20	1.30
218	Types of material handling systems - capacities	5	4.80	0.99
247	Jig and fixture design	5	4.20	1.30
232	Design for cost	5	4.00	1.79
24	Machine guarding	5	3.00	1.00
250	Lean manufacturing implementation	4	7.25	1.24

Table 4.9.1: Top 50 KIs, sorted on raters rating, that manufacturing engineers believe are the most job applicable to this subgroup (continued)

Table 4.9.1 (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
219	Types of layouts - product, process, fixed position, cellular, spine	4	6.50	0.79
331	Technical communication	4	6.25	0.88
55	3-D CAD	4	5.50	1.09
212	Paced assembly lines	4	5.50	1.75
282	Bill of materials	4	5.50	1.06
248	Just-in-time manufacturing implementation	4	5.25	0.88
143	Quality standards - ISO, QS	4	5.00	1.41
208	Material flow analysis - capacities under given demands, unit loads/distances	4	5.00	1.12
131	Benchmarking	4	4.50	0.79
222	Automation concepts	4	4.50	1.06
284	Business plan development	4	4.50	2.25
141	Process empowerment - Quality circles, employee suggestions etc.	4	4.00	2.00
25	Occupational safety and health standards	4	3.75	0.89
114	Control charts	4	3.50	0.79
4	Hand tool design	4	3.25	1.38
130	Auditing	4	2.75	0.64
310	Creativity and innovation	3	7.33	1.04
316	Information gathering, researching, and organization	3	7.00	1.15
162	Break-even analysis	3	6.67	0.77
309	Consensus building	3	6.67	1.36
322	Process thinking	3	6.67	1.35

4.10 Ideal Undergraduate Analysis – Manufacturing Engineers (n=7)

The $r_{(1,1)}$ and $r_{(k,k)}$ values were .5538 and .8968, respectively.. The average number of raters per item was seven since all items were rated. The mean rating per item was 4.86. Only seven raters would have been needed to reach an $r_{(k,k)}$ of .90. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that manufacturing engineers believe the ideal ISE undergraduate should possess.

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
235	Design for manufacturing	7	7.57	0.36
181	Method improvements	7	7.43	0.67
182	Methods analysis	7	7.43	0.63
224	Blueprint interpretation	7	7.43	0.84
231	Design for assembly	7	7.43	0.43
318	Non-technical communication	7	7.43	0.84
184	Time studies	7	7.29	0.70
238	Design for reliability	7	7.29	0.47
239	Design for safety	7	7.29	0.47
240	Design for usability	7	7.29	0.54
176	Calculation of time standards - normal and standard time, allowances	7	7.14	0.77
185	Work breakdown	7	7.14	0.77
236	Design for performance	7	7.14	0.56
237	Design for product	7	7.14	0.56
183	Monitor methods	7	7.00	0.85
202	Evaluation of layouts	7	7.00	0.65
203	Expansion planning	7	7.00	0.65
221	Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.	7	7.00	0.93
222	Automation concepts	7	7.00	0.85
232	Design for cost	7	7.00	0.65
251	Lean manufacturing implementation	7	7.00	1.31
278	Troubleshooting	7	7.00	0.85
310	Creativity and innovation	7	7.00	1.20
311	Documentation	7	7.00	1.00
321	Problem solution implementation	7	7.00	1.00
332	Time management	7	7.00	0.85
333	Values/ethics	7	7.00	0.93
73	Spreadsheets	7	6.86	1.10
143	Quality standards - ISO, QS	7	6.86	0.92
134	Customer focus	7	6.71	1.00
215	Space planning	7	6.71	0.24
248	Just-in-time manufacturing implementation	7	6.71	0.88
249	KANBAN/Pull versus CONWIP/Push	7	6.71	1.10
252	Line balancing techniques	7	6.71	0.88
320	Presentation	7	6.71	1.32
12	Workstation design	7	6.57	1.19

Table 4.10.1: Top 50 KIs, sorted on mean value, that manufacturing engineers believe the ideal ISE undergraduate should possess

Table 4.10.1 (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
135	Effect of part tolerance on process and warranty cost	7	6.57	1.08
223	Basic shop practices	7	6.57	1.08
233	Design for distribution	7	6.57	0.78
241	Economics - per unit cost under various demand rates, machine selection	7	6.57	0.61
244	Geometric dimensioning and tolerancing (GD&T)	7	6.57	0.76
330	Teamwork implementation	7	6.57	1.31
331	Technical communication	7	6.57	0.96
11	Workplace design	7	6.43	1.16
136	Failure and effect analysis	7	6.43	1.00
154	Rate of return	7	6.43	0.43
177	Flow process charts	7	6.43	1.04
205	Flexibility planning	7	6.43	0.70
234	Design for environment	7	6.43	0.87
272	Tool design	7	6.43	1.00

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
78	Dynamic programming	7	2.86	0.62
80	Network optimization	7	2.86	0.82
84	Discrete event concepts	7	2.86	0.75
87	Input analysis	7	2.86	0.62
334	Biological sciences	7	2.86	0.45
38	Mental models of complex systems	7	2.71	0.24
82	Optimization methods - large systems, integer	7	2.71	1.00
297	Patent process	7	2.71	0.52
339	Linguistics	7	2.71	1.10
19	Heat stress	7	2.57	0.95
75	Assignment algorithm	7	2.57	0.61
77	Combinatorial optimization	7	2.57	0.95
79	Linear programming - setting up, recognizing the dual	7	2.57	0.95
86	Initialization bias	7	2.57	0.95
91	Surface search methods	7	2.57	0.96
345	Philosophy	7	2.57	0.96
39	Protocol analysis	7	2.43	0.43
66	Markov models	7	2.43	0.37
68	Neural networks	7	2.43	0.67
76	Calculus-based optimization	7	2.43	0.37
80	Non-linear programming - setting up	7	2.43	0.70
90	Random variate generation	7	2.43	0.70
70	Pseudocode	7	2.29	0.47
31	Workplace violence control	7	2.14	1.08
93	Terminating versus non-terminating	7	2.00	0.53

Table 4.10.2: Bottom 25 KIs, sorted on mean value, that manufacturing engineers believe the ideal ISE undergraduate should possess

4.11 Unique Core KIs Discriminators Matched to Technical Top Technical Ideal Undergraduate Recommendations – Manufacturing Engineers

Table 4.11.1 shows the KIs that were identified as unique core KIs, ranked from top to bottom, that manufacturing engineers matched to top scoring technical ideal undergraduate recommendations made by this subgroup. The arrows help map between these variables.

Manufacturing Engineers	*Stage 43, Homogeneity index=34.06*	*n=7*
Core Item Discriminators	Ideal Graduate Recommendation	Mean
Design for assembly	Design for manufacturing	7.57
Space planning	Methods improvements	7.43
Design for manufacturing	Methods analysis	7.43
Time studies	Blueprint interpretation	7.43
Calculation of time standards	Design for assembly	7.43
Types of mtl handling systems	Time studies	7.29
Design for cost	Design for reliability	7.29
Jig and fixture designs	Design for safety	7.29
Manual material handling	Design for usability	7.29
Workstation design	Calculation of time standards	7.14
Method improvements	Work breakdown	7.14
Method analysis	Design for performance	7.14
2-D CAD	Design for product	7.14
Machine guarding	Assembly processes - welding etc.	7.00
Line balancing techniques	Automation concepts	7.00

Table 4.11.1: Unique core KIs ranked from top to bottom in scoring matched to top scoring technical ideal undergraduate recommendations – manufacturing engineers

4.12 Job Applicability Results – Safety Engineers (n=7)

Although this subgroup was also small, the safety engineers were the most difficult to job type based on their unique applicable KIs. The $r_{(1,1)}$ and $r_{(k,k)}$ values were .4384 and .5935, respectively. The average number of raters per item was 1.87 with 14%

of possible responses rated. The mean rating per item was 5.87. Forty-three raters would have been needed to reach an $r_{(k,k)}$ of .90. The safety engineer subgroup consisted of an ergonomics specialist, senior research engineering associate specializing in biomechanics, environmental and quality assurance manager, in-plant support manager, systems analysts, systems engineer, and engineering manager. Table 4.12.1 lists the top 50 KIs, sorted on raters rating, that safety engineers believe are the most job applicable KIs to this subgroup. Like the manufacturing engineer subgroup, the bottom 25 KIs that graduates believe had low job applicability is not reported due to the low sample size. There were 167 KIs that did not receive a rating from any of the raters. Therefore, no meaningful data can be easily summarized from this report.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
11	Workplace design	7	4.29	1.48
73	Spreadsheets	6	7.50	0.87
42	Database - types, information content, relational	6	6.83	1.11
348	Statistics	6	5.83	1.01
12	Workstation design	6	4.00	1.53
18	Health and safety record keeping process	5	6.00	0.77
35	Human-computer interaction	5	5.80	0.55
28	Safety culture implementation	5	5.40	1.78
25	Occupational safety and health standards	4	7.50	0.75
43	Database management	4	7.25	0.95
17	Hazardous communication	4	6.00	1.58
324	Risk management	4	5.75	1.13
9	Tasks design	4	5.50	0.35
26	Occupational/personal protection equipment	4	5.25	1.91
328	Supervision	4	5.25	1.91
16	Fire safety	4	5.00	2.24
2	Design concepts - anthropometry limits	4	4.50	1.46
8	Task demand analysis	4	4.50	0.79
346	Physics	4	4.00	0.71
130	Auditing	3	8.00	0.58
45	Network and communication terminology - types, protocols	3	7.33	0.96
301	Purchasing	3	7.33	0.38
332	Time management	3	7.33	0.38
88	Interpreting flow charts	3	7.00	0.58
108	Statistical software use	3	7.00	1.29
336	Computer Science	3	7.00	1.15
29	Workplace air quality	3	6.67	1.35
127	Sampling plans	3	6.33	1.54
114	Control charts	3	6.00	1.73
146	Benefit cost analysis	3	6.00	0.82
337	Electrical	3	6.00	0.00
44	Graphical user interfaces (GUIs)	3	5.67	1.92
63	Flow chart interpretations	3	5.67	1.35
89	Output analysis	3	5.67	0.77
341	Mathematics	3	5.67	0.27
1	Biomechanics analysis	3	5.33	1.59

Table 4.12.1: Top 50 KIs, sorted on raters rating, that safety engineers believe are the most job applicable to this subgroup (continued)

Table 4.12.1 (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
36	Human-information processing	3	5.00	0.58
202	Evaluation of layouts	3	5.00	0.58
347	Psychology	3	5.00	0.00
49	2-D computer aided design (CAD)	3	4.67	0.79
278	Troubleshooting	2	9.00	0.00
311	Documentation	2	9.00	0.00
143	Quality standards - ISO, QS	2	8.50	0.35
30	Workplace hazards - anticipation, recognition, evaluation, and control (AREC)	2	8.00	0.71
219	Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.	2	8.00	0.00
231	Design for assembly	2	8.00	0.00
235	Design for manufacturing	2	8.00	0.00
316	Information gathering, researching, and organization	2	8.00	0.00
27	Regulatory agency functions	2	7.50	1.06
34	Human error identification	2	7.50	1.06

4.13 Ideal Undergraduate Analysis – Safety Engineers (n=6)

The $r_{(1,1)}$ and $r_{(k,k)}$ values were .2123 and .6179, respectively. The average number of raters per item was six because one rater, number 37, was identified as a divergent rater with a correlation of .0452. The mean rating per item was 5.40. Thirty-three raters would have been needed to reach an $r_{(k,k)}$ of .90. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that safety engineers believe the ideal ISE undergraduate should posses.

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
12	Workstation design	6	7.83	0.68
73	Spreadsheets	6	7.83	0.68
332	Time management	6	7.83	0.68
320	Presentation	6	7.50	0.68
11	Workplace design	6	7.33	0.78
63	Flow chart interpretations	6	7.33	0.96
290	Labor/management relations	6	7.33	1.00
74	Verification	6	7.17	0.48
321	Problem solution implementation	6	7.00	0.58
322	Process thinking	6	7.00	0.91
162	Break-even analysis	6	6.83	1.11
199	Short-term forecasting	6	6.83	1.25
330	Teamwork implementation	6	6.83	1.01
331	Technical communication	6	6.83	0.68
333	Values/ethics	6	6.83	0.83
42	Database - types, information content, relational	6	6.67	0.97
43	Database management	6	6.67	1.11
64	High level computer languages - C, Pascal, ADA, etc.	6	6.67	1.11
173	Types of cost - labor, material, overhead, and marginal	6	6.67	0.97
188	Dependent demand inventory modeling	6	6.67	0.98
325	Role identification	6	6.67	0.59
164	Cost estimation equations for manufacturing or service	6	6.50	1.04
187	Capacity planning	6	6.50	1.21
215	Space planning	6	6.50	1.04
231	Design for assembly	6	6.50	1.04
232	Design for cost	6	6.50	1.04
234	Design for environment	6	6.50	1.04
236	Design for performance	6	6.50	1.04
237	Design for product	6	6.50	1.04
241	Economics - per unit cost under various demand rates, machine selection	6	6.50	0.68
286	Financial justification	6	6.50	1.21
323	Resource identification	6	6.50	0.68
324	Risk management	6	6.50	0.89

Table 4.13.1: Top 50 KIs, sorted on mean value, that safety engineers believe the ideal ISE undergraduate should possess (continued)

Table 4.13.1 (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
329	System perspective	6	6.50	0.89
10	Work-rest cycles	6	6.33	0.83
45	Network and communication terminology - types, protocols	6	6.33	1.56
53	Decision trees	6	6.33	0.83
160	Activity based costing	6	6.33	1.15
163	Breakdown of fixed costs - fixed, variable, direct, and indirect labor and materials	6	6.33	0.73
165	Environmental costing	6	6.33	1.09
171	Quote preparation	6	6.33	1.12
202	Evaluation of layouts	6	6.33	0.78
207	Human/machine tradeoffs	6	6.33	1.15
209	Number of machines/people required	6	6.33	0.78
210	Optimum location - single/multiple location/storage	6	6.33	1.12
220	Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.	6	6.33	1.00
224	Blueprint interpretation	6	6.33	1.12
233	Design for distribution	6	6.33	0.73
235	Design for manufacturing	6	6.33	0.73

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
344	Neuroscience	6	4.33	0.54
37	Knowledge elicitation of intelligent systems	6	4.17	0.95
68	Neural networks	6	4.17	0.95
90	Random variate generation	6	4.17	1.21
93	Variance reduction	6	4.17	1.38
270	Surface integrity	6	4.17	0.89
326	Shape/scale visualization	6	4.17	0.59
340	Materials	6	4.17	1.11
349	Thermodynamics	6	4.17	1.21
19	Heat stress	6	4.00	1.53
47	Utility functions	6	4.00	1.22
86	Initialization bias	6	4.00	0.58
91	Surface search methods	6	4.00	0.91
112	Combinatorics - combinations, permutations, etc.	6	4.00	1.00
156	Taxes	6	4.00	1.22
227	Coating/curing/pretreatment	6	4.00	0.91
102	Non parametric analysis	6	3.83	0.83
111	Central limit theory	6	3.83	1.01
38	Mental models of complex systems	6	3.67	1.85
39	Protocol analysis	6	3.67	1.47
75	Assignment algorithm	6	3.67	1.22
76	Calculus-based optimization	6	3.67	1.11
92	Terminating versus non-terminating	6	3.67	0.97
334	Biological sciences	6	3.67	0.78
78	Dynamic programming	6	3.50	1.21
226	Casting processes - sand, die, investment, etc.	6	3.50	1.06
338	Foreign languages	6	3.50	1.44
339	Linguistics	6	3.50	1.55
345	Philosophy	6	3.50	0.89
350	Tribology - friction, lubrication and wear of interacting surfaces	6	3.50	1.34

Table 4.13.2: Bottom 25 KIs, sorted on mean value, that safety engineers believe the ideal ISE undergraduate should possess

4.14 Unique Core KIs Discriminators Matched to Technical Top Technical Ideal Undergraduate Recommendations – Safety Engineers

Table 4.14.1 shows the KIs that were identified as unique core KIs, ranked from top to bottom, for safety engineers matched to top scoring technical ideal undergraduate recommendations made by this subgroup. The arrows help map between these variables.

Safety Engineers	*Stage 14, Homogeneity index=10.86*	*n=7,6*
Core Item Discriminators	Ideal Graduate Recommendation	Mean
Health/safety record keep proc	Workstation design	7.83
Safety culture implementation	Spreadsheets	7.83
Human-computer interaction	Workplace design	7.33
Workplace design	Flow chart interpretation	7.33
Workstation design	Process thinking	7.00
Database - types, info, relation	Break-even analysis	6.83
Statistics	Short-term forecasting	6.83
Design concepts-anthropometry	Database - types, info content, relatio	6.67
Task demand analysis	HOL - C, Pascal, ADA, etc.	6.67
Fire safety	Types of costs - Labor, mtl, oh, marg	6.67
Workplace air quality	Dependent demand inventory	6.67
Hazardous communication	Cost estimation eqs for manu service	6.50
Physics	Capacity planning	6.50
Human-information processing	Space planning	6.50
Output analysis	Design for assembly	6.50

Table 4.14.1: Unique core KIs ranked from top to bottom in scoring matched to top scoring technical ideal undergraduate recommendations – safety engineers

4.15 Job Applicability Results – Operations Research Personnel (n=4)

Although this subgroup was also small, operations research personnel were also easy to job type based on their unique applicable KIs. The $r_{(1,1)}$ and $r_{(k,k)}$ values were .5577 and .7208, respectively. The average number of raters per item was 2.05 with 29% of possible responses rated. The mean rating per item was 6.56. Fourteen raters would have been needed to reach an $r_{(k,k)}$ of .90. The operations research personnel subgroup consisted of an engineering coordinator, military member specializing in operations research, systems analyst, and a vice president. The following table lists the top 50 KIs, sorted on raters rating, that operations research personnel believe are the most job applicable KIs to this subgroup. Like the manufacturing engineer and safety subgroups, the bottom 25 KIs that graduates believe had low job applicability is not reported due to the low sample size. There were 150 KIs that did not receive a rating from any of the raters. Therefore, no meaningful data can be easily summarized from this report.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
73	Spreadsheets	4	8.75	0.22
348	Statistics	4	8.00	0.50
113	Confidence intervals	4	7.75	0.65
120	Probability distributions - normal, binomial, etc.	4	7.50	0.79
316	Information gathering, researching, and organization	4	7.50	0.83
157	Time value of money	4	7.25	1.24
116	Goodness of fit	4	7.00	1.12
154	Rate of return	4	6.75	0.88
159	Worth - Present, Future,Expect	4	6.75	1.13
126	Sampling - distribution	4	6.50	0.79
60	Discrete probability models	4	6.25	0.53
161	Basic accounting	4	6.25	1.43
117	Hypothesis testing	4	6.00	1.00
156	Taxes	4	6.00	0.50
123	Reliability	4	5.75	1.29
149	Depreciation	4	5.75	1.13
59	Continuous probability models	4	5.50	1.06
153	Make/buy/lease decisions	4	5.00	1.58
253	Logistics	3	8.67	0.27
320	Presentation	3	8.67	0.27
332	Time management	3	8.67	0.27
333	Values/ethics	3	8.67	0.27
315	Global awareness	3	8.33	0.38
50	Decision making under risk	3	8.00	0.58
50	Decision making under uncert	3	8.00	0.58
155	Sensitivity analysis	3	8.00	0.58
328	Supervision	3	8.00	0.58
69	Numerical analysis	3	7.67	0.77
77	Combinatorial optimization	3	7.67	0.79
108	Statistical software use	3	7.67	0.79
141	Process empowerment - Quality circles, employee suggestions, etc.	3	7.67	0.77
304	Accountability	3	7.67	0.77
305	Active listening	3	7.67	0.77
306	Assessing performance	3	7.67	0.77
313	Facilitation	3	7.67	0.77
318	Non-technical communication	3	7.67	0.77
322	Process thinking	3	7.67	0.27
324	Risk management	3	7.67	1.09
52	Decision support systems	3	7.33	0.38
336	Computer Science	3	7.33	0.38

Table 4.15.1: Top 50 KIs, sorted on raters rating, that operations research personnel believe are the most job applicable to this subgroup (continued)

Table 4.15.1: (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
111	Central limit theory	3	7.00	0.58
119	Point estimates	3	7.00	0.58
286	Financial justification	3	7.00	1.15
341	Mathematics	3	7.00	0.00
53	Decision trees	3	6.67	0.79
75	Assignment algorithm	3	6.67	0.79
103	Randomness	3	6.67	0.77
134	Customer focus	3	6.33	1.59
146	Benefit cost analysis	3	6.33	0.96
71	Queuing theory and modeling	3	6.00	0.58

4.16 Ideal Undergraduate Analysis – Operations Research Personnel (n=4)

The $r_{(1,1)}$ and $r_{(k,k)}$ values were .4638 and .7758, respectively. The average number of raters per item was four and all items were rated. The mean rating per item was 5.63. Ten raters would have been needed to reach an $r_{(k,k)}$ of .90. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that operations research personnel believe the ideal ISE undergraduate should possess.

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
320	Presentation	4	8.50	0.35
322	Process thinking	4	8.50	0.35
332	Time management	4	8.50	0.35
333	Values/ethics	4	8.50	0.35
73	Spreadsheets	4	8.25	0.53
120	Probability distributions - normal, binomial, etc.	4	8.25	0.38
140	Principles - Crosby, Deming, Feigenbaum, Juran	4	8.25	0.53
154	Rate of return	4	8.25	0.53
159	Worth - Present, Future, Expected	4	8.25	0.53
316	Information gathering, researching, and organization	4	8.25	0.38
318	Non-technical communication	4	8.25	0.38
327	Social and cultural awareness	4	8.25	0.38
67	Mathematical programming	4	8.00	0.71
157	Time value of money	4	8.00	0.71
304	Accountability	4	8.00	0.50
305	Active listening	4	8.00	0.50
306	Assessing performance	4	8.00	0.50
307	Conclusion drawing	4	8.00	0.50
308	Conflict resolution	4	8.00	0.50
309	Consensus building	4	8.00	0.50
310	Creativity and innovation	4	8.00	0.50
311	Documentation	4	8.00	0.50
312	Empowerment	4	8.00	0.50
313	Facilitation	4	8.00	0.50
341	Mathematics	4	8.00	0.50
113	Confidence intervals	4	7.75	0.64
134	Customer focus	4	7.75	0.64
155	Sensitivity analysis	4	7.75	0.89
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	4	7.75	0.22
315	Global awareness	4	7.75	0.89
319	Predictive/anticipation of problems	4	7.75	0.22
320	Problem solution implementation	4	7.75	0.65
329	System perspective	4	7.75	0.89
336	Computer Science	4	7.75	0.64

Table 4.16.1: Top 50 KIs, sorted on mean value, that operations research personnel believe the ideal ISE undergraduate should possess (continued)

Table 4.16.1: (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
348	Statistics	4	7.75	0.64
52	Decision support systems	4	7.50	0.79
74	Verification	4	7.50	0.79
108	Statistical software use	4	7.50	0.79
111	Central limit theory	4	7.50	0.79
122	Regression - linear, multiple	4	7.50	0.83
161	Basic accounting	4	7.50	1.06
317	Leadership implementation	4	7.50	0.43
328	Supervision	4	7.50	0.83
330	Teamwork implementation	4	7.50	0.83
63	Flow chart interpretations	4	7.25	0.88
80	Network optimization	4	7.25	0.38
107	Scientific method	4	7.25	0.95
117	Hypothesis testing	4	7.25	0.53
131	Benchmarking	4	7.25	0.95
141	Process empowerment - Quality circles, employee suggestions, etc.	4	7.25	0.65

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
23	Loss control program design	4	3.75	1.13
29	Workplace air quality	4	3.75	1.13
177	Incentive systems - wage, payment	4	3.75	1.63
250	Kinematics of machine tools	4	3.75	0.64
252	Line balancing techniques	4	3.75	0.64
266	Product recycling	4	3.75	0.64
267	Sensoring	4	3.75	0.64
268	Sheet metalworking processes - blanking, punching, drawing, stretching, etc.	4	3.75	0.64
269	Stress analysis	4	3.75	0.64
350	Tribology - friction, lubrication and wear of interacting surfaces	4	3.75	0.64
3	Energy consumption measurement	4	3.50	1.06
4	Hand tool design	4	3.50	1.06
17	Hazardous communication	4	3.50	0.79
20	Industrial noise	4	3.50	1.25
228	Computer Numeric Control (CNC) programming	4	3.50	1.27
335	Chemistry	4	3.50	0.79
339	Linguistics	4	3.50	1.06
19	Heat stress	4	3.25	0.88
21	Industrial toxicology	4	3.25	0.88
22	Industrial ventilation	4	3.25	0.88
24	Machine guarding	4	3.25	0.88
13	Accident investigation and analysis	4	3.00	1.50
14	Electrical safety	4	3.00	1.50
15	Fall hazard control	4	2.75	1.13
16	Fire safety	4	2.75	1.13

Table 4.16.2: Bottom 25 KIs, sorted on mean value, that operations research personnel believe the ideal ISE undergraduate should possess

4.17 Unique Core KIs Discriminators Matched to Technical Top Technical Ideal Undergraduate Recommendations – Operations Research Personnel

Table 4.17.1 shows the KIs that were identified as unique core KIs, ranked from top to bottom, for operations research personnel matched to this subgroup's top scoring technical ideal undergraduate recommendations. The arrows help map between these variables.

Ops Research Personnel	*Stage 57, Homogeneity index=46.23*	*n=4*
Core Item Discriminators	Ideal Graduate Recommendation	Mean
Taxes	Probability distro - normal, binomial	8.25
Continuous probability models	Principles - Crosby, Deming, etc.	8.25
Discrete probability models	Rate of return	8.25
Goodness of fit	Worth - Present, Future, Expected	8.25
Hypothesis testing	Mathematical programming	8.25
Reliability	Time value of money	8.00
Basic accounting	Mathematics	8.00
Depreciation	Confidence intervals	7.75
Confidence intervals	Sensitivity analysis	7.75
Combinatorial optimization	Computer science	7.75
Sampling - distribution	Statistics	7.75
Worth-present,future,expected	Decision support systems	7.50
Assignment algorithm	Statistical software use	7.50
Discrete event concepts	Central limit theory	7.50
Rate of return	Regression - linear, multiple	7.50

Table 4.17.1: Unique core KIs ranked from top to bottom in scoring matched to top scoring technical ideal undergraduate recommendations – operations research personnel

4.18 Job Applicability Results – Cost Analysts (n=6)

Although this subgroup was also small, cost analysts were also easy to job type based on their unique applicable KIs. The $r_{(1,1)}$ and $r_{(k,k)}$ values were .4114 and .5546, respectively. The average number of raters per item was 1.78 with 13% of possible responses rated. The mean rating per item was 5.45. Forty-three raters would have been needed to reach an $r_{(k,k)}$ of .90. The cost analysts subgroup consisted of an IE manager, project controls engineer, senior consultant, management consultant, product assurance manager, and a cost engineer. The following table lists the top 50 KIs, sorted on raters rating, that cost analysts believe are the most job applicable KIs to this subgroup. Like the manufacturing and safety engineers, and operations research subgroups, the bottom 25 KIs that graduates believe had low job applicability is not reported due to the low sample size. There were 201 KIs that did not receive a rating from any of the raters. Therefore, no meaningful data can be easily summarized from this report.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
173	Types of cost - labor, material, overhead, and marginal	6	7.17	0.82
134	Customer focus	5	5.60	1.24
42	Database - types, information content, relational	5	4.40	0.81
73	Spreadsheets	4	8.25	0.65
163	Breakdown of fixed costs - fixed, variable, direct, and indirect labor and matls	4	8.00	0.50
322	Process thinking	4	6.75	1.29
166	Labor computation	4	6.25	1.63
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	4	6.25	1.43
164	Cost estimation equations for manufacturing or service	4	5.75	1.74
159	Worth - Present, Future, Expected	4	5.50	0.79
147	Capital budgeting	4	5.25	1.43
157	Time value of money	4	5.25	0.53
300	Proposal preparation	3	6.67	0.79
146	Benefit cost analysis	3	6.33	0.54
122	Regression - linear, multiple	3	5.67	1.09
125	Sample statistics - central tendency, dispersion	3	5.67	1.09
172	Target costing	3	5.67	1.36
132	Change management	3	5.33	1.54
170	Overhead allocation	3	5.33	2.15
303	Strategic plan development	3	5.33	1.54
348	Statistics	3	5.33	0.96
108	Statistical software use	3	5.00	1.15
333	Values/ethics	3	5.00	0.82
171	Quote preparation	3	4.67	1.93
286	Financial justification	3	4.67	0.79
104	Regression	3	4.33	1.54
155	Sensitivity analysis	3	4.33	0.96
62	Factory and systems applications	3	4.00	0.82

Table 4.18.1: Top 50 KIs, sorted on raters rating, that cost analysts believe are the most job applicable to this subgroup (continued)

Table 4.18.1: (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
133	Cost of quality	3	3.33	0.96
194	Material Requirements Planning (MRP) and Material Resource Planning (MRPII)	3	3.00	1.15
328	Supervision	2	9.00	0.00
332	Time management	2	8.50	0.35
52	Decision support systems	2	8.00	0.71
160	Activity based costing	2	8.00	0.71
321	Problem solution implementation	2	7.50	0.35
121	Process capability	2	7.00	0.71
282	Bill of materials	2	7.00	0.00
161	Basic accounting	2	6.50	1.77
185	Work breakdown	2	6.50	1.77
320	Presentation	2	6.50	0.35
324	Risk management	2	6.50	1.06
48	"Black-box" approach	2	6.00	0.00
107	Scientific method	2	6.00	0.00
119	Point estimates	2	6.00	2.12
130	Auditing	2	6.00	1.41
316	Information gathering, researching, and organization	2	6.00	0.71
319	Predictive/anticipation of problems	2	6.00	2.12
74	Verification	2	5.50	0.35
95	Analysis of variance (ANOVA)	2	5.50	0.35
138	Management and planning tools - SPC	2	5.50	1.77

4.19 Ideal Undergraduate Analysis – Cost Analysts (n=6)

The $r_{(1,1)}$ and $r_{(k,k)}$ values were .2620 and .6805, respectively. The average number of raters per item was six and all items were rated. The mean rating per item was 5.40. Twenty-five raters would have been needed to reach an $r_{(k,k)}$ of .90. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that cost analysts believe the ideal ISE undergraduate should possess.

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
138	Management and planning tools - SPC	6	7.33	0.47
332	Time management	6	7.33	1.00
348	Statistics	6	7.33	0.68
290	Labor/management relations	6	7.17	0.95
320	Problem solution implementation	6	7.17	1.11
73	Spreadsheets	6	7.00	1.22
250	Lean manufacturing implementation	6	7.00	1.22
253	Logistics	6	7.00	0.71
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	6	7.00	1.00
322	Process thinking	6	7.00	1.22
336	Computer Science	6	7.00	0.91
35	Human-computer interaction	6	6.83	1.25
71	Queuing theory and modeling	6	6.83	0.68
108	Statistical software use	6	6.83	1.11
121	Process capability	6	6.83	1.01
134	Customer focus	6	6.83	1.25
139	Principles - Crosby, Deming, Feigenbaum, Juran	6	6.83	1.34
181	Method improvements	6	6.83	1.11
342	Mechanical	6	6.83	0.68
11	Workplace design	6	6.67	1.11
12	Workstation design	6	6.67	1.11
42	Database - types, information content, relational	6	6.67	0.95
43	Graphical user interfaces (GUIs)	6	6.67	1.11
132	Change management	6	6.67	1.35
241	Economics - per unit cost under various demand rates, machine selection	6	6.67	0.78
286	Financial justification	6	6.67	0.78
330	Teamwork implementation	6	6.67	1.23
333	Values/ethics	6	6.67	1.11
52	Decision support systems	6	6.50	1.06
104	Regression	6	6.50	1.21

Table 4.19.1: Top 50 KIs, sorted on mean value, that cost analysts believe the ideal ISE undergraduate should possess (continued)

Table 4.19.1: (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
107	Scientific method	6	6.50	1.44
126	Sampling - distribution	6	6.50	1.06
182	Methods analysis	6	6.50	1.19
194	Material Requirements Planning (MRP) and Material Resource Planning (MRPII)	6	6.50	1.06
211	Number of machines/people required	6	6.50	1.19
310	Creativity and innovation	6	6.50	1.08
311	Documentation	6	6.50	1.04
320	Presentation	6	6.50	1.34
341	Mathematics	6	6.50	0.89
43	Database management	6	6.33	1.00
57	Computer aided manufacturing (CAM)	6	6.33	1.28
58	Computer integrated manufacturing (CIM)	6	6.33	1.28
141	Process empowerment - Quality circles, employee suggestions, etc.	6	6.33	1.00
176	Calculation of time standards - normal and standard time, allowances	6	6.33	1.31
192	Inventory analysis	6	6.33	0.78
213	Physical control of machinery	6	6.33	1.28
227	Computer Numeric Control (CNC) programming	6	6.33	1.28
252	Line balancing techniques	6	6.33	0.78
278	Troubleshooting	6	6.33	1.00
295	Negotiating and arbitrating	6	6.33	1.04

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
102	Non parametric analysis	6	4.17	0.95
165	Environmental costing	6	4.17	0.68
167	Marginal analysis	6	4.17	0.59
270	Surface integrity	6	4.17	0.48
297	Patent process	6	4.17	0.82
337	Electrical	6	4.17	0.89
31	Workplace violence control	6	4.00	1.08
90	Random variate generation	6	4.00	0.58
156	Taxes	6	4.00	0.58
338	Foreign languages	6	4.00	0.41
2	Design concepts - anthropometry limits	6	3.83	0.82
13	Accident investigation and analysis	6	3.83	0.82
16	Fire safety	6	3.83	1.01
27	Regulatory agency functions	6	3.83	1.11
335	Chemistry	6	3.83	0.68
1	Biomechanics analysis	6	3.67	0.94
15	Fall hazard control	6	3.67	1.10
334	Biological sciences	6	3.67	0.59
344	Neuroscience	6	3.67	0.78
345	Philosophy	6	3.67	1.11
86	Initialization bias	6	3.50	0.71
91	Surface search methods	6	3.50	0.68
3	Energy consumption measurement	6	3.33	0.78
29	Workplace air quality	6	3.33	0.96
339	Linguistics	6	3.33	0.73

Table 4.19.2: Bottom 25 KIs, sorted on mean value, that cost analysts believe the ideal ISE undergraduate should possess

4.20 Unique Core KIs Discriminators Matched to Technical Top Technical Ideal Undergraduate Recommendations – Cost Analysts

Table 4.20.1 shows KIs that were identified as unique core KIs, ranked from top to bottom, for cost analysts matched to top scoring technical ideal undergraduate recommendations made by this subgroup.

Cost Analysts	*Stage 13, Homogeneity index=19.06*	*n=6*
Core Item Discriminators	Ideal Graduate Recommendation	Mean
Types of cost - labor, mtl	Mgt and planning tools - SPC	7.33
Cost estimation equations	Statistics	7.33
Labor computation	Problem solution implementation	7.17
Worth-present,future,expected	Spreadsheets	7.00
Database - types, info content	Lean manu implementation	7.00
Time value of money	Logistics	7.00
Breakdown of fixed costs	Project mgt - PERT, CPM	7.00
Capital budgeting	Process thinking	7.00
Project management	Computer science	7.00
Quote preparation	Human-computer interaction	6.83
"Black-box" approach	Queuing theory and modeling	6.83
Target costing	Statistical software use	6.83
Non parametric analysis	Process capability	6.83
Factory and systems apps	Methods improvements	6.83
Minimum cost analysis	Mechanical	6.83

Table 4.20.1: Unique core KIs ranked from top to bottom in scoring matched to top scoring technical ideal undergraduate recommendations – cost analysts

4.21 Job Applicability Results – General Managers (n=27)

The general manager job is the second largest identified subgroup. It was job typed based on the unique KIs that were applicable to this subgroup. The $r_{(1,1)}$ and $r_{(k,k)}$ values were .4286 and .8359, respectively. The average number of raters per item was 6.79 with 17% of possible responses rated. The mean rating per item was 6.37.

Forty-eight raters would have been needed to reach an $r_{(k,k)}$ of .90. The general manager subgroup consisted mainly of non-manufacturing manager level positions to include: product and account managers, consultants, and information technology managers. Table 4.21.1 lists the top 50 KIs sorted on raters rating that cost analysts believe are the most and least job applicable to this subgroup. Like the manufacturing engineer, safety, operations research, and cost analysts subgroups, the bottom 25 KIs that graduates believe had low job applicability is not reported due to the low sample size. There were 120 KIs that did not receive a rating from any of the raters. Therefore, no meaningful data can be easily summarized from this report.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
332	Time management	27	7.56	0.90
333	Values/ethics	27	7.07	1.28
311	Documentation	25	7.48	0.98
318	Non-technical communication	25	7.12	1.06
330	Teamwork implementation	25	7.12	0.93
320	Presentation	25	6.20	1.14
305	Active listening	24	7.79	0.79
321	Problem solution implementation	24	7.42	0.90
322	Process thinking	24	7.38	0.93
331	Technical communication	24	7.38	0.85
319	Predictive/anticipation of problems	24	6.83	1.06
316	Information gathering, researching, and organization	23	7.83	0.74
304	Accountability	23	7.48	0.99
310	Creativity and innovation	22	7.36	0.85
309	Consensus building	22	7.14	1.06
306	Assessing performance	22	6.64	0.98
312	Empowerment	21	6.57	1.01
308	Conflict resolution	21	6.52	1.11
313	Facilitation	20	6.85	1.06
307	Conclusion drawing	20	6.80	0.85
293	Mentoring of personnel	20	5.95	1.45
323	Resource identification	20	5.85	1.37
73	Spreadsheets	19	7.84	0.75
134	Customer focus	19	7.84	0.80
317	Leadership implementation	19	6.58	1.14
286	Financial justification	19	6.21	1.18
42	Database - types, information content, relational	18	7.39	1.04
327	Social and cultural awareness	18	6.00	1.15
146	Benefit cost analysis	18	5.28	1.54
43	Database management	17	6.71	1.12
336	Computer Science	16	7.88	0.80
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	16	7.00	1.22
300	Proposal preparation	16	7.00	1.03
324	Risk management	16	5.75	1.50
43	Graphical user interfaces (GUIs)	15	6.53	1.34

Table 4.21.1: Top 50 KIs, sorted on raters rating, that general managers believe are the most job applicable to this subgroup (continued)

Table 4.21.1: (continued)

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
325	Role identification	15	5.47	1.28
131	Benchmarking	15	5.00	1.71
329	System perspective	14	7.57	0.80
132	Change management	14	6.64	1.22
284	Business plan development	14	5.57	1.08
328	Supervision	13	7.23	0.84
315	Global awareness	13	6.38	1.23
303	Strategic plan development	13	6.08	1.06
44	Network and communication terminology - types, protocols	13	6.00	1.11
177	Flow process charts	12	6.67	1.40
63	High level computer languages - C, Pascal, ADA, etc.	12	6.50	1.27
163	Breakdown of fixed costs - fixed, variable, direct, and indirect labor and materials	12	5.75	1.00
173	Types of cost - labor, material, overhead, and marginal	11	5.91	1.06
140	Process empowerment - Quality circles, employee suggestions, etc.	11	5.82	1.74
194	Material Requirements Planning (MRP) and Material Resource Planning (MRPII)	11	5.45	1.77

4.22 Ideal Undergraduate Analysis – General Managers (n=27)

The $r_{(1,1)}$ and $r_{(k,k)}$ values were .3438 and .9291, respectively. The average number of raters per item was 25 and all items were rated. Thus, two raters were considered to be divergent with correlation's of .0000 and –0.1216 and were eliminated from the analysis. The mean rating per item was 4.98. Seventeen raters would have been needed to reach an $r_{(k,k)}$ of .90. The following tables list the top 50 and bottom 25 KIs, sorted on mean value, that cost analysts believe the ideal ISE undergraduate should possess.

Item	Description	Sorted Raters Rating	Mean Value	Standard Deviation
332	Time management	25	7.72	0.74
310	Creativity and innovation	25	7.44	0.92
316	Information gathering, researching, and organization	25	7.36	1.00
330	Teamwork implementation	25	7.36	1.02
320	Presentation	25	7.32	0.95
333	Values/ethics	25	7.32	1.15
134	Customer focus	25	7.28	1.01
320	Problem solution implementation	25	7.24	1.03
322	Process thinking	25	7.20	0.92
299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	25	7.16	0.99
305	Active listening	25	7.08	1.11
318	Non-technical communication	25	7.04	1.03
311	Documentation	25	7.00	1.15
317	Leadership implementation	25	7.00	1.08
331	Technical communication	25	6.96	1.02
307	Conclusion drawing	25	6.84	1.12
336	Computer Science	25	6.84	0.94
309	Consensus building	25	6.80	1.18
319	Predictive/anticipation of problems	25	6.80	1.10
286	Financial justification	25	6.76	1.15
313	Facilitation	25	6.72	0.92
308	Conflict resolution	25	6.68	1.26
133	Cost of quality	25	6.64	1.23
306	Assessing performance	25	6.64	1.29
329	System perspective	25	6.60	1.10
146	Benefit cost analysis	25	6.56	1.12
304	Accountability	25	6.56	1.34
132	Change management	25	6.52	1.24
303	Strategic plan development	25	6.48	1.17
73	Spreadsheets	25	6.44	1.39
300	Proposal preparation	25	6.40	1.10
323	Resource identification	25	6.40	0.98
324	Risk management	25	6.40	1.21
287	Forecasting of technology	25	6.36	1.16
312	Empowerment	25	6.32	1.41

Table 4.22.1: Top 50 KIs, sorted on mean value, that general managers believe the ideal ISE undergraduate should possess (continued)

Table 4.22.1: (continued)

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
348	Statistics	25	6.32	1.08
284	Business plan development	25	6.28	1.13
315	Global awareness	25	6.28	1.52
341	Mathematics	25	6.24	1.17
177	Flow process charts	25	6.16	1.21
325	Role identification	25	6.16	1.12
45	Graphical user interfaces (GUIs)	25	6.12	1.24
292	Marketing impact	25	6.12	1.18
328	Supervision	25	6.12	1.29
154	Rate of return	25	6.08	1.34
43	Database management	25	6.04	1.00
181	Method improvements	25	6.04	1.42
193	Long-term forecasting	25	6.04	1.21
253	Logistics	25	6.04	1.39
157	Time value of money	25	5.96	1.30

Item	Description	Raters Rating	Sorted Mean Value	Standard Deviation
72	Solid modeling	25	3.52	1.14
92	Terminating versus non-terminating	25	3.52	1.07
29	Workplace air quality	25	3.48	1.27
66	Markov models	25	3.48	1.26
3	Energy consumption measurement	25	3.44	1.07
6	Muscle performance	25	3.44	1.04
14	Electrical safety	25	3.44	1.37
21	Industrial toxicology	25	3.44	1.08
335	Chemistry	25	3.44	1.12
345	Philosophy	25	3.44	1.20
22	Industrial ventilation	25	3.40	1.09
349	Thermodynamics	25	3.40	1.46
4	Hand tool design	25	3.36	1.19
17	Hazardous communication	25	3.36	1.17
18	Health and safety record keeping process	25	3.36	1.26
20	Industrial noise	25	3.36	1.04
31	Workplace violence control	25	3.36	1.26
23	Loss control program design	25	3.32	1.11
13	Accident investigation and analysis	25	3.28	1.09
339	Linguistics	25	3.24	1.17
54	2-D to 3-D transitioning	25	3.20	1.17
334	Biological sciences	25	3.12	1.16
15	Fall hazard control	25	3.08	1.12
16	Fire safety	25	3.04	1.14
19	Heat stress	25	2.96	1.08

Table 4.22.2: Bottom 25 KIs, sorted on mean value, that general managers believe the ideal ISE undergraduate should possess

4.23 Unique Core KIs Discriminators Matched to Technical Top Technical Ideal Undergraduate Recommendations – General Managers

Table 4.23.1 shows the KIs that were identified as unique core KIs for general manager personnel matched to top scoring technical ideal undergraduate recommendations made by this subgroup. The arrows help map between these variables.

General Managers	*Stage 41, Homogeneity index=41.04*	*n=27*
<u>Core Item Discriminators</u>	<u>Ideal Graduate Recommendation</u>	<u>Mean</u>
Resource identification	Time management	7.48
Accountability	Creativity and innovation	7.22
Teamwork implementation	Information gathering	7.25
Values/ethics	Presentation	7.15
Assessing performance	Teamwork implementation	7.15
Mentoring of personnel	Values/ethics	7.11
Empowerment	Customer focus	7.07
Social and culture awareness	Problem solution implementation	7.04
Consensus building	Process thinking	7.00
Time management	Project management	6.96
Conclusion drawing	Active listening	6.89
Conflict resolution	Documentation	6.85
Predict/anticipation of problems	Non-tech communication	6.85
Leadership implementation	Leadership implementation	6.81
Documentation	Technical implementation	6.78

Table 4.23.1: Unique core KIs ranked from top to bottom in scoring matched to top scoring technical ideal undergraduate recommendations – general managers

4.24 Ideal Undergraduate Analysis – Pre 1995 (n=89) and From 1995 (n=43) ISE Graduates

These subgroups were formed as a result of changes made during this timeframe to OSU's IW&SE undergraduate program. The main differences in responses to the background variables reside in their age, highest degree of any education, and deciding whether a real-world application gap exists in ISE. The average age of the pre 1995 graduates is 34.1. Thirty-one percent have master's degrees and 57% believe a real-world application gap exists in ISE. On the other hand, 1995 and newer graduates had an average age of 26.9. Nine percent have master's degrees and 73% believe a real-world application gap exists in ISE. The pre 1995 subgroup had an $r_{(1,1)}$ of .2956 and an $r_{(k,k)}$ of .9742. The from 1995 subgroups had an $r_{(1,1)}$ of .3228 and an $r_{(k,k)}$ of .9535, respectively. The largest differences between mean KI ratings are given in Table 4.24.1.

Sub Head	**KI #**	**KI**	**Pre 95**	**From 95**	**Diff**
6	55	3-D CAD	4.47	5.23	-.76
6	73	Spreadsheets	6.81	7.79	-.98
7	76	Calculus-based optimization	3.90	4.74	-.84
7	82	Optimization methods – large sys	4.51	5.26	-.75
11	130	Auditing	5.34	4.53	.81
17	249	KANBAN/Pull Vs CONWIP/Push	5.63	6.49	-.86
17	277	Tradeoffs between manu processes	5.00	5.84	-.84
17	278	Troubleshooting	5.80	6.58	-.78
19	311	Documentation	6.33	7.21	-.88
19	318	Non-technical communication	6.19	7.14	-.95
19	322	Process thinking	6.62	7.44	-.82
19	331	Technical communication	6.39	7.42	-1.03

Table 4.24.1: Large differences in mean ratings for pre 1995 and from 1995 subgroups

A cross mean comparison summary for the total sample and each stage (Appendix B), and pre 1995 and from 1995 graduates (Appendix C) is provided. It allows the user of the data to quickly compare the mean rating values for each KI across the different job titles.

4.25 Knowledge Survey – OSU Core Curriculum Match Summary

As stated in section 3.2, only three KIs were identified by OSU undergraduate alumni as being relevant, but not included in this survey. These KIs were enterprise resource planning, programmable logic control programming, and merger and acquisition strategy. The first two KIs being clearly within an IEs expert domain with the later being a KI related to more business than engineering.

Now that the relevant numeric data has been collected. The next step in this study was to identify how these KIs related to OSU's IW&SE Department's core undergraduate curriculum. Appendix B, Knowledge Survey – OSU Core Curriculum Match Summary, matched each KI to OSU IW&SE department's core curriculum. Furthermore, the top 100 and bottom 100 reported job applicability and ideal undergraduate emphasis ratings from the survey for the total sample are identified in this appendix. They are coded using the symbols, ↑, ↓, ⇑, and ⇓ to designate membership in one of these four categories. This allows the user of the data to quickly perform a cluster void analysis looking for any outstanding gaps in OSU's core IW&SE's curriculum.

In addition, Appendix C, Knowledge Survey – Job Ratings Result Summary Match, summarizes all the GRPREL data reports produced during this study. Essentially, the 100 top and bottom job applicability and ideal emphasis ratings are provided for each subgroup and are also categorized into four categories using the same coding scheme discussed in the preceding paragraph. The application of this grouping process from Appendices B and C are discussed in Chapter 5, Application.

CHAPTER 5

APPLICATION

"A little knowledge that acts is worth infinitely more than much knowledge that is idle."
- Kahlil Gibran[6]

5.1 Discussion

Overall, the data acquired indicate that IEs perform a wide variety of functions and tasks throughout many different work sectors for many different sizes of organizations. Even though such a large diversity exists, OSU alumni are in very much agreement as to what KIs are important to their respective jobs and which ones are more and less important in producing the "ideal" ISE undergraduate. Table 5.1.1 summarizes the results at the KI subgroup level for job applicability and KI emphasis. It identifies those subgroups scoring high, neutral, and low in job applicability and ideal ISE undergraduate analysis. This table was produced by examining and summarizing the specific results found in Appendices B and C. KI subgroup T., Disciplines, was left off intentionally and will be discussed latter.

KI SUBHEADING	ALL	Manu Mgrs	Manu Eng	Safety Eng	Ops Res	Cost Analy	Gen Mgrs
A. Biomechanics	↓ ⇓	↑ ⇓	↑ ⇓	↑ ⇑	- ⇓	- ⇓	- ⇓
B. Safety	↓ ⇓	- ⇓	↑ ⇓	↑ ⇓	- ⇓	- ⇓	- ⇓
C. Cognitive Science	↓ ⇓	- ⇓	- ⇓	↑ ⇓	- -	- -	- -
D. Information Systems Decision	- -	↑ ⇑	- ⇓	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑
E. Decision Analysis	- -	- ⇑	- -	- ⇑	↑ ⇑	↑ ⇑	↑ ⇑
F. Scientific Computations and Modeling	↓ ⇓	- ⇓	- ⇓	- -	↑ ⇑	- -	↑ ⇓
G. Mathematical Optimization and Modeling	↓ ⇓	- ⇓	- ⇓	- ⇓	↑ ⇑	- ⇓	- ⇓
H. Simulation	↓ ⇓	- ⇓	- ⇓	- ⇓	- -	- ⇓	- ⇓
I. Design of Experiments	↓ ⇓	- ⇓	- ⇓	↑ ⇓	↑ ⇑	↑ -	- ⇓
J. Engineering Statistics and Quality Control	- -	↑ ⇑	- ⇓	↑ ⇓	↑ ⇑	↑ ⇑	- -
K. Quality and Continuous Improvement	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑
L. Engineering Economics	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇓	↑ ⇑	↑ ⇓	↑ ⇑
M. Costs Analysis	↑ ⇑	↑ ⇑	↑ -	↑ ⇑	↑ ⇑	↑ ⇓	↑ ⇑
N. Productivity, Work Measurement, and Methods	↑ ⇑	↑ ⇑	↑ ⇑	- ⇑	- ⇓	- ⇑	↑ ⇑
O. Production Planning, Scheduling, and Control	- -	↑ ⇑	- -	- -	- -	- -	↑ ⇑
P. Facility Design, Layout and Material Handling	↑ ⇑	↑ ⇑	↑ ⇑	- ⇑	- ⇓	- ⇑	- -
Q. Manufacturing Processes and System Design	↓ ⇓	↑ ⇓	↑ ⇑	↑ -	- ⇓	- ⇓	- ⇓

↑ = High in job applicability
⇑ = High in knowledge emphasis
- = Neutral in job applicability

↓ = Low in job applicability
⇓ = Low in knowledge emphasis
- = Neutral in knowledge emphasis

Table 5.1.1: Summary of job applicability and knowledge emphasis at the KI subgroup level (continued)

Table 5.1.1: (continued)

KI SUBHEADING	ALL	Manu Mgrs	Manu Eng	Safety Eng	Ops Res	Cost Analy	Gen Mgrs
R. Management	↑ ⇑	↑ ⇑	↑ -	- ⇑	↑ ⇑	↑ -	↑ ⇑
S. Personal and Professional Skills	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑	↑ ⇑

↑ = High in job applicability
⇑ = High in knowledge emphasis
- = Neutral in job applicability
↓ = Low in job applicability
⇓ = Low in knowledge emphasis
- = Neutral in knowledge emphasis

Statistically, inter-rater reliabilities were extremely high for the total sample and even for most subgroups. In fact, for the total sample, only one KI, manual materials handling, scored in the top 100 for job applicability and the bottom 100 for ideal graduate knowledge emphasis. Upon further examination, this KI rated number 250 out of 350 for knowledge emphasis placing it at the top of the bottom 100 KIs. No item scored in the bottom 100 for job applicability and in the top 100 for ideal undergraduate knowledge emphasis. To demonstrate the agreement for the total sample, Table 5.1.2 is provided. Similarly, these summary tables for each of the identified jobs are also given.

TOTAL SAMPLE

		⇑	⇓
↑	20	79	1
↓	29	0	71
		18	26

MANUFACTURING MANAGERS

		⇑	⇓
↑	18	81	1
↓	*	*	*
		*	*

MANUFACTURING ENGINEERS

		⇑	⇓
↑	30	67	3
↓	*	*	*
		*	*

SAFETY ENGINEERS

		⇑	⇓
↑	45	37	18
↓	*	*	*
		*	*

OPERATIONS RESEARCH PERSONNEL

		⇑	⇓
↑	21	78	1
↓	*	*	*
		*	*

↑ = Top 100 rated job applicability items
↓ = Bottom 100 job rated applicability items
⇑ = Top 100 rated ideal undergraduate knowledge emphasis items
⇓ = Bottom 100 rated ideal undergraduate knowledge emphasis items

* = Sample size too small to report

Table 5.1.2: Job applicability versus ideal knowledge emphasis summary matrices (continued)

Table 5.1.2: (continued)

COST ANALYTS

		⇑	⇓
↑	44	45	11
↓	*	*	*
		*	*

GENERAL MANAGERS

		⇑	⇓
↑	18	81	1
↓	*	*	*
		*	*

After examining the summary matrices for each subgroup, it is apparent that each subgroup believes what they apply in their jobs is also important to teach undergraduates. The manufacturing manager's group also had only one KI scoring in the top 100 in job applicability and bottom 100 in ideal emphasis. Like the total sample, this KI was manual materials handling except it scored number 257 out of 350 KIs. Manufacturing engineers had three KIs scoring in the top 100 in job applicability and bottom 100 in ideal emphasis. These were accident investigations and analysis, electrical safety, and strategic plan development. Safety engineers had the most KIs, 18, having this type of disparity. These KIs were: physiological control models, heat stress, industrial noise, loss control program, displays and control design, human-information processing, psychological measures of human performance, usability testing, utility functions, input analysis, degrees of freedom, main effects, non parametric analysis, supervision, chemistry, philosophy, psychology, and foreign languages.

Out of all the subgroups, safety engineers were the most difficult to job type. Most of their job applicable KIs were in biomechanics, safety, and information systems design. These areas typically score low in ideal emphasis across all subgroups. This statement also includes safety engineers. However, on a relative basis, safety engineers scored these knowledge areas higher than any other subgroup. Although not a ringing endorsement, this result still provides a good indicator for descriptive job typing purposes.

On the other hand, operations research personnel were in agreement on their ratings much like the total sample, manufacturing managers, and manufacturing engineers. Their only KI in disparity was the assignment algorithm.

Cost analyts had 11 KIs that showed disparity in rating high in job applicability and low in ideal emphasis. These KIs include: regulatory agency functions, protocol analysis, factory applications and systems analysis, optimization methods - large systems - integer, non parametric analysis, non destructive testing, incremental analysis, quote preparation, mentoring of personnel, active listening, and biological sciences.

General managers, on the other hand, were in good agreement with only one KI, pseudocode, scoring high in job applicability, but low in ideal emphasis. All in all, at the summary level, the data indicates the total sample and subgroups are in agreement which helps confirm the results of this study.

Not surprisingly based on previous research, non technical KIs scored higher than technical KIs indicating the need for increased emphasis in personal and professional skills. However, based on Appendix D, Knowledge Survey – OSU Core Curriculum

Match Summary, this is one of the most heavily stressed areas in this department's curriculum indicating that a lot of emphasis is already being placed in the current curriculum at OSU. Interestingly, the from1995 subgroup placed a heavier emphasis on non-technical and technical communication than the pre 1995 subgroup. This may be a result of the increased focus in these areas since the change in the OSU curriculum.

In knowledge area, T., Disciplines, computer science, mathematics, and statistics were identified as being both job applicable and in need of high knowledge emphasis. Although mechanical engineering has a neutral score in job applicability, it did score high for knowledge emphasis. Material science, on the other hand, scored high in job applicability, but was neutral in knowledge emphasis. Many of the write-in comments also support these findings. Overall, these findings confirm most of the results from the previous studies cited in this paper.

Applying these results to the OSU ISE curriculum would indicate the need for more emphasis in computer science and mechanical engineering. A need for more course work in materials was also a common theme. Undergraduates are already required to complete two statistics courses and six math courses so these areas seem to be adequately covered. Other core curriculum courses at OSU include: physics, chemistry, and accounting. The first two items were included in knowledge area, T., Disciplines. Physics had a neutral score across both criteria, while chemistry was neutral in job applicability, but scored low in ideal undergraduate knowledge emphasis. Basic accounting was included in knowledge area, M., Cost Analysis, scoring high in both criteria which enforces the need to retain this area in the core curriculum.

In addition, since the subgroup jobs were identified, the data can be used to help shape which KIs are important to teach for the technical electives in these areas. For example, examining the manufacturing engineering subgroup will help identify those items deemed more and less important in this technical elective area. Currently, at OSU, these electives are grouped into Manufacturing, Human Factors, Operations Research, and Industrial Engineering. Overall, the data supports OSU's ISE curriculum quite well indicating the need for a diverse, well-rounded curriculum.

The background and write-in comments data further support this finding. Only 10% of ISE undergraduates pursue graduate degrees in ISE. This compares to 40% of the sample holding graduate degrees in general. Most of these degrees are business related. A possible explanation to this theme is provided by one survey incumbent.

> To my dismay I have found that in the real-world ... IEs are not fully utilized. There is a misconception industry wide that thinks IEs are only good for time studies. There are many things that IEs are capable of doing .... I have found that upward mobility for an IE requires engineers to move away from engineering. Where as other engineering disciplines have more opportunities to move up the ladder.

Another common theme graduates expressed concern over was the need for more coop/intern opportunities to experience real-world engineering challenges and to be exposed to real-world group dynamics. OSU's ISE department provides coop/intern opportunities along with senior design projects that attempt to model real-world engineering problems. Most graduates were pleased with these opportunities, but wanted more of them. However, to provide this may conflict with a university's fundamental purpose. As one alumni states, "If I had wanted an education that was entirely real-world based, I would have gone to a technical school. However, I wanted to learn to use my mind and my soul to be a better person and a more valuable member of society, so I went to a university." Another alumni concludes, "A real-world application gap exists between any formal educational program and the real working environment. However, I strongly believe that OSU's ISE program was very sufficient in minimizing the extent of this gap." Finally, another graduate proclaims, "I can not complain about the fundamentals I have learned at OSU. They have served me well. The gap exists in learning to practice as an IE. Can OSU teach this? I do not know."

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"It is not quantity but the quality of knowledge which determines the mind's dignity."
– William Ellery Channing[10]

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APPENDIX A

Knowledge Survey

INDUSTRIAL AND SYSTEMS ENGINEERING EDUCATION FOR THE 21st CENTURY: DISCOVERING AND ASSESSING THE MULTIFACETED NEEDS OF INDUSTRY

T · H · E
OHIO
STATE
UNIVERSITY

1. Because of the broad skill mix and diverse roles of industrial engineers, The Ohio State University's Industrial and Systems Engineering (ISE) Department is conducting a knowledge based survey of alumni. Your participation in this survey is vital to its success because your inputs will be used to assess and redirect the education of undergraduate students in this department.

2. The purpose of this software administered survey is to identify what knowledge items (KIs) are used by ISE alumni in their own current jobs. You are also asked to rate KIs to determine how much educational emphasis should be placed on each of them for undergraduate curriculum development.

3. Your inputs are the single most important aspect of this survey. It is critical that you answer all questions objectively and honestly. The key to having a successful analysis is the receipt of accurate and complete data from each respondent. The validity of the analysis report is directly related to the information that you provide.

4. Your inputs will make a positive difference in the department's undergraduate curriculum. We would like to receive a high response rate, because a very powerful computer analysis package developed primarily for the U.S. military will be used to manipulate and analyze tremendous amounts of data. If you have any questions please contact Gary Foster at (937) 426-5960 or e-mail at foster.236@osu.edu.

5. Please mail the survey back in the enclosed envelope or send to: The Ohio State University, ISE Department, 210 Baker Systems Engineering Building, 1971 Neil Avenue, Columbus OH, 43210-1271. Again, your participation will be greatly appreciated in educating undergraduate ISE students for the 21st Century.

Signature of Department Head

INTRODUCTION

1. The Ohio State University's Industrial and Systems Engineering (ISE) Department is conducting a knowledge-based survey to determine what ISE KIs are being used in your current job. This survey is also being used to help determine how much of an educational emphasis should be placed on different KIs for undergraduate curriculum development. Since you are an alumnus of this department, your assistance in completing this survey is very important to the department. Your answers and the answers of other alumni completing this knowledge based survey will be analyzed using a very powerful computer analysis package. These results will directly impact the department's undergraduate ISE curriculum.

2. This knowledge based inventory consists of four sections:
   a) A BIOGRAPHICAL SECTION for general information about yourself
   b) A BACKGROUND SECTION for information about various pertinent questions
   c) A KNOWLEDGE SECTION to rate the level of applicability of the KIs in YOUR CURRENT job and to identify overall educational emphasis of the different KIs in ISE at the undergraduate level.
   d) A WRITE-IN COMMENTS SECTION

3. To qualify for this survey, YOU MUST:
   a) Be an undergraduate alumnus of The Ohio State University's ISE Department
   b) Have been working at your present job for at least 6 months

If you do not meet these requirements, STOP. Return the survey to Ohio State's ISE Department with a short explanation of why you do not meet these requirements.

GENERAL INSTRUCTIONS

1. Use a pencil. Do not use ink, ball-point, or felt tip pens.
2. Erase cleanly any changes you wish to make.
3. Do not make any stray marks in this book.
4. Print all write-in information.

DISCLOSURE STATEMENT

Participation in this survey is strictly voluntary. Individual responses will be treated confidentially and will not be disclosed. All data will be reported in aggregate groupings to prevent singling out individual responses. Each questionnaire contains a case control number for administrative, tracking, and control purposes only.

BIOGRAPHICAL SECTION

PLEASE ENTER INFORMATION REQUESTED

1. Name (Last, First) ____________________
2. Address ____________________
3. Work Telephone ____________________
4. E-mail Address ____________________
5. Sex ____________________
6. Age ____________________
7. Title of Present Job ____________________
8. Standard Industrial Classification (SIC) Code, if known ____________________
9. Number of People You Directly Supervise ____________________
10. Name of Company, Self-Employed, Unemployed - seeking employment, Unemployed - not seeking employment, or Retired ____________________
11. Size of Company or N/A ____________________
12. Number of People Working at Your Site or N/A ____________________
13. Product(s) produced in plant, if applicable ____________________
14. Year of graduation from OSU's ISE undergraduate program 19__________________
15. Can You be Contacted? (Yes/No) ____________________

BACKGROUND SECTION

Instructions:

To answer the following background questions, place a check to the right of the appropriate response. Please use a pencil only.

Check Here ↓

1. Have you read the instructions for completing this survey?	
YES	
NO	
2. How does your job utilize your ISE training? CHOOSE ONLY ONE.	
PERFECTLY	
VERY WELL	
FAIRLY WELL	
SO-SO	
FAIRLY LITTLE	
VERY LITTLE	
NOT AT ALL, WHY?	
3. How satisfied are you with the sense of accomplishment you gain from your job? CHOOSE ONLY ONE.	
EXTREMELY SATISFIED	
VERY SATISFIED	
SLIGHTLY SATISFIED	
NEITHER SATISFIED NOR DISSATISFIED	
SLIGHTLY DISSATISFIED	
VERY DISSATISFIED	
EXTREMELY DISSATISFIED	
4. To what degree has the formal education you have received in ISE at OSU been useful in your present job? CHOOSE ONLY ONE	
PERFECTLY	
VERY WELL	
FAIRLY WELL	
SO-SO	
FAIRLY LITTLE	
VERY LITTLE	
NOT AT ALL, WHY?	

5. Indicate the highest level of ISE education you have completed. CHOOSE ONLY ONE.	
BACHELOR'S DEGREE	
BACHELOR'S PLUS, BUT NO MASTER'S DEGREE	
MASTER'S DEGREE	
MASTER'S DEGREE PLUS	
MORE THAN ONE MASTER'S DEGREE	
DOCTORAL LEVEL	
OTHER - Explain	
6. Indicate the highest level of education you have completed. CHOOSE ONLY ONE .	
BACHELOR'S DEGREE	
BACHELOR'S PLUS, BUT NO MASTER'S DEGREE	
MASTER'S DEGREE	
MASTER'S DEGREE PLUS	
MORE THAN ONE MASTER'S DEGREE	
DOCTORAL LEVEL	
OTHER - Explain	
7. Besides your ISE degree, indicate the area of specialization of your other undergraduate degree(s). CHOOSE ALL THAT APPLY.	
BIOMEDICAL ENGINEERING	
BUSINESS OR MANAGEMENT	
COMPUTER SCIENCE	
ELECTRICAL ENGINEERING	
ENGINEERING MANAGEMENT	
ENGINEERING SCIENCES	
ENGINEERING TECHNOLOGY	
LOGISTICS	
MANUFACTURING TECHNOLOGY	
MATERIAL SCIENCES	
MATHEMATICS	
MECHANICAL ENGINEERING	
METALLURGY	
STATISTICS	
WELDING	
OTHER - Explain	

8. Indicate the area of specialization of your master's degree(s). CHOOSE ALL THAT APPLY.		
NOT APPLICABLE		
BIOMECHANICS		
BIOMEDICAL ENGINEERING		
BUSINESS OR MANAGEMENT		
COGNITIVE SCIENCE		
COMPUTER SCIENCE		
INDUSTRIAL AND SYSTEMS ENGINEERING		
ELECTRICAL ENGINEERING		
ENGINEERING MANAGEMENT		
ENGINEERING SCIENCES		
ENGINEERING TECHNOLOGY		
HUMAN FACTORS/ERGONOMICS		
LOGISTICS		
MANUFACTURING PROCESSES ENGINEERING		
MANUFACTURING SYSTEMS ENGINEERING		
MATERIAL SCIENCES		
MATHEMATICS		
MECHANICAL ENGINEERING		
METALLURGY		
OPERATIONS RESEARCH		
STATISTICS		
WELDING		
OTHER- Explain		

9. Indicate the area of specialization of your doctoral degree(s). CHOOSE ALL THAT APPLY.		
NOT APPLICABLE		
BIOMECHANICS		
BUSINESS OR MANAGEMENT		
COGNITIVE SCIENCE		
COMPUTER SCIENCE		
INDUSTRIAL AND SYSTEMS ENGINEERING		
ELECTRICAL ENGINEERING		
ENGINEERING MANAGEMENT		
ENGINEERING SCIENCES		
HUMAN FACTORS/ERGONOMICS		
LOGISTICS		
MANUFACTURING PROCESSES ENGINEERING		
MANUFACTURING SYSTEMS ENGINEERING		
MATERIAL SCIENCES		
MATHEMATICS		
MECHANICAL ENGINEERING		
METALLURGY		
OPERATIONS RESEARCH		
STATISTICS		
WELDING		
OTHER- EXPLAIN		
10. Approximately, how many degreed practicing industrial engineers reside in your work facility?		
1 TO 5		
6 TO 10		
11 TO 15		
16 TO 20		
21 TO 25		
MORE THAN 25		
UNKNOWN		

11. Approximately, how many non-degreed practicing industrial engineers reside in your work facility?		
1 TO 5		
6 TO 10		
11 TO 15		
16 TO 20		
21 TO 25		
MORE THAN 25		
UNKNOWN		
12. Does your facility have a separate ISE department?		
YES		
NO (Please specify in what department they reside in on the blank page at the end of booklet.)		
NOT APPLICABLE		
13. Does your facility have a separate manufacturing engineering department?		
YES		
NO (Please specify in what department they reside in on the blank page at the end of booklet.)		
NOT APPLICABLE		

14. What primary types of tasks do practicing industrial engineers perform in your facility? CHOOSE ALL THAT APPLY		
NOT APPLICABLE		
COST ANALYSIS AND ENGINEERING ECONOMICS		
BIOMECHANICS		
SAFETY		
COGNITIVE SCIENCE		
INFORMATION SYSTEMS DESIGN		
DESIGN OF EXPERIMENTS		
FACILITY DESIGN, LAYOUT, AND MATERIAL HANDLING		
MANAGEMENT		
MANUFACTURING PROCESSES		
MANUFACTURING SYSTEMS DESIGN		
SIMULATION AND MODELING		
PRODUCTIVITY, WORK MEASUREMENT, AND METHODS		
PRODUCTION PLANNING, SCHEDULING, AND CONTROL		
QUALITY AND CONTINUOUS IMPROVEMENT		
OTHER - For additional comments, please specify on the blank page at the end of booklet.		
15. Currently, with what work sectors are you most involved? CHOOSE ALL THAT APPLY.		
AEROSPACE		
AUTOMOTIVE		
CONSULTING		
CONSUMER PRODUCTS AND PROCESS INDUSTRIES		
DEFENSE		
EDUCATION		
ELECTRONICS		
GOVERNMENT		
HEAVY EQUIPMENT		
MACHINE TOOLS		
MEDICAL		
HEAVY EQUIPMENT		
RETAIL		
TRANSPORTATION		
WAREHOUSING AND DISTRIBUTION		
OTHER- For additional comments, please specify on the blank page at the end of booklet.		

16. Do you believe that OSU's ISE Program adequately prepared you for your first job following graduation?	
YES	
NO, WHY?	
17. In what curriculum areas in the OSU's ISE Department did you specialize? CHOOSE ALL THAT APPLY	
BIOMECHANICS	
COGNITIVE SCIENCE	
MANUFACTURING PROCESSES	
MANUFACTURING SYSTEMS	
OPERATIONS RESEARCH	
WELDING	
NONE	
18. Does a real-world application gap exist between education and industry in the field of ISE?	
YES, WHY?	
NO	

KNOWLEDGE SECTION

INSTRUCTIONS FOR COMPLETING YOUR CURRENT JOB APPLICABILITY AND MOST QUALIFIED KNOWLEDGE EMPHASIS COLUMNS

It is important that you read through the KIs first so you are familiar with the content. This familiarity will allow you to make judgments about the:

1) Job applicability of each KI in your current job,

2) Relative importance of each KI as it relates to all other KIs in producing the most qualified ISE bachelor degree at The OSU.

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1. RATING YOUR CURRENT JOB APPLICABILITY COLUMN

a) Read KI, then check column (1) if you apply KI in your current job.

b) For all the checked items, provide ratings for the level in which you *personally* apply each KI in your current job in column (2).

c) Rate KIs you *frequently* apply in your current job with numbers at the top of the scale (ratings 8-9).

d) Rate KIs you *moderately* apply in your current job with numbers in the middle of the range of the scale (ratings 4-7).

e) Rate KIs you *seldom* apply in your current job with numbers at the bottom of the scale (ratings 1-3).

f) Place the ratings, according to the scale below, in column (2). When marking your responses, care should be taken not to overlap into other lines.

YOUR CURRENT JOB APPLICABILITY

9. Extremely High
8. Very High
7. High
6. Above Average
5. Average
4. Below Average
3. Low
2. Very Low
1. Extremely Low

RATING MOST QUALIFIED UNDERGRADUATE KNOWLEDGE EMPHASIS COLUMN

a) Regardless of the knowledge areas you perform in your current job, rate the emphasis EACH KI should receive in the ISE curriculum to produce the most qualified bachelors degree in the column (3).

b) Rate KIs you believe should receive *high* undergraduate knowledge emphasis in ISE with numbers at the top of the scale (ratings 8-9).

c) Rate KIs you believe should receive a *moderate* undergraduate knowledge emphasis in ISE with numbers in the middle range of the scale (ratings 4-7).

d) Rate KIs you believe should receive *low* undergraduate knowledge emphasis in ISE with numbers at the bottom of the scale (ratings 1-3).

e) Place the ratings, according to the scale below, in column (3). When marking your responses, care should be taken not to overlap into lines.

MOST QUALIFIED UNDERGRADUATE KNOWLEDGE EMPHASIS

9. Extremely High
8. Very High
7. High
6. Above Average
5. Average
4. Below Average
3. Low
2. Very Low
1. Extremely Low

KNOWLEDGE ITEM SECTION

Instructions:

1. Check column (1) if applied in your current job.
2. If column (1) is checked, then rate your job applicability in column (2) according to the job applicability scale .
3. Rate ALL items for undergraduate knowledge emphasis in column (3) according to the most qualified undergraduate knowledge emphasis scale.

Your Current Job Applicability

9. Extremely High
8. Very High
7. High
6. Above Average
5. Average
4. Below Average
3. Low
2. Very Low
1. Extremely Low

Most Qualified Undergraduate Knowledge Emphasis

9. Extremely High
8. Very High
7. High
6. Above Average
5. Average
4. Below Average
3. Low
2. Very Low
1. Extremely Low

A. BIOMECHANICS	(1) CHECK HERE ↓	(2) RATE HERE ↓	(3) RATE HERE ↓
Biomechanics analysis			
Design concepts – anthropometry limits			
Energy consumption measurement			
Hand tool design			
Manual materials handling			
Muscle performance			
Physiological control models			
Task demand analysis			
Tasks design			
Work-rest cycles			
Workplace design			
Workstation design			
Other, please specify on blank page at end of booklet.			

B. SAFETY				
Accident investigation and analysis				
Electrical safety				
Fall hazard control				
Fire safety				
Hazardous communication				
Health and safety record keeping process				
Heat stress				
Industrial noise				
Industrial toxicology				
Industrial ventilation				
Loss control program design				
Machine guarding				
Occupational safety and health standards				
Occupational/personal protection equipment				
Regulatory agency functions				
Safety culture implementation				
Workplace air quality				
Workplace hazards - anticipation, recognition, evaluation, and control (AREC)				
Workplace violence control				
Other, please specify on blank page at end of booklet.				
C. COGNITIVE SCIENCE				
Cognitive task analysis				
Displays and control design				
Human error identification				
Human-computer interaction				
Human-information processing				
Knowledge elicitation of intelligent systems				
Mental models of complex systems				
Protocol analysis				
Psychological measures of human performance				
Other, please specify on blank page at end of booklet.				

D. INFORMATION SYSTEM DESIGN				
Controls – vendor and shop feedback				
Database - types, information content, relational				
Database management				
Graphical user interfaces (GUIs)				
Network and communication terminology - types, protocols				
Usability testing process				
Utility functions				
Other, please specify on blank page at end of booklet.				
E. DECISION ANALYSIS				
Decision making under risk				
Decision making under uncertainty				
Decision support systems				
Decision trees				
Other, please specify on blank page at end of booklet.				

F. SCIENTIFIC COMPUTATIONS AND MODELING				
"Black-box" approach				
2-D computer aided design (CAD)				
2-D to 3-D transitioning				
3-D CAD				
Artificial intelligence (AI)				
Computer aided manufacturing (CAM)				
Computer integrated manufacturing (CIM)				
Continuous probability models				
Discrete probability models				
Expert systems				
Factory and systems applications				
Flow chart interpretations				
High level computer languages - C, Pascal, ADA, etc.				
Low level computer languages - machine, etc.				
Markov models				
Mathematical programming				
Neural networks				
Numerical analysis				
Pseudocode				
Queuing theory and modeling				
Solid modeling				
Spreadsheets				
Verification				
Other, please specify on blank page at end of booklet.				

G. MATHEMATICAL OPTIMIZATION AND MODELING				
Assignment algorithm				
Calculus-based optimization				
Combinatorial optimization				
Dynamic programming				
Linear programming - setting up, recognizing the dual				
Network optimization				
Non-linear programming - setting up				
Optimization methods - large systems, integer				
Transportation algorithm				
Other, please specify on blank page at end of booklet.				
H. SIMULATION				
Discrete event concepts				
Finite element analysis (FEM)				
Initialization bias				
Input analysis				
Interpreting flow charts				
Output analysis				
Random variate generation				
Surface search methods				
Terminating versus non-terminating				
Variance reduction				
Verification/validation				
Other, please specify on blank page at end of booklet.				

I. DESIGN OF EXPERIMENTS				
Analysis of variance (ANOVA)				
Blocking				
Degrees of freedom				
Factorial design – fractional				
Interactions				
Magnitude of effects - estimation				
Main effects				
Non parametric analysis				
Randomness				
Regression				
Replication				
Response plots				
Scientific method				
Statistical software use				
Taguchi methods				
Test methods				
Other, please specify on blank page at end of booklet.				

J. ENGINEERING STATISTICS AND QUALITY CONTROL				
Central limit theory				
Combinatorics – combinations, permutations, etc.				
Confidence intervals				
Control charts				
Fraction defective and specifications				
Goodness of fit				
Hypothesis testing				
Inference				
Point estimates				
Probability distributions - normal, binomial, etc.				
Process capability				
Regression – linear, multiple				
Reliability				
Reliability prediction				
Sample statistics - central tendency, dispersion				
Sampling – distribution				
Sampling plans				
Tendency – central, dispersion				
Variability concepts				
Other, please specify on blank page at end of booklet.				

K. QUALITY AND CONTINUOUS IMPROVEMENT				
Auditing				
Benchmarking				
Change management				
Cost of quality				
Customer focus				
Effect of part tolerance on process and warranty cost				
Failure and effect analysis				
Inspection and gauging				
Management and planning tools - SPC				
Non destructive testing (NDT)				
Principles – Crosby, Deming, Feigenbaum, Juran				
Process empowerment - Quality circles, employee suggestions, etc.				
Quality function deployment (QFD)				
Quality standards – ISO, QS				
Other, please specify on blank page at end of booklet.				
L. ENGINEERING ECONOMICS				
Annual worth				
Balance sheet				
Benefit cost analysis				
Capital budgeting				
Capitalized costs				
Depreciation				
Incremental analysis				
Life-cycle analysis				
Loan amortization				
Make/buy/lease decisions				
Rate of return				
Sensitivity analysis				
Taxes				
Time value of money				
Uniform period costs				
Worth - Present, Future, Expected				
Other, please specify on blank page at end of booklet.				

M. COST ANALYSIS				
Activity based costing				
Basic accounting				
Break-even analysis				
Breakdown of fixed costs - fixed, variable, direct, and indirect labor and materials				
Cost estimation equations for manufacturing or service				
Environmental costing				
Labor computation				
Marginal analysis				
Material allocation				
Minimum cost analysis				
Overhead allocation				
Quote preparation				
Target costing				
Types of cost - labor, material, overhead, and marginal				
Other, please specify on blank page at end of booklet.				
N. PRODUCTIVITY, WORK MEASUREMENT, AND METHODS				
Allowances				
Basic measures				
Calculation of time standards - normal and standard time, allowances				
Flow process charts				
Incentive systems - wage, payment				
Input/output				
Learning curves				
Method improvements				
Methods analysis				
Monitor methods				
Time studies				
Work breakdown				
Other, please specify on blank page at end of booklet.				

O. PRODUCTION PLANNING, SCHEDULING, AND CONTROL				
Aggregate planning				
Capacity planning				
Demand management				
Dependent demand inventory modeling				
Distribution Requirements Planning (DRP)				
Finite capacity scheduling				
Independent demand inventory modeling				
Inventory analysis				
Long-term forecasting				
Material Requirements Planning (MRP) and Material Resource Planning (MRPII)				
Non-recurring scheduling				
Replenishment systems				
Scrap analysis				
Sensitivity analysis				
Short-term forecasting				
Other, please specify on blank page at end of booklet.				

P. FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING				
Capacity planning				
Distance metrics				
Evaluation of layouts				
Expansion planning				
Factors in location use analysis				
Flexibility planning				
Flow measurements				
Human/machine tradeoffs				
Material flow analysis - capacities under given demands, unit loads/distances				
Material handling equipment equations - principles				
Number of machines/people required				
Optimum location – single/multiple location/storage				
Paced assembly lines				
Physical control of machinery				
Selection of material handling systems and equipment - capabilities				
Space planning				
Storage retrieval - safety				
Systematic Layout Planning (SLP)				
Types of layouts – product, process, fixed position, cellular, spine				
Types of material handling systems - capacities				
Waste handling				
Other, please specify on blank page at end of booklet.				

Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN	[redacted]			
Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.				
Automation concepts				
Basic shop practices				
Blueprint interpretation				
Bulk deformation processes - forging, rolling, bending, deep drawing, etc.				
Casting processes - sand, die, investment, etc.				
Coating/curing/pretreatment				
Computer Numeric Control (CNC) programming				
Concurrent engineering				
Cutting tool design				
Design for assembly				
Design for cost				
Design for distribution				
Design for environment				
Design for manufacturing				
Design for performance				
Design for product				
Design for reliability				
Design for safety				
Design for usability				
Economics – per unit cost under various demand rates, machine selection				
Flexible Manufacturing Systems (FMSs)				
Gauge design				
Geometric Dimensioning & Tolerancing (GD&T)				
Heat transfer				
Hydraulics and pneumatics				
Jig and fixture design				
Just-in-time (JIT) manufacturing implementation				
KANBAN/Pull versus CONWIP/Push				
Kinematics of machine tools				
Lean manufacturing implementation				
Line balancing techniques				
Logistics				
Machine production performance characteristics				
Machine tool elements design				
Machining formulas				

Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN				
Machining processes - turning, facing, milling, drilling, etc.				
Material removal rates - feeds, speeds, depths of cut				
Materials – selection, properties				
Modular tooling				
Number of machining/people equipment selection				
On-line gauging systems				
Polymer processing processes - extrusion, injection molding, blow molding, thermoforming, etc.				
Powder metallurgy processes				
Process mapping - route sheets				
Product recycling				
Sensoring				
Sheet metalworking processes - blanking, punching, drawing, stretching, etc.				
Stress analysis				
Surface integrity				
System capabilities				
Tool design				
Tool materials				
Tool wear				
Total predictive maintenance				
Traceability of design				
Tradeoffs between manufacturing processes				
Troubleshooting				
Types of manufacturing processes - forming, casting, joining, machining				
Work holding principles				
Other, please specify on blank page at end of booklet.				

R. MANAGEMENT				
Annual report reading				
Bill of materials				
Billing				
Business plan development				
Distribution				
Financial justification				
Forecasting of technology				
Job design				
Job evaluation				
Labor/management relations				
Liability				
Marketing impact				
Mentoring of personnel				
Mission statement development				
Negotiating and arbitrating				
Organizational structure				
Patent process				
Pay structure – wage payment methods				
Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)				
Proposal preparation				
Purchasing				
Resource deployment				
Strategic plan development				
Other, please specify on blank page at end of booklet.				

S. PERSONAL AND PROFESSIONAL SKILLS				
Accountability				
Active listening				
Assessing performance				
Conclusion drawing				
Conflict resolution				
Consensus building				
Creativity and innovation				
Documentation				
Empowerment				
Facilitation				
Followership				
Global awareness				
Information gathering, researching, and organization				
Leadership implementation				
Non-technical communication				
Predictive/anticipation of problems				
Presentation				
Problem solution implementation				
Process thinking				
Resource identification				
Risk management				
Role identification				
Shape/scale visualization				
Social and cultural awareness				
Supervision				
System perspective				
Teamwork implementation				
Technical communication				
Time management				
Values/ethics				
Other, please specify on blank page at end of booklet.				

T. DISCIPLINES				
Biological sciences				
Chemistry				
Computer Science				
Electrical				
Foreign languages				
Linguistics				
Materials				
Mathematics				
Mechanical				
Metrology – science dealing with measurement				
Neuroscience				
Philosophy				
Physics				
Psychology				
Statistics				
Thermodynamics				
Tribology - friction, lubrication and wear of interacting surfaces				
Other, please specify on blank page at end of booklet.				

WRITE-IN COMMENTS SECTION

Please write-in any comments or suggestions.

Thank-you for participating!

Your inputs will be used to help educate future industrial and systems engineers for the 21st Century.

Please mail the survey back in the enclosed envelope or send to: The Ohio State University, ISE Department, 210 Baker Systems Engineering Building, 1971 Neil Avenue, Columbus OH, 43210-1271.

APPENDIX B

Cross Mean Comparison Summary for the Total Sample and Each Stage – Ideal Undergraduate Ratings

CROSS MEAN COMPARISON REPORT
IDEAL RATINGS

Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
1	1	Biomechanics analysis	4.16	4.42	4.25	4.48	4.71	3.67	5.00
1	2	Design concepts - anthropometry limits	3.85	4.24	3.75	3.72	4.57	3.83	6.17
1	3	Energy consumption measurement	3.49	3.70	3.50	3.44	3.14	3.33	5.00
1	4	Hand tool design	3.92	4.06	3.50	3.36	4.86	5.50	5.67
1	5	Manual materials handling	4.60	4.72	4.25	4.04	5.00	5.33	5.17
1	6	Muscle performance	3.80	4.14	3.75	3.44	3.57	4.17	4.67
1	7	Physiological control models	3.61	3.90	3.75	3.52	3.43	4.17	4.67
1	8	Task demand analysis	4.42	4.74	4.75	4.08	3.43	5.33	5.17
1	9	Tasks design	4.82	5.04	4.75	4.80	3.71	5.33	6.00
1	10	Work-rest cycles	4.39	4.76	4.25	4.16	3.71	4.33	6.33
1	11	Workplace design	5.86	6.16	4.75	5.04	6.43	6.67	7.33
1	12	Workstation design	5.98	6.24	4.75	5.28	6.57	6.67	7.83
2	13	Accident investigation and analysis	4.23	4.82	3.00	3.28	3.57	3.83	5.67
2	14	Electrical safety	3.84	3.92	3.00	3.44	3.86	4.17	5.17
2	15	Fall hazard control	3.64	3.96	2.75	3.08	3.14	3.67	5.00
2	16	Fire safety	3.67	3.90	2.75	3.04	2.86	3.83	5.50
2	17	Hazardous communication	3.96	4.32	3.50	3.36	2.86	4.67	5.67
2	18	Health and safety record keeping process	3.81	3.84	4.00	3.36	3.29	4.33	5.50
2	19	Heat stress	3.35	3.34	3.25	2.96	2.57	4.17	4.00
2	20	Industrial noise	3.92	4.10	3.50	3.36	3.71	4.50	4.50
2	21	Industrial toxicology	3.81	3.98	3.25	3.44	3.43	4.17	4.33
2	22	Industrial ventilation	3.85	3.92	3.25	3.40	3.43	4.17	5.33
2	23	Loss control program design	3.67	3.68	3.75	3.32	3.29	4.33	4.67
2	24	Machine guarding	4.28	4.60	3.25	3.68	4.29	4.67	4.67
2	25	Occupational safety and health standards	4.83	4.88	4.50	4.24	4.86	5.33	5.83
2	26	Occupational/personal protection equipment	4.54	4.74	4.75	3.80	4.57	5.33	5.50
2	27	Regulatory agency functions	4.19	4.26	4.50	3.96	3.86	3.83	5.50
2	28	Safety culture implementation	4.48	4.80	4.50	4.16	3.86	4.33	5.50
2	29	Workplace air quality	3.86	3.82	3.75	3.48	3.43	3.33	5.33
2	30	Workplace hazards - anticipation, recognition, evaluation, and control (AREC)	4.63	4.72	4.25	4.36	4.14	4.83	5.67
2	31	Workplace violence control	3.70	3.90	4.25	3.36	2.14	4.00	5.67
3	32	Cognitive task analysis	4.65	4.96	5.25	4.96	4.00	5.33	4.33
3	33	Displays and control design	4.89	4.82	5.25	5.16	4.43	5.17	5.33
3	34	Human error identification	4.70	5.00	5.25	4.76	3.57	4.33	5.00

CROSS MEAN COMPARISON REPORT
IDEAL RATINGS

Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
3	35	Human-computer interaction	5.23	5.36	5.50	5.48	3.43	6.83	5.33
3	36	Human-information processing	5.08	5.26	5.50	5.44	4.00	5.67	4.83
3	37	Knowledge elicitation of intelligent systems	4.36	4.48	5.00	4.60	3.14	6.00	4.17
3	38	Mental models of complex systems	4.16	4.42	4.75	4.48	2.71	5.67	3.67
3	39	Protocol analysis	3.88	4.18	4.75	4.08	2.43	4.17	3.67
3	40	Psychological measures of human performance	4.36	4.88	4.75	4.32	3.29	4.50	4.83
4	41	Controls - vendor and shop feedback	4.58	4.96	4.75	4.08	3.71	5.00	5.50
4	42	Database - types, information content, relational	5.68	5.98	6.50	5.92	4.14	6.67	6.67
4	43	Database management	5.67	5.96	6.75	6.04	4.00	6.33	6.67
4	44	Graphical user interfaces (GUIs)	5.43	5.42	6.50	6.12	3.43	6.67	6.00
4	45	Network and communication terminology - types, protocols	5.22	5.24	5.75	5.56	3.86	6.17	6.33
4	46	Usability testing process	4.76	4.92	5.25	5.44	3.00	5.00	4.83
4	47	Utility functions	4.18	4.54	5.50	4.08	3.00	4.67	4.00
5	48	Black-box approach	4.00	4.18	4.25	3.76	3.29	5.67	5.00
5	49	2-D computer aided design (CAD)	4.94	5.24	4.25	3.92	6.00	4.83	6.17
5	50	Decision making under risk	5.56	5.74	6.75	5.28	5.00	5.83	6.17
5	51	Decision making under uncertainty	5.61	5.82	6.75	5.36	5.43	5.83	6.00
5	52	Decision support systems	5.52	5.80	7.50	5.56	4.71	6.50	6.17
5	53	Decision trees	5.38	5.70	6.25	5.04	5.29	5.67	6.33
6	54	2-D to 3-D transitioning	4.13	4.30	4.50	3.20	5.00	4.17	5.83
6	55	3-D CAD	4.72	4.90	5.00	3.68	6.14	5.17	6.17
6	56	Artificial intelligence (AI)	4.04	4.02	4.75	4.20	3.14	5.50	4.83
6	57	Computer aided manufacturing (CAM)	5.26	5.40	5.75	4.76	5.86	6.33	5.83
6	58	Computer integrated manufacturing (CIM)	5.23	5.24	5.75	4.84	5.86	6.33	6.00
6	59	Continuous probability models	4.76	5.16	5.25	4.28	3.57	5.33	5.33
6	60	Discrete probability models	4.71	5.18	6.00	4.24	3.57	5.33	4.50
6	61	Expert systems	4.54	4.82	5.00	4.92	3.29	5.33	5.33
6	62	Factory and systems applications	5.42	5.76	5.50	5.36	5.00	4.83	6.17
6	63	Flow chart interpretations	5.85	6.20	7.25	5.80	4.86	6.00	7.33
6	64	High level computer languages - C, Pascal, ADA, etc.	4.72	4.18	6.25	4.84	3.71	5.67	6.67
6	65	Low level computer languages - machine, etc.	4.42	4.36	4.75	4.52	4.86	5.00	5.00
6	66	Markov models	3.81	4.00	6.75	3.48	2.43	5.00	4.50
6	67	Mathematical programming	4.17	4.00	8.00	3.84	3.14	5.33	4.83
6	68	Neural networks	3.61	3.62	5.25	3.72	2.43	4.33	4.17
6	69	Numerical analysis	4.49	4.58	6.50	4.12	3.57	5.67	5.83
6	70	Pseudocode	3.76	3.62	5.00	4.16	2.29	5.67	4.50
6	71	Queuing theory and modeling	5.52	5.62	7.00	4.96	4.29	6.83	5.83
6	72	Solid modeling	4.11	4.22	6.75	3.52	3.86	5.00	4.67
6	73	Spreadsheets	7.13	7.46	8.25	6.44	6.86	7.00	7.83
6	74	Verification	5.36	5.80	7.50	4.56	4.14	5.83	7.17
7	75	Assignment algorithm	3.89	4.22	4.50	3.84	2.57	4.17	3.67
7	76	Calculus-based optimization	4.17	4.36	6.25	4.24	2.43	4.17	3.67
7	77	Combinatorial optimization	4.03	4.10	6.00	4.24	2.57	4.33	4.33
7	78	Dynamic programming	4.02	4.14	5.00	4.24	2.86	4.83	3.50
7	79	Linear programming - setting up, recognizing the dual	4.58	4.82	6.50	4.48	2.57	5.33	4.33
7	80	Network optimization	4.70	5.00	7.25	4.56	2.86	5.83	5.33

CROSS MEAN COMPARISON REPORT
IDEAL RATINGS

Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
7	81	Non-linear programming - setting up	4.19	4.40	6.00	4.16	2.43	4.50	4.50
7	82	Optimization methods - large systems, integer	4.75	4.98	7.00	5.24	2.71	4.50	4.50
7	83	Transportation algorithm	4.39	4.84	4.75	3.92	3.29	5.00	4.33
8	84	Discrete event concepts	4.30	4.64	6.25	4.08	2.86	4.17	4.50
8	85	Finite element analysis (FEM)	4.26	4.64	5.25	4.00	3.71	4.33	4.67
8	86	Initialization bias	3.73	4.12	4.75	3.60	2.57	3.50	4.00
8	87	Input analysis	4.32	4.64	6.25	4.12	2.86	4.67	4.67
8	88	Interpreting flow charts	5.47	5.74	6.00	5.56	4.14	6.17	5.67
8	89	Output analysis	4.89	5.06	7.00	5.08	3.00	5.83	5.00
8	90	Random variate generation	3.98	4.12	5.00	4.32	2.43	4.00	4.17
8	91	Surface search methods	3.63	3.88	4.50	3.88	2.57	3.50	4.00
8	92	Terminating versus non-terminating	3.58	3.88	4.50	3.52	2.00	4.17	3.67
8	93	Variance reduction	4.96	5.68	6.50	4.44	4.00	5.67	4.17
8	94	Verification/validation	4.99	5.40	6.50	4.68	3.86	6.17	4.83
9	95	Analysis of variance (ANOVA)	5.08	5.60	6.75	5.16	4.14	5.83	5.00
9	96	Blocking	4.20	4.66	4.75	3.88	3.29	4.67	4.50
9	97	Degrees of freedom	4.55	4.82	6.50	4.44	4.00	5.33	4.83
9	98	Factorial design - fractional	4.30	4.68	5.50	4.12	3.43	5.00	5.00
9	99	Interactions	4.45	4.72	5.00	4.16	3.57	6.00	5.17
9	100	Magnitude of effects - estimation	4.68	5.32	4.75	4.68	3.29	5.50	4.67
9	101	Main effects	4.53	5.12	4.75	4.32	3.14	5.50	4.50
9	102	Non parametric analysis	4.05	4.36	4.50	4.00	3.00	4.17	3.83
9	103	Randomness	4.58	4.82	7.00	4.40	3.57	4.50	4.83
9	104	Regression	5.06	5.28	7.00	4.80	4.00	6.50	5.17
9	105	Replication	4.46	4.84	6.00	4.00	3.29	5.00	5.00
9	106	Response plots	4.21	4.44	5.50	4.08	3.14	4.67	5.00
9	107	Scientific method	5.30	5.66	7.25	5.28	3.86	6.50	5.50
9	108	Statistical software use	5.81	6.28	7.50	5.56	4.86	6.83	5.67
9	109	Taguchi methods	4.86	5.42	5.00	4.60	4.86	5.33	4.33
9	110	Test methods	5.05	5.46	6.75	5.16	4.00	5.83	5.00
10	111	Central limit theory	4.60	5.20	7.50	4.36	3.14	5.00	3.83
10	112	Combinatorics - combinations, permutations, etc.	4.52	4.90	6.00	4.40	3.00	5.00	4.00
10	113	Confidence intervals	5.48	5.90	7.75	4.96	4.00	6.17	5.33
10	114	Control charts	5.90	6.54	6.75	5.12	6.00	6.00	5.17
10	115	Fraction defective and specifications	4.78	5.28	5.00	4.44	3.71	5.33	4.67
10	116	Goodness of fit	5.08	5.38	7.00	4.72	4.29	5.17	4.67
10	117	Hypothesis testing	5.46	5.76	7.25	5.40	4.00	5.67	5.33
10	118	Inference	4.90	5.08	6.50	4.80	3.71	5.17	5.17
10	119	Point estimates	4.67	4.88	6.75	4.64	3.29	5.17	5.17
10	120	Probability distributions - normal, binomial, etc.	5.80	6.16	8.25	5.40	5.00	5.83	5.50
10	121	Process capability	6.12	6.68	5.25	5.72	6.29	6.83	5.50
10	122	Regression - linear, multiple	5.42	5.86	7.50	4.88	4.43	6.00	5.50
10	123	Reliability	5.44	6.02	7.00	4.96	4.71	5.50	5.67
10	124	Reliability prediction	5.32	5.92	7.00	4.80	4.29	5.17	5.33
10	125	Sample statistics - central tendency, dispersion	5.56	5.98	7.00	5.52	3.71	6.00	5.33
10	126	Sampling - distribution	5.48	5.88	6.50	5.36	4.14	6.50	5.50
10	127	Sampling plans	5.40	5.92	6.50	5.12	3.86	6.00	5.17
10	128	Tendency - central, dispersion	5.09	5.20	6.50	5.04	3.57	6.17	5.00
10	129	Variability concepts	5.36	5.90	6.75	5.12	3.57	5.67	4.67
11	130	Auditing	5.08	5.52	5.00	5.00	5.14	5.00	5.50

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Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
11	131	Benchmarking	5.77	6.18	7.25	5.76	5.29	6.00	5.67
11	132	Change management	6.33	6.96	6.00	6.52	5.29	6.67	5.17
11	133	Cost of quality	6.33	6.92	6.75	6.64	5.43	5.67	5.83
11	134	Customer focus	6.83	7.08	7.75	7.28	6.71	6.83	6.17
11	135	Effect of part tolerance on process and warranty cost	5.35	5.58	4.50	5.20	6.57	4.83	5.17
11	136	Failure and effect analysis	5.65	5.82	5.50	5.52	6.43	5.67	5.50
11	137	Inspection and gauging	5.28	5.54	5.00	5.04	6.14	5.33	5.17
11	138	Management and planning tools - SPC	6.11	6.46	6.25	5.84	5.43	7.33	5.67
11	139	Non destructive testing (NDT)	4.97	5.16	5.25	5.36	4.71	4.67	5.33
11	140	Principles – Crosby, Deming, Feigenbaum, Juran	5.67	6.02	8.25	5.28	5.00	6.83	5.50
11	141	Process empowerment - Quality circles, employee suggestions, etc.	5.98	6.46	7.25	5.80	5.29	6.33	6.17
11	142	Quality function deployment (QFD)	5.30	5.56	4.75	5.36	4.71	4.83	5.83
11	143	Quality standards - ISO, QS	6.05	6.26	6.25	5.88	6.86	6.17	6.00
12	144	Annual worth	4.94	4.86	5.00	5.52	4.14	5.67	4.67
12	145	Balance sheet	5.20	5.16	7.00	5.64	4.00	5.50	4.83
12	146	Benefit cost analysis	5.88	5.92	6.25	6.56	4.86	5.50	5.33
12	147	Capital budgeting	5.72	5.82	7.25	5.64	6.14	5.50	5.33
12	148	Capitalized costs	5.53	5.56	7.25	5.52	5.71	5.33	5.33
12	149	Depreciation	5.39	5.32	7.25	5.40	5.71	5.17	4.83
12	150	Incremental analysis	5.17	5.34	7.00	5.48	4.43	4.67	5.00
12	151	Life-cycle analysis	5.27	5.38	5.25	5.56	4.57	5.33	5.00
12	152	Loan amortization	4.66	4.56	6.25	4.68	4.29	4.50	4.83
12	153	Make/buy/lease decisions	5.52	5.60	6.75	5.52	5.71	5.83	4.83
12	154	Rate of return	6.05	6.14	8.25	6.08	6.43	5.83	5.00
12	155	Sensitivity analysis	5.47	5.74	7.75	5.56	4.86	5.17	5.33
12	156	Taxes	4.47	4.28	6.50	4.64	3.86	4.00	4.00
12	157	Time value of money	5.94	6.12	8.00	5.96	5.86	5.17	5.17
12	158	Uniform period costs	4.89	5.08	6.25	5.12	4.29	4.83	4.67
12	159	Worth - Present, Future, Expected	5.68	5.78	8.25	5.88	5.14	6.00	5.00
13	160	Activity based costing	5.21	5.34	5.75	5.32	4.86	6.17	6.33
13	161	Basic accounting	5.59	5.84	7.50	5.68	4.71	5.33	6.00
13	162	Break-even analysis	5.74	6.00	6.50	5.84	5.14	5.17	6.83
13	163	Breakdown of fixed costs - fixed, variable, direct, and indirect labor and materials	5.83	6.14	5.25	5.80	5.71	5.50	6.33
13	164	Cost estimation equations for manufacturing or service	5.83	6.18	5.25	5.80	5.14	6.17	6.50
13	165	Environmental costing	4.94	5.10	6.50	5.24	3.71	4.17	6.33
13	166	Labor computation	5.45	5.74	6.00	5.36	5.14	5.33	6.17
13	167	Marginal analysis	5.10	5.34	5.25	5.44	4.00	4.17	6.17
13	168	Material allocation	5.21	5.48	5.00	5.52	4.57	4.50	5.83
13	169	Minimum cost analysis	5.21	5.42	5.00	5.68	4.43	5.00	5.67
13	170	Overhead allocation	5.17	5.28	5.00	5.20	5.00	5.00	5.67
13	171	Quote preparation	5.39	5.46	5.50	5.48	5.43	4.50	6.33
13	172	Target costing	5.07	5.16	5.00	5.20	4.71	5.17	6.00
13	173	Types of cost - labor, material, overhead, and marginal	5.92	6.18	6.50	5.84	5.57	5.83	6.67
14	174	Allowances	4.96	5.26	4.50	4.60	6.00	4.33	5.50
14	175	Basic measures	5.29	5.54	5.25	5.24	6.14	5.50	4.67

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Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
14	176	Calculation of time standards - normal and standard time, allowances	5.66	5.96	5.25	5.40	7.14	6.33	4.67
14	177	Flow process charts	6.20	6.70	5.25	6.16	6.43	6.00	5.00
14	178	Incentive systems - wage, payment	5.46	5.68	3.75	5.28	6.14	5.67	6.17
14	179	Input/output	5.35	5.70	4.75	5.12	5.00	5.67	6.17
14	180	Learning curves	5.44	5.56	5.75	5.40	5.00	5.67	6.17
14	181	Method improvements	6.52	7.10	6.25	6.04	7.43	6.83	6.17
14	182	Methods analysis	6.45	6.94	5.75	5.76	7.43	6.50	6.17
14	183	Monitor methods	5.84	6.20	4.75	5.24	7.00	6.17	5.83
14	184	Time studies	5.77	6.04	5.25	4.88	7.29	6.17	4.50
14	185	Work breakdown	5.98	6.38	4.75	5.56	7.14	5.83	5.00
15	186	Aggregate planning	4.98	5.04	7.00	5.00	4.86	5.17	5.17
15	187	Capacity planning	5.67	5.98	6.50	5.40	6.00	5.33	6.50
15	188	Dependent demand inventory modeling	5.17	5.24	5.25	5.08	4.71	5.67	6.67
15	189	Distribution Requirements Planning (DRP)	5.23	5.20	5.50	5.12	4.57	5.17	6.17
15	190	Finite capacity scheduling	5.15	5.32	5.25	5.08	4.71	6.00	5.67
15	191	Independent demand inventory modeling	4.95	5.00	5.50	4.88	4.43	5.50	5.50
15	192	Inventory analysis	5.61	5.82	5.75	5.52	4.86	6.33	5.67
15	193	Long-term forecasting	5.48	5.58	6.00	6.04	4.71	5.00	5.17
15	194	Material Requirements Planning (MRP) and Material Resource Planning (MRPII)	5.78	6.00	5.50	5.88	5.43	6.50	5.67
15	195	Non-recurring scheduling	4.77	4.82	4.25	5.16	4.71	5.00	4.83
15	196	Replenishment systems	5.12	5.48	5.00	5.36	5.00	4.67	4.83
15	197	Scrap analysis	5.11	5.38	5.00	4.96	4.86	5.17	5.67
15	198	Sensitivity analysis	5.32	5.50	7.00	5.36	4.43	5.67	5.17
15	199	Short-term forecasting	5.28	5.30	5.75	5.68	4.86	5.00	6.83
16	200	Capacity planning	5.91	6.20	5.25	5.76	6.00	6.00	6.50
16	201	Distance metrics	4.62	4.90	4.50	4.28	3.86	5.00	4.83
16	202	Evaluation of layouts	5.82	5.94	5.75	5.04	7.00	6.17	6.33
16	203	Expansion planning	5.62	5.80	5.50	5.08	7.00	5.00	5.50
16	204	Factors in location use analysis	5.23	5.20	4.50	4.76	6.29	5.50	5.17
16	205	Flexibility planning	5.31	5.54	4.25	4.96	6.43	5.67	5.17
16	206	Flow measurements	5.34	5.76	4.50	4.80	5.57	5.83	5.17
16	207	Human/machine tradeoffs	5.42	5.80	4.00	4.72	5.43	5.33	6.33
16	208	Material flow analysis - capacities under given demands, unit loads/distances	5.58	5.98	4.00	5.00	5.14	6.00	5.33
16	209	Material handling equipment equations - principles	5.33	5.54	4.50	4.84	5.71	6.00	6.00
16	210	Number of machines/people required	5.83	5.86	5.75	5.12	6.29	6.50	6.33
16	211	Optimum location - single/multiple location/storage	5.67	5.64	5.50	5.20	6.00	6.00	6.33
16	212	Paced assembly lines	5.51	5.70	4.75	4.72	5.71	6.17	6.17
16	213	Physical control of machinery	5.01	5.04	4.50	4.20	5.43	6.33	5.83
16	214	Selection of material handling systems and equipment capabilities	5.35	5.36	4.75	4.84	5.86	5.67	6.17
16	215	Space planning	5.65	5.68	5.25	5.08	6.71	6.00	6.50
16	216	Storage retrieval - safety	4.80	4.64	5.00	4.56	5.43	5.33	6.17
16	217	Systematic Layout Planning (SLP)	5.07	5.10	5.00	4.60	5.29	5.33	6.00

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Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
16	218	Types of layouts - product, process, fixed position, cellular, spine	5.45	5.82	4.25	4.88	6.14	5.67	5.33
16	219	Types of material handling systems - capacities	5.42	5.76	4.25	4.84	5.86	5.50	6.00
16	220	Waste handling	4.62	4.82	4.50	4.12	4.43	4.83	6.00
17	221	Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.	5.32	5.24	4.75	4.88	7.00	5.83	6.33
17	222	Automation concepts	5.70	5.94	4.25	5.04	7.00	5.50	6.00
17	223	Basic shop practices	5.47	5.84	5.25	4.48	6.57	5.33	5.67
17	224	Blueprint interpretation	5.68	5.92	5.25	4.56	7.43	5.50	6.33
17	225	Bulk deformation processes - forging, rolling, bending, deep drawing, etc.	4.89	4.94	4.75	4.72	5.29	5.17	4.50
17	226	Casting processes - sand, die, investment, etc.	4.70	4.82	4.75	4.44	4.71	5.33	3.50
17	227	Coating/curing/pretreatment	4.61	4.72	4.75	4.28	5.29	4.83	4.00
17	228	Computer Numeric Control (CNC) programming	4.73	4.62	3.50	4.64	5.43	6.33	5.33
17	229	Concurrent engineering	5.20	5.38	4.50	5.36	5.29	5.50	5.50
17	230	Cutting tool design	4.14	4.08	4.25	4.00	4.57	5.00	4.67
17	231	Design for assembly	5.39	5.44	5.00	4.64	7.43	5.33	6.50
17	232	Design for cost	5.36	5.42	4.75	4.56	7.00	5.83	6.50
17	233	Design for distribution	5.19	5.14	5.25	4.76	6.57	5.50	6.33
17	234	Design for environment	5.06	5.06	5.00	4.80	6.43	4.50	6.50
17	235	Design for manufacturing	5.70	5.76	5.50	4.96	7.57	6.00	6.33
17	236	Design for performance	5.50	5.44	5.50	4.88	7.14	6.00	6.50
17	237	Design for product	5.36	5.28	5.75	4.88	7.14	5.00	6.50
17	238	Design for reliability	5.48	5.42	5.75	4.96	7.29	5.00	6.17
17	239	Design for safety	5.44	5.52	5.25	4.64	7.29	5.17	6.33
17	240	Design for usability	5.48	5.50	5.50	4.92	7.29	5.17	6.33
17	241	Economics - per unit cost under various demand rates, machine selection	5.67	5.72	4.50	5.36	6.57	6.67	6.50
17	242	Flexible Manufacturing Systems (FMSs)	5.47	5.58	5.25	5.12	5.57	6.00	6.17
17	243	Gauge design	4.39	4.46	4.25	4.00	5.71	5.00	4.83
17	244	Geometric dimensioning and Tolerancing (GD&T)	4.68	4.96	4.25	3.88	6.57	5.50	4.67
17	245	Heat transfer	3.97	4.04	4.25	3.56	4.00	4.67	4.50
17	246	Hydraulics and pneumatics	4.42	4.42	4.75	3.68	4.71	5.33	4.50
17	247	Jig and fixture design	4.48	4.48	4.25	3.96	6.14	5.33	4.67
17	248	Just-in-time manufacturing implementation	5.94	6.30	5.00	5.04	6.71	6.17	6.00
17	249	KANBAN/Pull versus CONWIP/Push	5.92	6.38	5.00	5.28	6.71	6.00	5.83
17	250	Kinematics of machine tools	4.32	4.22	3.75	4.04	4.43	4.83	5.50
17	251	Lean manufacturing implementation	5.98	6.40	4.50	5.08	7.00	7.00	5.83
17	252	Line balancing techniques	5.94	6.40	3.75	5.44	6.71	6.33	5.83
17	253	Logistics	6.08	6.12	6.50	6.04	6.29	7.00	5.83
17	254	Machine production performance characteristics	4.99	5.12	4.50	4.56	5.00	5.67	5.67
17	255	Machine tool elements design	4.33	4.16	4.50	3.92	4.43	5.17	5.67
17	256	Machining formulas	4.28	4.22	4.25	3.84	4.29	5.17	5.67
17	257	Machining processes - turning, facing, milling, drilling, etc.	4.77	4.60	4.50	4.64	5.86	5.83	5.17

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Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
17	258	Material removal rates - feeds, speeds, depths of cut	4.33	4.18	4.00	4.00	5.29	5.67	4.50
17	259	Materials - selection, properties	4.68	4.64	4.25	4.56	5.57	5.50	5.00
17	260	Modular tooling	4.32	4.20	4.25	4.08	5.29	4.83	5.00
17	261	Number of machining/people equipment selection	4.93	5.00	4.50	4.20	6.14	5.50	5.83
17	262	On-line gauging systems	4.36	4.38	4.00	3.92	6.00	5.00	5.33
17	263	Polymer processing processes - extrusion, injection molding, blow molding, thermoforming, etc.	4.48	4.46	4.75	4.24	4.86	4.83	5.00
17	264	Powder metallurgy processes	4.21	4.20	4.25	4.04	4.14	4.67	4.83
17	265	Process mapping - route sheets	5.24	5.86	5.25	4.88	5.00	4.83	5.33
17	266	Product recycling	4.54	4.78	3.75	4.36	4.86	4.50	6.00
17	267	Sensoring	4.38	4.34	3.75	3.92	5.00	4.67	5.50
17	268	Sheet metalworking processes - blanking, punching, drawing, stretching, etc.	4.57	4.62	3.75	4.60	5.00	4.83	5.00
17	269	Stress analysis	4.30	4.16	3.75	4.36	4.29	4.83	5.50
17	270	Surface integrity	4.03	4.08	5.00	4.00	4.14	4.17	4.17
17	271	System capabilities	4.90	5.08	5.00	4.88	4.43	4.83	5.17
17	272	Tool design	4.36	4.26	4.75	3.88	6.43	4.67	4.67
17	273	Tool materials	4.23	4.02	5.25	3.92	5.29	4.83	4.50
17	274	Tool wear	4.11	4.00	4.50	3.80	5.00	4.50	4.33
17	275	Total predictive maintenance	4.89	5.20	5.00	4.36	5.00	5.50	4.83
17	276	Traceability of design	4.52	4.50	4.00	4.08	5.00	5.67	5.50
17	277	Tradeoffs between manufacturing processes	5.27	5.42	5.25	5.00	5.43	5.50	5.33
17	278	Troubleshooting	6.06	6.34	6.25	5.64	7.00	6.33	6.17
17	279	Types of manufacturing processes - forming, casting, joining, machining	5.03	5.06	5.50	5.00	6.29	5.33	5.00
17	280	Work holding principles	4.30	4.26	4.50	4.08	4.71	4.83	4.50
18	281	Annual report reading	4.90	4.68	6.75	5.56	3.71	5.33	5.33
18	282	Bill of materials	5.49	5.70	5.50	5.72	5.14	5.83	5.00
18	283	Billing	4.66	4.48	4.75	5.60	3.57	4.33	4.67
18	284	Business plan development	5.79	5.72	6.50	6.28	5.43	6.00	5.83
18	285	Distribution	5.41	5.42	5.75	5.68	4.86	6.00	5.50
18	286	Financial justification	6.35	6.44	6.50	6.76	5.86	6.67	6.50
18	287	Forecasting of technology	5.64	5.58	5.75	6.36	5.29	6.17	6.17
18	288	Job design	5.70	5.76	6.25	5.88	6.00	5.83	6.00
18	289	Job evaluation	5.67	5.80	6.25	5.80	6.14	5.67	5.50
18	290	Labor/management relations	5.88	6.16	6.50	5.32	5.29	7.17	7.33
18	291	Liability	4.98	4.88	6.25	5.44	4.43	4.67	5.67
18	292	Marketing impact	5.13	4.78	5.75	6.12	5.00	5.00	5.83
18	293	Mentoring of personnel	5.70	5.96	7.25	5.96	5.14	4.83	6.17
18	294	Mission statement development	5.02	4.82	5.75	5.64	3.86	5.17	5.33
18	295	Negotiating and arbitrating	5.30	5.40	5.25	5.56	3.57	6.33	5.50
18	296	Organizational structure	5.52	5.80	6.75	5.80	4.29	5.17	6.17
18	297	Patent process	4.02	3.84	5.00	4.24	2.71	4.17	4.67
18	298	Pay structure - wage payment methods	4.72	4.62	6.00	5.04	3.43	4.83	5.17
18	299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	6.70	6.80	7.75	7.16	5.86	7.00	5.33
18	300	Proposal preparation	6.16	6.20	6.75	6.40	5.57	6.17	6.33

CROSS MEAN COMPARISON REPORT IDEAL RATINGS

Sub head	KI #	Title	TOTAL	Manu Mgr STG 46	Ops Re STG 57	Gen Mgr STG 41	Manu Eng STG 43	Cost Anal STG 13	Safety Eng STG 14
18	301	Purchasing	5.14	5.16	5.25	5.32	3.86	5.50	5.67
18	302	Resource deployment	5.30	5.30	5.25	5.48	4.57	5.83	5.50
18	303	Strategic plan development	5.72	5.68	5.50	6.48	3.86	6.17	6.17
19	304	Accountability	5.83	6.10	8.00	6.56	4.71	5.67	5.33
19	305	Active listening	6.39	6.80	8.00	7.08	6.43	4.67	5.00
19	306	Assessing performance	6.25	6.56	8.00	6.64	6.29	6.00	4.83
19	307	Conclusion drawing	6.21	6.60	8.00	6.84	6.00	5.67	4.67
19	308	Conflict resolution	6.19	6.44	8.00	6.68	5.71	6.17	5.17
19	309	Consensus building	6.25	6.62	8.00	6.80	6.14	5.83	5.33
19	310	Creativity and innovation	6.80	6.96	8.00	7.44	7.00	6.50	5.50
19	311	Documentation	6.63	6.78	8.00	7.00	7.00	6.50	5.83
19	312	Empowerment	6.11	6.40	8.00	6.32	6.00	5.33	5.83
19	313	Facilitation	6.32	6.60	8.00	6.72	5.86	5.83	6.00
19	314	Followership	5.25	5.16	6.25	5.92	5.29	4.83	5.00
19	315	Global awareness	5.72	5.66	7.75	6.28	5.00	5.67	5.83
19	316	Information gathering, researching, and organization	6.72	6.94	8.25	7.36	6.29	6.00	6.33
19	317	Leadership implementation	6.44	6.76	7.50	7.00	5.86	5.50	5.83
19	318	Non-technical communication	6.51	6.58	8.25	7.04	7.43	5.67	5.67
19	319	Predictive/anticipation of problems	6.39	6.50	7.75	6.80	6.43	6.00	5.67
19	320	Presentation	6.95	7.00	8.50	7.32	6.71	6.50	7.50
19	321	Problem solution implementation	6.97	7.16	7.75	7.24	7.00	7.17	7.00
19	322	Process thinking	6.90	7.14	8.50	7.20	6.43	7.00	7.00
19	323	Resource identification	6.00	6.06	6.50	6.40	5.71	6.17	6.50
19	324	Risk management	5.98	6.02	7.00	6.40	5.43	6.17	6.50
19	325	Role identification	5.58	5.50	7.00	6.16	5.00	6.17	6.67
19	326	Shape/scale visualization	4.85	4.82	6.50	4.80	4.71	5.50	4.17
19	327	Social and cultural awareness	5.45	5.46	8.25	5.76	5.57	5.00	4.83
19	328	Supervision	6.08	6.06	7.50	6.12	6.14	6.17	5.00
19	329	System perspective	6.25	6.52	7.75	6.60	4.57	6.00	6.50
19	330	Teamwork implementation	6.87	7.10	7.50	7.36	6.57	6.67	6.83
19	331	Technical communication	6.73	6.84	7.25	6.96	6.57	6.33	6.83
19	332	Time management	7.36	7.64	8.50	7.72	7.00	7.33	7.83
19	333	Values/ethics	6.92	7.12	8.50	7.32	7.00	6.67	6.83
20	334	Biological sciences	3.31	3.28	4.75	3.12	2.86	3.67	3.67
20	335	Chemistry	3.77	3.94	3.50	3.44	3.71	3.83	4.50
20	336	Computer Science	6.32	6.08	7.75	6.84	5.86	7.00	5.83
20	337	Electrical	4.86	4.58	5.00	4.64	5.43	4.17	4.67
20	338	Foreign languages	4.10	4.16	5.25	4.52	4.29	4.00	3.50
20	339	Linguistics	3.25	3.42	3.50	3.24	2.71	3.33	3.50
20	340	Materials	5.12	5.26	4.75	4.84	5.29	6.00	4.17
20	341	Mathematics	6.30	6.44	8.00	6.24	5.86	6.50	5.50
20	342	Mechanical	5.81	5.72	5.25	5.36	6.00	6.83	5.50
20	343	Metrology - science dealing with measurement	5.09	5.40	6.25	4.60	5.71	5.17	5.50
20	344	Neuroscience	3.63	3.62	4.50	3.60	3.14	3.67	4.33
20	345	Philosophy	3.61	3.92	5.25	3.44	2.57	3.67	3.50
20	346	Physics	5.11	5.12	6.25	4.24	5.14	5.17	5.33
20	347	Psychology	5.02	5.18	5.25	5.04	4.57	5.00	5.00
20	348	Statistics	6.59	6.76	7.75	6.32	6.29	7.33	6.00
20	349	Thermodynamics	4.23	4.40	4.00	3.40	4.43	4.83	4.17
20	350	Tribology - friction, lubrication and wear of interacting surfaces	4.12	4.26	3.75	3.60	4.14	5.00	3.50

APPENDIX C

Cross Mean Comparison Summary for Pre 1995 and From 1995 Graduate Subgroups – Ideal Undergraduate Ratings

CROSS MEAN COMPARISON REPORT IDEAL RATINGS

Sub head	KI #	Title	Pre 95	From 95	Diff Pre-From
1	1	Biomechanics analysis	3.97	4.60	-0.63
1	2	Design concepts - anthropometry limits	3.70	4.21	-0.51
1	3	Energy consumption measurement	3.38	3.79	-0.41
1	4	Hand tool design	3.97	3.88	0.09
1	5	Manual materials handling	4.47	4.91	-0.44
1	6	Muscle performance	3.81	3.84	-0.03
1	7	Physiological control models	3.68	3.53	0.15
1	8	Task demand analysis	4.43	4.42	0.01
1	9	Tasks design	4.71	5.07	-0.36
1	10	Work-rest cycles	4.34	4.51	-0.17
1	11	Workplace design	5.88	5.81	0.07
1	12	Workstation design	6.03	5.86	0.17
2	13	Accident investigation and analysis	4.29	4.14	0.15
2	14	Electrical safety	3.80	3.95	-0.15
2	15	Fall hazard control	3.69	3.58	0.11
2	16	Fire safety	3.71	3.63	0.08
2	17	Hazardous communication	4.01	3.88	0.13
2	18	Health and safety record keeping process	3.84	3.77	0.07
2	19	Heat stress	3.36	3.37	-0.01
2	20	Industrial noise	3.83	4.14	-0.31
2	21	Industrial toxicology	3.80	3.86	-0.06
2	22	Industrial ventilation	3.79	4.00	-0.21
2	23	Loss control program design	3.68	3.70	-0.02
2	24	Machine guarding	4.24	4.37	-0.13
2	25	Occupational safety and health standards	4.79	4.93	-0.14

CROSS MEAN COMPARISON REPORT

IDEAL RATINGS

Sub head	KI #	Title	Pre 95	From 95	Diff Pre-From
2	26	Occupational/personal protection equipment	4.53	4.56	-0.03
2	27	Regulatory agency functions	4.22	4.14	0.08
2	28	Safety culture implementation	4.53	4.40	0.13
2	29	Workplace air quality	3.87	3.88	-0.01
2	30	Workplace hazards - anticipation, recognition, evaluation, and control (AREC)	4.72	4.44	0.28
2	31	Workplace violence control	3.71	3.70	0.01
3	32	Cognitive task analysis	4.63	4.72	-0.09
3	33	Displays and control design	4.80	5.09	-0.29
3	34	Human error identification	4.69	4.74	-0.05
3	35	Human-computer interaction	5.10	5.53	-0.43
3	36	Human-information processing	5.06	5.14	-0.08
3	37	Knowledge elicitation of intelligent systems	4.41	4.28	0.13
3	38	Mental models of complex systems	4.07	4.40	-0.33
3	39	Protocol analysis	3.84	4.00	-0.16
3	40	Psychological measures of human performance	4.34	4.44	-0.10
4	41	Controls - vendor and shop feedback	4.53	4.67	-0.14
4	42	Database - types, information content, relational	5.59	5.84	-0.25
4	43	Database management	5.58	5.84	-0.26
4	44	Graphical user interfaces (GUIs)	5.26	5.77	-0.51
4	45	Network and communication terminology - types, protocols	5.14	5.35	-0.21
4	46	Usability testing process	4.62	5.02	-0.40
4	47	Utility functions	4.09	4.37	-0.28
5	48	Black-box approach	4.11	3.77	0.34
5	49	2-D computer aided design (CAD)	4.77	5.28	-0.51
5	50	Decision making under risk	5.44	5.77	-0.33
5	51	Decision making under uncertainty	5.47	5.86	-0.39
5	52	Decision support systems	5.48	5.58	-0.10
5	53	Decision trees	5.28	5.56	-0.28
6	54	2-D to 3-D transitioning	3.97	4.47	-0.50
6	55	3-D CAD	4.47	5.23	-0.76
6	56	Artificial intelligence (AI)	4.08	3.95	0.13
6	57	Computer aided manufacturing (CAM)	5.18	5.40	-0.22
6	58	Computer integrated manufacturing (CIM)	5.21	5.23	-0.02

Sub head	KI #	CROSS MEAN COMPARISON REPORT IDEAL RATINGS Title	Pre 95	From 95	Diff Pre-From
6	59	Continuous probability models	4.68	4.91	-0.23
6	60	Discrete probability models	4.61	4.91	-0.30
6	61	Expert systems	4.50	4.60	-0.10
6	62	Factory and systems applications	5.24	5.74	-0.50
6	63	Flow chart interpretations	5.71	6.09	-0.38
6	64	High level computer languages - C, Pascal, ADA, etc.	4.50	5.19	-0.69
6	65	Low level computer languages - machine, etc.	4.31	4.67	-0.36
6	66	Markov models	3.61	4.26	-0.65
6	67	Mathematical programming	4.06	4.42	-0.36
6	68	Neural networks	3.47	3.95	-0.48
6	69	Numerical analysis	4.46	4.58	-0.12
6	70	Pseudocode	3.69	3.93	-0.24
6	71	Queuing theory and modeling	5.31	5.93	-0.62
6	72	Solid modeling	3.93	4.49	-0.56
6	73	Spreadsheets	6.81	7.79	-0.98
6	74	Verification	5.20	5.70	-0.50
7	75	Assignment algorithm	3.82	4.07	-0.25
7	76	Calculus-based optimization	3.90	4.74	-0.84
7	77	Combinatorial optimization	3.94	4.23	-0.29
7	78	Dynamic programming	3.88	4.35	-0.47
7	79	Linear programming - setting up, recognizing the dual	4.38	5.02	-0.64
7	80	Network optimization	4.64	4.81	-0.17
7	81	Non-linear programming - setting up	4.07	4.47	-0.40
7	82	Optimization methods - large systems, integer	4.51	5.26	-0.75
7	83	Transportation algorithm	4.31	4.56	-0.25
8	84	Discrete event concepts	4.13	4.65	-0.52
8	85	Finite element analysis (FEM)	4.03	4.74	-0.71
8	86	Initialization bias	3.53	4.19	-0.66
8	87	Input analysis	4.14	4.70	-0.56
8	88	Interpreting flow charts	5.39	5.63	-0.24
8	89	Output analysis	4.69	5.33	-0.64
8	90	Random variate generation	3.81	4.35	-0.54
8	91	Surface search methods	3.47	4.00	-0.53
8	92	Terminating versus non-terminating	3.42	3.93	-0.51
8	93	Variance reduction	4.90	5.09	-0.19
8	94	Verification/validation	4.97	5.05	-0.08
9	95	Analysis of variance (ANOVA)	5.04	5.19	-0.15
9	96	Blocking	4.17	4.30	-0.13

Sub head	KI #	CROSS MEAN COMPARISON REPORT IDEAL RATINGS Title	Pre 95	From 95	Diff Pre-From
9	97	Degrees of freedom	4.52	4.65	-0.13
9	98	Factorial design - fractional	4.31	4.33	-0.02
9	99	Interactions	4.40	4.60	-0.20
9	100	Magnitude of effects - estimation	4.63	4.81	-0.18
9	101	Main effects	4.52	4.58	-0.06
9	102	Non parametric analysis	3.97	4.26	-0.29
9	103	Randomness	4.57	4.63	-0.06
9	104	Regression	5.06	5.09	-0.03
9	105	Replication	4.42	4.58	-0.16
9	106	Response plots	4.20	4.28	-0.08
9	107	Scientific method	5.22	5.49	-0.27
9	108	Statistical software use	5.73	5.98	-0.25
9	109	Taguchi methods	4.83	4.91	-0.08
9	110	Test methods	5.01	5.16	-0.15
10	111	Central limit theory	4.56	4.72	-0.16
10	112	Combinatorics - combinations, permutations, etc.	4.51	4.56	-0.05
10	113	Confidence intervals	5.56	5.33	0.23
10	114	Control charts	5.97	5.77	0.20
10	115	Fraction defective and specifications	4.80	4.77	0.03
10	116	Goodness of fit	5.07	5.12	-0.05
10	117	Hypothesis testing	5.56	5.28	0.28
10	118	Inference	4.90	4.93	-0.03
10	119	Point estimates	4.70	4.65	0.05
10	120	Probability distributions - normal, binomial, etc.	5.72	6.00	-0.28
10	121	Process capability	6.17	6.05	0.12
10	122	Regression - linear, multiple	5.40	5.51	-0.11
10	123	Reliability	5.53	5.28	0.25
10	124	Reliability prediction	5.39	5.21	0.18
10	125	Sample statistics - central tendency, dispersion	5.63	5.44	0.19
10	126	Sampling - distribution	5.52	5.44	0.08
10	127	Sampling plans	5.54	5.14	0.40
10	128	Tendency - central, dispersion	5.17	4.98	0.19
10	129	Variability concepts	5.42	5.26	0.16
11	130	Auditing	5.34	4.53	0.81
11	131	Benchmarking	5.97	5.35	0.62
11	132	Change management	6.46	6.02	0.44

Sub head	KI #	CROSS MEAN COMPARISON REPORT IDEAL RATINGS Title	Pre 95	From 95	Diff Pre-From
11	133	Cost of quality	6.36	6.26	0.10
11	134	Customer focus	6.96	6.53	0.43
11	135	Effect of part tolerance on process and warranty cost	5.43	5.16	0.27
11	136	Failure and effect analysis	5.69	5.56	0.13
11	137	Inspection and gauging	5.40	5.02	0.38
11	138	Management and planning tools - SPC	6.18	5.93	0.25
11	139	Non destructive testing (NDT)	4.97	4.98	-0.01
11	140	Principles – Crosby, Deming, Feigenbaum, Juran	5.69	5.63	0.06
11	141	Process empowerment - Quality circles, employee suggestions, etc.	6.09	5.72	0.37
11	142	Quality function deployment (QFD)	5.33	5.21	0.12
11	143	Quality standards - ISO, QS	6.20	5.70	0.50
12	144	Annual worth	4.96	4.95	0.01
12	145	Balance sheet	5.26	5.14	0.12
12	146	Benefit cost analysis	6.00	5.65	0.35
12	147	Capital budgeting	5.91	5.35	0.56
12	148	Capitalized costs	5.66	5.30	0.36
12	149	Depreciation	5.48	5.23	0.25
12	150	Incremental analysis	5.22	5.12	0.10
12	151	Life-cycle analysis	5.32	5.21	0.11
12	152	Loan amortization	4.77	4.49	0.28
12	153	Make/buy/lease decisions	5.72	5.12	0.60
12	154	Rate of return	6.09	5.98	0.11
12	155	Sensitivity analysis	5.54	5.35	0.19
12	156	Taxes	4.59	4.28	0.31
12	157	Time value of money	5.99	5.86	0.13
12	158	Uniform period costs	4.94	4.84	0.10
12	159	Worth - Present, Future, Expected	5.68	5.72	-0.04
13	160	Activity based costing	5.28	5.09	0.19
13	161	Basic accounting	5.57	5.65	-0.08
13	162	Break-even analysis	5.97	5.28	0.69
13	163	Breakdown of fixed costs - fixed, variable, direct, and indirect labor and materials	5.90	5.70	0.20
13	164	Cost estimation equations for manufacturing or service	5.89	5.72	0.17
13	165	Environmental costing	4.92	5.00	-0.08
13	166	Labor computation	5.60	5.14	0.46
13	167	Marginal analysis	5.22	4.86	0.36

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IDEAL RATINGS

Sub head	KI #	Title	Pre 95	From 95	Diff Pre-From
13	168	Material allocation	5.24	5.16	0.08
13	169	Minimum cost analysis	5.27	5.12	0.15
13	170	Overhead allocation	5.30	4.91	0.39
13	171	Quote preparation	5.56	5.05	0.51
13	172	Target costing	5.23	4.74	0.49
13	173	Types of cost - labor, material, overhead, and marginal	5.92	5.93	-0.01
14	174	Allowances	5.16	4.58	0.58
14	175	Basic measures	5.33	5.21	0.12
14	176	Calculation of time standards - normal and standard time, allowances	5.70	5.58	0.12
14	177	Flow process charts	6.03	6.53	-0.50
14	178	Incentive systems - wage, payment	5.68	5.02	0.66
14	179	Input/output	5.27	5.53	-0.26
14	180	Learning curves	5.52	5.28	0.24
14	181	Method improvements	6.50	6.56	-0.06
14	182	Methods analysis	6.50	6.33	0.17
14	183	Monitor methods	6.01	5.49	0.52
14	184	Time studies	5.69	5.93	-0.24
14	185	Work breakdown	6.01	5.93	0.08
15	186	Aggregate planning	5.04	4.86	0.18
15	187	Capacity planning	5.77	5.49	0.28
15	188	Dependent demand inventory modeling	5.16	5.23	-0.07
15	189	Distribution Requirements Planning (DRP)	5.22	5.28	-0.06
15	190	Finite capacity scheduling	5.16	5.16	0.00
15	191	Independent demand inventory modeling	4.86	5.16	-0.30
15	192	Inventory analysis	5.46	5.93	-0.47
15	193	Long-term forecasting	5.49	5.47	0.02
15	194	Material Requirements Planning (MRP) and Material Resource Planning (MRPII)	5.78	5.79	-0.01
15	195	Non-recurring scheduling	4.79	4.74	0.05
15	196	Replenishment systems	5.08	5.23	-0.15
15	197	Scrap analysis	5.10	5.14	-0.04
15	198	Sensitivity analysis	5.26	5.47	-0.21
15	199	Short-term forecasting	5.37	5.12	0.25
16	200	Capacity planning	5.94	5.81	0.13
16	201	Distance metrics	4.64	4.58	0.06
16	202	Evaluation of layouts	5.78	5.88	-0.10

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IDEAL RATINGS

Sub head	KI #	Title	Pre 95	From 95	Diff Pre-From
16	203	Expansion planning	5.63	5.58	0.05
16	204	Factors in location use analysis	5.11	5.47	-0.36
16	205	Flexibility planning	5.38	5.16	0.22
16	206	Flow measurements	5.28	5.47	-0.19
16	207	Human/machine tradeoffs	5.34	5.58	-0.24
16	208	Material flow analysis - capacities under given demands, unit loads/distances	5.44	5.84	-0.40
16	209	Material handling equipment equations - principles	5.34	5.30	0.04
16	210	Number of machines/people required	5.72	6.05	-0.33
16	211	Optimum location - single/multiple location/storage	5.51	5.98	-0.47
16	212	Paced assembly lines	5.47	5.58	-0.11
16	213	Physical control of machinery	4.89	5.26	-0.37
16	214	Selection of material handling systems and equipment capabilities	5.18	5.70	-0.52
16	215	Space planning	5.64	5.65	-0.01
16	216	Storage retrieval - safety	4.84	4.70	0.14
16	217	Systematic Layout Planning (SLP)	5.09	5.02	0.07
16	218	Types of layouts - product, process, fixed position, cellular, spine	5.30	5.77	-0.47
16	219	Types of material handling systems - capacities	5.32	5.63	-0.31
16	220	Waste handling	4.51	4.86	-0.35
17	221	Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.	5.32	5.30	0.02
17	222	Automation concepts	5.73	5.60	0.13
17	223	Basic shop practices	5.43	5.53	-0.10
17	224	Blueprint interpretation	5.59	5.86	-0.27
17	225	Bulk deformation processes - forging, rolling, bending, deep drawing, etc.	4.82	5.05	-0.23
17	226	Casting processes - sand, die, investment, etc.	4.63	4.86	-0.23
17	227	Coating/curing/pretreatment	4.57	4.72	-0.15
17	228	Computer Numeric Control (CNC) programming	4.90	4.37	0.53
17	229	Concurrent engineering	5.29	5.02	0.27
17	230	Cutting tool design	4.20	4.02	0.18
17	231	Design for assembly	5.44	5.28	0.16

Sub head	KI #	CROSS MEAN COMPARISON REPORT IDEAL RATINGS Title	Pre 95	From 95	Diff Pre-From
17	232	Design for cost	5.37	5.35	0.02
17	233	Design for distribution	5.09	5.40	-0.31
17	234	Design for environment	4.96	5.28	-0.32
17	235	Design for manufacturing	5.59	5.91	-0.32
17	236	Design for performance	5.39	5.72	-0.33
17	237	Design for product	5.23	5.60	-0.37
17	238	Design for reliability	5.38	5.67	-0.29
17	239	Design for safety	5.37	5.58	-0.21
17	240	Design for usability	5.38	5.70	-0.32
17	241	Economics - per unit cost under various demand rates, machine selection	5.69	5.60	0.09
17	242	Flexible Manufacturing Systems (FMSs)	5.37	5.67	-0.30
17	243	Gauge design	4.39	4.42	-0.03
17	244	Geometric dimensioning and Tolerancing (GD&T)	4.72	4.60	0.12
17	245	Heat transfer	3.94	4.05	-0.11
17	246	Hydraulics and pneumatics	4.28	4.72	-0.44
17	247	Jig and fixture design	4.41	4.65	-0.24
17	248	Just-in-time manufacturing implementation	5.72	6.37	-0.65
17	249	KANBAN/Pull versus CONWIP/Push	5.63	6.49	-0.86
17	250	Kinematics of machine tools	4.22	4.53	-0.31
17	251	Lean manufacturing implementation	5.81	6.33	-0.52
17	252	Line balancing techniques	5.74	6.33	-0.59
17	253	Logistics	5.84	6.56	-0.72
17	254	Machine production performance characteristics	4.86	5.28	-0.42
17	255	Machine tool elements design	4.28	4.44	-0.16
17	256	Machining formulas	4.18	4.51	-0.33
17	257	Machining processes - turning, facing, milling, drilling, etc.	4.73	4.86	-0.13
17	258	Material removal rates - feeds, speeds, depths of cut	4.26	4.49	-0.23
17	259	Materials - selection, properties	4.56	4.95	-0.39
17	260	Modular tooling	4.32	4.33	-0.01
17	261	Number of machining/people equipment selection	4.93	4.93	0.00
17	262	On-line gauging systems	4.50	4.07	0.43

Sub head	KI #	CROSS MEAN COMPARISON REPORT IDEAL RATINGS Title	Pre 95	From 95	Diff Pre-From
17	263	Polymer processing processes - extrusion, injection molding, blow molding, thermoforming, etc.	4.36	4.74	-0.38
17	264	Powder metallurgy processes	4.19	4.28	-0.09
17	265	Process mapping - route sheets	5.19	5.35	-0.16
17	266	Product recycling	4.49	4.65	-0.16
17	267	Sensoring	4.39	4.37	0.02
17	268	Sheet metalworking processes - blanking, punching, drawing, stretching, etc.	4.51	4.70	-0.19
17	269	Stress analysis	4.29	4.33	-0.04
17	270	Surface integrity	3.98	4.16	-0.18
17	271	System capabilities	4.83	5.05	-0.22
17	272	Tool design	4.34	4.40	-0.06
17	273	Tool materials	4.22	4.26	-0.04
17	274	Tool wear	4.06	4.26	-0.20
17	275	Total predictive maintenance	4.72	5.23	-0.51
17	276	Traceability of design	4.42	4.74	-0.32
17	277	Tradeoffs between manufacturing processes	5.00	5.84	-0.84
17	278	Troubleshooting	5.80	6.58	-0.78
17	279	Types of manufacturing processes - forming, casting, joining, machining	4.91	5.28	-0.37
17	280	Work holding principles	4.20	4.51	-0.31
18	281	Annual report reading	4.83	5.05	-0.22
18	282	Bill of materials	5.43	5.60	-0.17
18	283	Billing	4.54	4.91	-0.37
18	284	Business plan development	5.82	5.70	0.12
18	285	Distribution	5.39	5.44	-0.05
18	286	Financial justification	6.40	6.21	0.19
18	287	Forecasting of technology	5.68	5.53	0.15
18	288	Job design	5.72	5.65	0.07
18	289	Job evaluation	5.64	5.72	-0.08
18	290	Labor/management relations	5.94	5.72	0.22
18	291	Liability	4.89	5.19	-0.30
18	292	Marketing impact	5.13	5.12	0.01
18	293	Mentoring of personnel	5.70	5.67	0.03
18	294	Mission statement development	5.02	5.00	0.02
18	295	Negotiating and arbitrating	5.29	5.30	-0.01

CROSS MEAN COMPARISON REPORT

IDEAL RATINGS

Sub head	KI #	Title	Pre 95	From 95	Diff Pre-From
18	296	Organizational structure	5.53	5.47	0.06
18	297	Patent process	3.91	4.28	-0.37
18	298	Pay structure - wage payment methods	4.76	4.65	0.11
18	299	Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	6.47	7.16	-0.69
18	300	Proposal preparation	6.01	6.44	-0.43
18	301	Purchasing	5.06	5.30	-0.24
18	302	Resource deployment	5.30	5.28	0.02
18	303	Strategic plan development	5.63	5.88	-0.25
19	304	Accountability	5.66	6.19	-0.53
19	305	Active listening	6.14	6.86	-0.72
19	306	Assessing performance	6.12	6.49	-0.37
19	307	Conclusion drawing	6.00	6.63	-0.63
19	308	Conflict resolution	5.97	6.63	-0.66
19	309	Consensus building	6.13	6.47	-0.34
19	310	Creativity and innovation	6.59	7.21	-0.62
19	311	Documentation	6.33	7.21	-0.88
19	312	Empowerment	5.99	6.33	-0.34
19	313	Facilitation	6.21	6.51	-0.30
19	314	Followership	5.06	5.65	-0.59
19	315	Global awareness	5.50	6.16	-0.66
19	316	Information gathering, researching, and organization	6.62	6.88	-0.26
19	317	Leadership implementation	6.26	6.79	-0.53
19	318	Non-technical communication	6.19	7.14	-0.95
19	319	Predictive/anticipation of problems	6.21	6.74	-0.53
19	320	Presentation	6.73	7.35	-0.62
19	321	Problem solution implementation	6.74	7.40	-0.66
19	322	Process thinking	6.62	7.44	-0.82
19	323	Resource identification	5.93	6.12	-0.19
19	324	Risk management	5.98	5.98	0.00
19	325	Role identification	5.54	5.65	-0.11
19	326	Shape/scale visualization	4.73	5.09	-0.36
19	327	Social and cultural awareness	5.22	5.91	-0.69
19	328	Supervision	5.94	6.33	-0.39
19	329	System perspective	6.02	6.70	-0.68
19	330	Teamwork implementation	6.63	7.33	-0.70
19	331	Technical communication	6.39	7.42	-1.03
19	332	Time management	7.10	7.84	-0.74
19	333	Values/ethics	6.74	7.23	-0.49

CROSS MEAN COMPARISON REPORT
IDEAL RATINGS

Sub head	KI #	Title	Pre 95	From 95	Diff Pre-From
20	334	Biological sciences	3.33	3.30	0.03
20	335	Chemistry	3.66	4.05	-0.39
20	336	Computer Science	6.17	6.60	-0.43
20	337	Electrical	4.69	5.21	-0.52
20	338	Foreign languages	4.13	4.05	0.08
20	339	Linguistics	3.27	3.26	0.01
20	340	Materials	4.97	5.44	-0.47
20	341	Mathematics	6.08	6.74	-0.66
20	342	Mechanical	5.56	6.33	-0.77
20	343	Metrology - science dealing with measurement	5.12	5.02	0.10
20	344	Neuroscience	3.60	3.72	-0.12
20	345	Philosophy	3.60	3.65	-0.05
20	346	Physics	4.92	5.51	-0.59
20	347	Psychology	4.93	5.21	-0.28
20	348	Statistics	6.46	6.84	-0.38
20	349	Thermodynamics	4.22	4.28	-0.06
20	350	Tribology - friction, lubrication and wear of interacting surfaces	3.94	4.51	-0.57

APPENDIX D

Knowledge Survey – OSU Core Curriculum Match Summary to Total Sample Results

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	↑ JA ↓	⇑ IE ⇓	311	500	503	504	509	521	522	523	531	532	533	573	608	610	640
A. BIOMECHANICS																	
Biomechanics analysis		⇓			X												
Design concepts – anthropometry limits	↓	⇓			X												
Energy consumption measurement	↓	⇓			X												
Hand tool design		⇓			X												
Manual materials handling	↑	⇓			X												
Muscle performance	↓	⇓			X												
Physiological control models	↓	⇓			X												
Task demand analysis	↓	⇓			X												
Tasks design					X												
Work-rest cycles	↓	⇓			X												
Workplace design	↑	⇑			X						X						
Workstation design	↑	⇑			X												

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OSU Industrial, Welding and System Engineering Undergraduate Core Classes	↑ JA ↓	⇑ IE ⇓	311	500	503	504	509	521	522	523	531	532	533	573	608	610	640
B. SAFETY																	
Accident investigation and analysis		⇓															
Electrical safety		⇓															
Fall hazard control		⇓															
Fire safety		⇓															
Hazardous communication		⇓															
Health and safety record keeping process		⇓															
Heat stress	↓	⇓	X														
Industrial noise		⇓															
Industrial toxicology	↓	⇓															
Industrial ventilation		⇓															
Loss control program design	↓	⇓															
Machine guarding																	
Occupational safety and health standards																	
Occupational/personal protection equipment																	
Regulatory agency functions		⇓															
Safety culture implementation		⇓															
Workplace air quality	↓	⇓															
Workplace hazards – anticipation, recognition, evaluation, and control (AREC)																	
Workplace violence control	↓	⇓															

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C. COGNITIVE SCIENCE																	
Cognitive task analysis														X			
Displays and control design														X			
Human error identification														X			
Human-computer interaction														X			
Human-information processing														X			
Knowledge elicitation of intelligent systems	↓	⇓												X			
Mental models of complex systems	↓	⇓												X			
Protocol analysis	↓	⇓												X			
Psychological measures of human performance	↓	⇓												X			
D. INFORMATION SYSTEM DESIGN																	
Controls – vendor and shop feedback		⇓					X						X				
Database - types, information content, relational	↑	⇑															
Database management	↑	⇑															
Graphical user interfaces (GUIs)	↑													X			
Network and communication terminology – types, protocols																	
Usability testing process														X			
Utility functions	↓	⇓												X			
E. DECISION ANALYSIS																	
Decision making under risk		⇑				X											
Decision making under uncertainty		⇑				X										X	
Decision support systems						X											
Decision trees						X											

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	↑ JA ↓	⇑ IE ⇓	311	500	503	504	509	521	522	523	531	532	533	573	608	610	640
F. SCIENTIFIC COMPUTATIONS AND MODELING																	
"Black-box" approach	↓	⇓															
2-D computer aided design (CAD)																	
2-D to 3-D transitioning	↓	⇓															
3-D CAD																	
Artificial intelligence (AI)	↓	⇓															
Computer aided manufacturing (CAM)	↓																
Computer integrated manufacturing (CIM)	↓																
Discrete probability models																	
Expert systems	↓	⇓															
Factory and systems applications	↑																
Flow chart interpretations	↑	⇑															
High level computer languages - C, Pascal, ADA, etc.																	
Low level computer languages – machine, etc.	↓	⇓															
Markov models	↓	⇓															
Mathematical programming	↓	⇓							X	X							
Neural networks	↓	⇓															
Numerical analysis		⇓								X							
Pseudocode	↓	⇓															
Queuing theory and modeling								X									
Solid modeling	↓	⇓															
Spreadsheets	↑	⇑				X				X							
Verification						X											

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	↑ JA ↓	⇑ IE ⇓	311	500	503	504	509	521	522	523	531	532	533	573	608	610	640
G. MATHEMATICAL OPTIMIZATION AND MODELING																	
Assignment algorithm	↓	⇓															
Calculus-based optimization	↓	⇓															
Combinatorial optimization	↓	⇓														X	
Dynamic programming	↓	⇓															
Linear programming - setting up, recognizing the dual	↓	⇓							X								
Network optimization	↓																
Non-linear programming - setting up	↓	⇓								X							
Optimization methods - large systems, integer									X								
Transportation algorithm	↓	⇓															
H. SIMULATION																	
Discrete event concepts	↓	⇓						X									
Finite element analysis (FEM)	↓	⇓															
Initialization bias		⇓						X									
Input analysis	↓	⇓						X									
Interpreting flow charts	↑							X									
Output analysis								X									
Random variate generation	↓	⇓						X									
Surface search methods	↓	⇓															
Terminating versus non-terminating		⇓						X									
Variance reduction								X									
Verification/validation								X									

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I. DESIGN OF EXPERIMENTS																	
Analysis of variance (ANOVA)								X								X	
Blocking	↓	⇓														X	
Degrees of freedom		⇓														X	
Factorial design – fractional		⇓														X	
Interactions		⇓														X	
Magnitude of effects – estimation	↓															X	
Main effects	↓	⇓														X	
Non parametric analysis	↓	⇓														X	
Randomness		⇓					X									X	
Regression							X									X	
Replication	↓	⇓														X	
Response plots	↓	⇓														X	
Scientific method																X	
Statistical software use	↑	⇑														X	
Taguchi methods																	
Test methods																X	

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J. ENGINEERING STATISTICS AND QUALITY CONTROL																	
Central limit theory		⇓					X									X	
Combinatorics – combinations, permutations, etc.	↓	⇓															
Confidence intervals	↑						X									X	
Control charts	↑	⇑					X										
Fraction defective and specifications							X									X	
Goodness of fit																	
Hypothesis testing							X									X	
Inference	↓						X									X	
Point estimates	↓						X									X	
Probability distributions – normal, binomial, etc.	↑	⇑					X									X	
Process capability	↑						X										
Regression – linear, multiple							X									X	
Reliability							X									X	
Reliability prediction							X									X	
Sample statistics - central tendency, dispersion		⇑						X								X	
Sampling – distribution							X									X	
Sampling plans							X									X	
Tendency – central, dispersion	↓						X									X	
Variability concepts							X									X	

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K. QUALITY AND CONTINUOUS IMPROVEMENT																	
Auditing	↑						X										
Benchmarking	↑	⇑					X										
Change management	↑	⇑					X										
Cost of quality	↑	⇑					X										
Customer focus	↑	⇑					X										
Effect of part tolerance on process and warranty cost																	
Failure and effect analysis	↑	⇑															
Inspection and gauging																	
Management and planning tools - SPC	↑	⇑					X										
Non destructive testing (NDT)																	
Principles – Crosby, Deming, Feigenbaum, Juran		⇑					X										
Process empowerment – Quality circles, employee suggestions, etc.	↑	⇑					X										
Quality function deployment (QFD)							X					X					
Quality standards – ISO, QS	↑	⇑					X										

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L. ENGINEERING ECONOMICS																	
Annual worth						X	X										
Balance sheet	↑					X	X										
Benefit cost analysis	↑	⇑				X	X										
Capital budgeting	↑	⇑				X	X										X
Capitalized costs	↑	⇑				X											
Depreciation	↑					X											
Incremental analysis						X											
Life-cycle analysis						X											
Loan amortization						X											
Make/buy/lease decisions	↑					X	X										
Rate of return	↑	⇑				X	X										
Sensitivity analysis	↓					X	X		X								
Taxes	↓	⇓				X											
Time value of money	↑	⇑				X											
Uniform period costs	↓					X											
Worth - Present, Future, Expected		⇑				X											

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M. COST ANALYSIS																	
Activity based costing						X	X				X						
Basic accounting	↑	⇑				X	X										
Breakdown of fixed costs – fixed, variable, direct, and indirect labor and materials	↑	⇑				X	X				X	X					
Break-even analysis	↑	⇑				X	X				X						
Cost estimation equations for manufacturing or service	↑	⇑					X				X	X					
Environmental costing	↓																
Labor computation	↑					X	X				X						
Marginal analysis	↓					X	X				X						
Material allocation						X	X				X						
Minimum cost analysis						X	X				X	X					
Overhead allocation						X	X				X						
Quote preparation						X	X				X						
Target costing						X	X				X	X					X
Types of cost - labor, material, overhead, and marginal	↑	⇑				X	X				X	X					

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N. PRODUCTIVITY, WORK MEASUREMENT, AND METHODS																	
Allowances											X						
Basic measures											X						
Calculation of time standards – normal and standard time, allowances	↑	⇑									X						
Flow process charts	↑	⇑									X		X				
Incentive systems - wage, payment																	
Input/output											X						
Learning curves																	
Method improvements	↑	⇑					X				X						
Methods analysis	↑	⇑									X						
Monitor methods		⇑									X						
Time studies	↑	⇑									X						
Work breakdown	↑	⇑									X						X

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OSU Industrial, Welding and System Engineering Undergraduate Core Classes	↑ J A ↓	⇑ I E ⇓	311	500	503	504	509	521	522	523	531	532	533	573	608	610	640
O. PRODUCTION PLANNING, SCHEDULING, AND CONTROL																	
Aggregate planning													X				
Capacity planning	↑	⇑											X				
Demand management													X				
Dependent demand inventory modeling													X				
Distribution Requirements Planning (DRP)													X				
Finite capacity scheduling													X				
Independent demand inventory modeling	↓												X				
Inventory analysis		⇑											X				
Long-term forecasting													X				
Material Requirements Planning (MRP) and Material Resource Planning (MRPII)	↑	⇑											X				
Non-recurring scheduling	↓												X				
Replenishment systems													X				
Scrap analysis													X				
Sensitivity analysis													X				
Short-term forecasting													X				

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P. FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING																	
Capacity planning											X	X	X				
Distance metrics	↓										X	X					
Evaluation of layouts	↑	⇑									X	X					
Expansion planning	↑	⇑									X	X					
Factors in location use analysis	↓										X	X					
Flexibility planning											X	X	X				
Flow measurements											X	X	X				
Human/machine tradeoffs											X	X					
Material flow analysis - capacities under given demands, unit loads/distances		⇑									X	X	X				
Material handling equipment equations – principles											X	X					
Number of machines/people required	↑	⇑									X	X	X				
Optimum location – single/multiple location/storage		⇑									X	X					
Paced assembly lines			X								X	X					
Physical control of machinery											X	X					
Selection of material handling systems and equipment - capabilities											X	X					
Space planning	↑	⇑									X	X					
Storage retrieval - safety	↓										X	X					
Systematic Layout Planning	↓										X	X					
Types of layouts – product, process, fixed position, cellular, spine											X	X	X				
Types of material handling systems – capacities											X	X	X				
Waste handling												X					

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Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN																	
Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.			X														
Automation concepts		⇑	X								X						
Basic shop practices	↑																
Blueprint interpretation	↑	⇑															
Bulk deformation processes – forging, rolling, bending, deep drawing, etc.	↓		X														
Casting processes - sand, die, investment, etc.	↓		X														
Coating/curing/pretreatment	↓																
Computer Numeric Control (CNC) programming	↓																
Concurrent engineering																	
Cutting tool design	↓	⇓	X														
Design for assembly											X						
Design for cost											X						
Design for distribution	↓										X						
Design for environment	↓										X						
Design for manufacturing	↑	⇑									X						
Design for performance											X						
Design for product	↓										X						
Design for reliability							X				X						
Design for safety											X						
Design for usability											X						
Economics - per unit cost under various demand rates, machine selection		⇑															
Flexible Manufacturing Systems (FMSs)	↓																
Gauge design	↓	⇓															

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Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN																	
Geometric dimensioning and tolerancing (GD&T)																	
Heat transfer	↓	⇓	X														
Hydraulics and pneumatics		⇓															
Jig and fixture design		⇓															
Just-in-time manufacturing implementation		⇑											X				
KANBAN/Pull versus CONWIP/Push		⇑											X				
Kinematics of machine tools	↓	⇓	X														
Lean manufacturing implementation	↑	⇑															
Line balancing techniques		⇑															
Logistics		⇑															
Machine production performance characteristics			X														
Machine tool elements design	↓	⇓	X														
Machining formulas	↓	⇓															
Machining processes - turning, facing, milling, drilling, etc.			X														
Material removal rates - feeds, speeds, depths of cut	↓	⇓															
Materials - selection, properties			X														
Modular tooling	↓	⇓	X														
Number of machining/people equipment selection																	
On-line gauging systems	↓	⇓															
Polymer processing processes - extrusion, injection molding, blow molding, thermoforming, etc.	↓	⇓	X														

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Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN																	
Powder metallurgy processes	↓	⇓	X														
Process mapping - route sheets																	
Product recycling	↓	⇓															
Sensoring	↓	⇓															
Sheet metalworking processes - blanking, punching, drawing, stretching, etc.		⇓	X														
Stress analysis	↓	⇓															
Surface integrity	↓	⇓															
System capabilities	↓																
Tool design	↓	⇓	X														
Tool materials	↓	⇓	X														
Tool wear	↓	⇓	X														
Total predictive maintenance																	
Traceability of design	↓	⇓															
Tradeoffs between manufacturing processes			X														
Troubleshooting	↑	⇑															
Types of manufacturing processes - forming, casting, joining, machining			X														
Work holding principles	↓	⇓															

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R. MANAGEMENT																	
Annual report reading	↑																
Bill of materials	↑																
Billing																	
Business plan development	↑	⇑															
Distribution																	
Financial justification	↑	⇑															
Forecasting of technology		⇑															
Job design		⇑															
Job evaluation	↑	⇑															
Labor/management relations	↑	⇑															
Liability	↓																
Marketing impact																	
Mentoring of personnel	↑	⇑															
Mission statement .development	↑																
Negotiating and arbitrating																	
Organizational structure	↑																X
Patent process	↓	⇓															
Pay structure – wage payment methods																	
Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	↑	⇑															X
Proposal preparation	↑																
Purchasing	↑																
Resource deployment																	
Strategic plan development	↑	⇑															

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S. PERSONAL AND PROFESSIONAL SKILLS																	
Accountability	↑	⇑		X	X		X			X					X	X	X
Active listening	↑	⇑		X	X	X	X								X	X	X
Assessing performance	↑	⇑					X			X							
Conclusion drawing	↑	⇑		X		X	X							X	X	X	X
Conflict resolution	↑			X			X								X	X	X
Consensus building	↑	⇑		X	X		X								X	X	X
Creativity and innovation	↑	⇑		X	X		X								X	X	X
Documentation	↑	⇑		X	X	X	X	X		X	X	X	X	X	X	X	X
Empowerment	↑	⇑					X								X	X	X
Facilitation	↑	⇑		X											X	X	X
Followership				X	X		X						X	X	X	X	X
Global awareness	↑	⇑										X					
Information gathering, researching, and organization	↑	⇑		X	X	X	X			X		X	X	X	X	X	X
Leadership implementation	↑	⇑		X	X		X						X		X	X	X
Non-technical communication	↑	⇑	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Predictive/anticipation of problems	↑	⇑		X	X		X	X						X	X	X	X
Presentation	↑	⇑		X	X		X	X			X	X	X	X	X	X	X
Problem solution implementation	↑	⇑		X	X		X				X	X	X	X	X	X	X
Process thinking	↑	⇑		X	X		X				X	X	X	X	X	X	X
Resource identification	↑	⇑		X											X	X	X
Risk management	↑	⇑		X											X	X	X
Role identification	↑	⇑		X	X										X	X	X
Shape/scale visualization	↓																
Social and cultural awareness	↑			X	X							X	X		X	X	X
Supervision	↑	⇑													X	X	X
System perspective	↑	⇑		X	X		X					X	X	X	X	X	X
Teamwork implementation	↑	⇑		X	X		X	X	X		X	X	X	X	X	X	X
Technical communication	↑	⇑		X	X		X	X		X	X	X	X	X	X	X	X
Time Management	↑	⇑		X													X
Values/ethics	↑	⇑		X													

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T. DISCIPLINES																	
Biological sciences	↓	⇓															
Chemistry		⇓															
Computer Science	↑	⇑															
Electrical																	
Foreign languages		⇓															
Linguistics	↓	⇓															
Materials	↑		X														
Mathematics	↑	⇑					X	X									
Mechanical		⇑															
Metrology – science dealing with measurement																	
Neuroscience	↓	⇓															
Philosophy	↓	⇓															
Physics																	
Psychology																	
Statistics	↑	⇑															
Thermodynamics	↓	⇓															
Tribology - friction, lubrication and wear of interacting surfaces		⇓															

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APPENDIX E

Job Applicability and ideal Undergraduate Emphasis Ratings Summary

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	**1**		**2**		**3**		**4**		**5**		**6**	
A. BIOMECHANICS												
Biomechanics analysis		⇓			↑			⇓		⇓		
Design concepts – anthropometry limits		⇓			↑	⇑		⇓		⇓		⇓
Energy consumption measurement		⇓		⇓				⇓		⇓		⇓
Hand tool design		⇓	↑					⇓				⇓
Manual materials handling	↑	⇓	↑		↑			⇓				⇓
Muscle performance		⇓		⇓		⇓		⇓		⇓		⇓
Physiological control models		⇓		⇓	↑	⇓		⇓		⇓		⇓
Task demand analysis		⇓		⇓	↑							⇓
Tasks design				⇓	↑	⇑						
Workplace design	↑	⇑	↑	⇑	↑	⇑				⇑		
Work-rest cycles		⇓		⇓	↑	⇑		⇓		⇓		⇓
Workstation design	↑	⇑	↑	⇑	↑	⇑				⇑		

1. Manufacturing Managers, Stage 46
2. Manufacturing Engineers, Stage 43
3. Safety Engineers, Stage 14
4. Operations Research Personnel, Stage 57
5. Cost Analysts, Stage 13
6. General Managers, Stage 41

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B. SAFETY												
Accident investigation and analysis			↑	⇓	↑			⇓		⇓		⇓
Electrical safety		⇓	↑	⇓	↑			⇓		⇓		⇓
Fall hazard control		⇓		⇓				⇓		⇓		⇓
Fire safety		⇓		⇓	↑			⇓		⇓		⇓
Hazardous communication		⇓		⇓	↑			⇓		⇓		⇓
Health and safety record keeping process		⇓		⇓	↑			⇓		⇓		⇓
Heat stress		⇓		⇓	↑	⇓		⇓		⇓		⇓
Industrial noise		⇓		⇓	↑	⇓		⇓		⇓		⇓
Industrial toxicology		⇓		⇓		⇓		⇓		⇓		⇓
Industrial ventilation		⇓		⇓				⇓		⇓		⇓
Loss control program design		⇓		⇓	↑	⇓		⇓		⇓		⇓
Machine guarding		⇓	↑			⇓		⇓		⇓		⇓
Occupational safety and health standards			↑		↑	⇑		⇓				⇓
Occupational/personal protection equipment		⇓	↑		↑							⇓
Regulatory agency functions		⇓		⇓	↑			⇓	↑	⇓		⇓
Safety culture implementation				⇓	↑			⇓		⇓		⇓
Workplace air quality		⇓		⇓	↑			⇓		⇓		⇓
Workplace hazards – anticipation, recognition, evaluation, and control (AREC)		⇓	↑		↑			⇓		⇓		
Workplace violence control		⇓		⇓				⇓		⇓		⇓

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C. COGNITIVE SCIENCE												
Cognitive task analysis					↑	⇓						
Displays and control design					↑							
Human error identification				⇓	↑					⇓		
Human-computer interaction				⇓	↑				↑	⇑	↑	⇑
Human-information processing					↑	⇓					↑	
Knowledge elicitation of intelligent systems		⇓		⇓		⇓				⇑		
Mental models of complex systems		⇓		⇓		⇓						
Protocol analysis		⇓		⇓		⇓			↑	⇓		⇓
Psychological measures of human performance				⇓	↑	⇓				⇓		⇓
D. INFORMATION SYSTEM DESIGN												
Controls – vendor and shop feedback	↑			⇓	↑							⇓
Database - types, information content, relational	↑	⇑			↑	⇑	↑	⇑	↑	⇑	↑	⇑
Database management	↑	⇑			↑	⇑	↑	⇑	↑	⇑	↑	⇑
Graphical user interfaces (GUIs)				⇓	↑	⇑	↑	⇑		⇑	↑	⇑
Network and communication terminology – types, protocols				⇓	↑	⇑	↑			⇑	↑	⇑
Usability testing process				⇓	↑	⇓			↑		↑	
Utility functions		⇓		⇓	↑	⇓				⇓		⇓
E. DECISION ANALYSIS												
Decision making under risk						⇑	↑	⇑		⇑	↑	
Decision making under uncertainty		⇑				⇑	↑	⇑	↑		↑	
Decision support systems		⇑				⇑	↑	⇑	↑	⇑		⇑
Decision trees			↑			⇑	↑		↑			

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	**1**		**2**		**3**		**4**		**5**		**6**	
F. SCIENTIFIC COMPUTATIONS AND MODELING												
"Black-box" approach		⇓		⇓				⇓	↑			⇓
2-D computer aided design (CAD)			↑	⇑	↑	⇑		⇓		⇓		⇓
2-D to 3-D transitioning		⇓				⇑		⇓		⇓		⇓
3-D CAD			↑	⇑	↑	⇑						⇓
Artificial intelligence (AI)		⇓		⇓		⇓						⇓
Computer aided manufacturing (CAM)				⇑		⇑				⇑		
Computer integrated manufacturing (CIM)				⇑		⇑				⇑		
Continuous probability models				⇓			↑					⇓
Discrete probability models				⇓		⇓	↑					⇓
Expert systems				⇓								
Factory and systems applications	↑					⇑			↑	⇓	↑	
Flow chart interpretations	↑	⇑			↑	⇑		⇑		⇑	↑	⇑
High level computer languages - C, Pascal, ADA, etc.		⇓		⇓		⇑					↑	
Low level computer languages – machine, etc.		⇓										
Markov models		⇓		⇓		⇓		⇑				⇓
Mathematical programming		⇓		⇓		⇓	↑			⇑		⇓
Neural networks		⇓		⇓		⇓				⇓		⇓
Numerical analysis		⇓		⇓		⇑	↑	⇑	↑			⇓
Pseudocode		⇓		⇓		⇓					↑	⇓
Queuing theory and modeling							↑	⇑		⇑		
Solid modeling		⇓		⇓		⇓		⇑				⇓
Spreadsheets	↑	⇑	↑	⇑	↑		↑	⇑	↑	⇑	↑	⇑
Verification		⇑				⇑	↑	⇑	↑			

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	**1**		**2**		**3**		**4**		**5**		**6**	
G. MATHEMATICAL OPTIMIZATION AND MODELING												
Assignment algorithm		⇓		⇓		⇓	↑	⇓		⇓		⇓
Calculus-based optimization		⇓		⇓		⇓				⇓		⇓
Combinatorial optimization		⇓		⇓		⇓	↑			⇓		⇓
Dynamic programming		⇓		⇓		⇓				⇓		⇓
Linear programming - setting up, recognizing the dual				⇓		⇓	↑	⇑	↑			
Network optimization				⇓			↑	⇑				
Non-linear programming - setting up		⇓		⇓		⇓				⇓		⇓
Optimization methods - large systems, integer				⇓		⇓	↑	⇑	↑	⇓		
Transportation algorithm				⇓		⇓	↑					⇓

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H. SIMULATION												
Discrete event concepts		⇓		⇓		⇓	↑			⇓		⇓
Finite element analysis (FEM)		⇓		⇓		⇓				⇓		⇓
Initialization bias		⇓		⇓		⇓				⇓		⇓
Input analysis		⇓		⇓	↑	⇓				⇓		⇓
Interpreting flow charts	↑		↑		↑					⇑	↑	⇑
Output analysis				⇓	↑			⇑				
Random variate generation		⇓		⇓		⇓				⇓		⇓
Surface search methods		⇓		⇓		⇓		⇓		⇓		⇓
Terminating versus non-terminating		⇓		⇓		⇓		⇓		⇓		⇓
Variance reduction						⇓		⇑				
Verification/validation				⇓		⇓		⇑		⇑		
I. DESIGN OF EXPERIMENTS												
Analysis of variance (ANOVA)					↑		↑	⇑	↑			
Blocking		⇓		⇓		⇓				⇓		⇓
Degrees of freedom					↑	⇓	↑	⇑				
Factorial design – fractional		⇓		⇓								⇓
Interactions		⇓		⇓						⇑		⇓
Magnitude of effects - estimation				⇓		⇓		⇓				
Main effects				⇓	↑	⇓		⇓				⇓
Non parametric analysis		⇓		⇓	↑	⇓		⇓	↑	⇓		⇓
Randomness		⇓		⇓		⇓	↑	⇑		⇓		
Regression							↑	⇑	↑	⇑		
Replication				⇓								⇓
Response plots		⇓		⇓						⇓		⇓
Scientific method				⇓	↑			⇑	↑	⇑		
Statistical software use	↑	⇑	↑		↑		↑	⇑	↑	⇑		⇑
Taguchi methods						⇓						
Test methods					↑		↑	⇑	↑		↑	

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	**1**		**2**		**3**		**4**		**5**		**6**	
J. ENGINEERING STATISTICS AND QUALITY CONTROL												
Central limit theory				⇓		⇓	↑	⇑	↑			
Combinatorics – combinations, permutations, etc.				⇓		⇓						
Confidence intervals	↑	⇑					↑	⇑	↑	⇑		
Control charts	↑	⇑	↑	⇑	↑			⇑		⇑		
Fraction defective and specifications				⇓		⇓						
Goodness of fit						⇓	↑	⇑				
Hypothesis testing				⇓	↑		↑	⇑	↑			
Inference				⇓			↑	⇑				
Point estimates				⇓			↑	⇑	↑			
Probability distributions - normal, binomial, etc.	↑	⇑	↑				↑	⇑	↑			
Process capability	↑	⇑	↑	⇑					↑	⇑		⇑
Regression – linear, multiple		⇑					↑	⇑	↑	⇑		
Reliability	↑	⇑					↑	⇑	↑			
Reliability prediction		⇑					↑	⇑	↑			
Sample statistics - central tendency, dispersion		⇑		⇓			↑	⇑	↑	⇑		⇑
Sampling – distribution		⇑			↑		↑	⇑	↑	⇑		
Sampling plans		⇑		⇓				⇑		⇑		
Tendency – central, dispersion				⇓	↑			⇑		⇑		
Variability concepts		⇑		⇓		⇓	↑	⇑				

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K. QUALITY AND CONTINUOUS IMPROVEMENT												
Auditing	↑		↑		↑				↑		↑	
Benchmarking	↑	⇑	↑		↑		↑	⇑	↑	⇑	↑	⇑
Change management	↑	⇑							↑	⇑	↑	⇑
Cost of quality	↑	⇑	↑				↑	⇑	↑		↑	⇑
Customer focus	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑
Effect of part tolerance on process and warranty cost			↑	⇑				⇓		⇓		
Failure and effect analysis	↑	⇑	↑	⇑					↑			⇑
Inspection and gauging	↑			⇑	↑							
Management and planning tools - SPC	↑	⇑	↑		↑		↑		↑	⇑	↑	⇑
Non destructive testing (NDT)					↑				↑	⇓		
Principles – Crosby, Deming, Feigenbaum, Juran	↑	⇑					↑	⇑		⇑		
Process empowerment - Quality circles, employee suggestions, etc.	↑	⇑	↑			⇑	↑	⇑	↑	⇑	↑	⇑
Quality function deployment (QFD)								⇓		⇓		
Quality standards – ISO, QS	↑	⇑	↑	⇑	↑	⇑			↑	⇑	↑	⇑

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L. ENGINEERING ECONOMICS												
Annual worth						⇓						⇑
Balance sheet				⇓		⇓	↑	⇑	↑		↑	⇑
Benefit cost analysis	↑	⇑	↑		↑		↑		↑		↑	⇑
Capital budgeting	↑	⇑	↑	⇑				⇑	↑		↑	⇑
Capitalized costs			↑	⇑			↑	⇑	↑		↑	⇑
Depreciation			↑	⇑		⇓	↑	⇑			↑	
Incremental analysis							↑	⇑	↑	⇓		⇑
Life-cycle analysis							↑		↑			⇑
Loan amortization		⇓				⇓				⇓		
Make/buy/lease decisions	↑		↑	⇑		⇓	↑	⇑	↑		↑	⇑
Rate of return	↑	⇑	↑	⇑			↑	⇑	↑		↑	⇑
Sensitivity analysis							↑	⇑	↑			⇑
Taxes		⇓		⇓		⇓	↑	⇑		⇓		
Time value of money		⇑		⇑	↑		↑	⇑	↑		↑	⇑
Uniform period costs						⇓				⇓		
Worth - Present, Future, Expected							↑	⇑	↑	⇑		⇑

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M. COST ANALYSIS												
Activity based costing						⇑	↑		↑	⇑	↑	
Basic accounting	↑	⇑				⇑	↑	⇑	↑		↑	⇑
Breakdown of fixed costs – fixed, variable, direct, and indirect labor and materials	↑	⇑	↑	⇑		⇑	↑		↑		↑	⇑
Break-even analysis	↑	⇑	↑			⇑	↑	⇑	↑		↑	⇑
Cost estimation equations for manufacturing or service	↑	⇑	↑			⇑			↑	⇑	↑	⇑
Environmental costing				⇓		⇑		⇑		⇓		
Labor computation	↑					⇑			↑		↑	
Marginal analysis				⇓		⇑				⇓		
Material allocation										⇓		⇑
Minimum cost analysis									↑			⇑
Overhead allocation							↑		↑			
Quote preparation			↑		↑	⇑			↑	⇓		⇑
Target costing					↑	⇑			↑			
Types of cost - labor, material, overhead, and marginal	↑	⇑	↑		↑	⇑	↑	⇑	↑		↑	⇑

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N. PRODUCTIVITY, WORK MEASUREMENT, AND METHODS												
Allowances			↑	⇑				⇓		⇓		
Basic measures				⇑		⇓						
Calculation of time standards – normal and standard time, allowances	↑	⇑	↑	⇑		⇓				⇑		
Flow process charts	↑	⇑	↑	⇑	↑					⇑	↑	⇑
Incentive systems - wage, payment				⇑		⇑		⇓				
Input/output						⇑		⇓			↑	
Learning curves						⇑			↑			
Method improvements	↑	⇑	↑	⇑	↑	⇑				⇑	↑	⇑
Methods analysis	↑	⇑	↑	⇑		⇑				⇑	↑	⇑
Monitor methods		⇑		⇑				⇓		⇑		
Time studies	↑	⇑	↑	⇑		⇓				⇑		
Work breakdown	↑	⇑	↑	⇑				⇓	↑			⇑

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O. PRODUCTION PLANNING, SCHEDULING, AND CONTROL												
Aggregate planning								⇑				
Capacity planning	↑	⇑	↑	⇑		⇑			↑		↑	⇑
Demand management												
Dependent demand inventory modeling						⇑						
Distribution Requirements Planning (DRP)						⇑					↑	
Finite capacity scheduling										⇑		
Independent demand inventory modeling												
Inventory analysis		⇑								⇑	↑	⇑
Long-term forecasting							↑		↑			⇑
Material Requirements Planning (MRP) and Material Resource Planning (MRPII)		⇑							↑	⇑	↑	⇑
Non-recurring scheduling						⇓		⇓				
Replenishment systems						⇓				⇓		
Scrap analysis	↑											
Sensitivity analysis								⇑				
Short-term forecasting						⇑					↑	⇑

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P. FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING												
Capacity planning		⇑		⇑		⇑				⇑		
Distance metrics				⇓		⇓		⇓				⇓
Evaluation of layouts	↑	⇑	↑	⇑	↑	⇑				⇑		
Expansion planning	↑	⇑	↑	⇑								
Factors in location use analysis			↑	⇑				⇓				
Flexibility planning				⇑				⇓				
Flow measurements								⇓				
Human/machine tradeoffs		⇑	↑			⇑		⇓				
Material flow analysis – capacities under given demands, unit loads/distances		⇑	↑					⇓		⇑		
Material handling equipment equations – principles				⇑		⇑		⇓		⇑		
Number of machines/people required	↑	⇑	↑	⇑	↑	⇑				⇑		
Optimum location – single/multiple location/storage				⇑		⇑	↑			⇑		
Paced assembly lines			↑	⇑		⇑		⇓		⇑		
Physical control of machinery			↑					⇓		⇑		⇓
Selection of material handling systems and equipment - capabilities			↑	⇑		⇑		⇓				
Space planning	↑		↑	⇑		⇑				⇑		
Storage retrieval - safety		⇓	↑			⇑						
Systematic Layout Planning (SLP)						⇑						
Types of layouts – product, process, fixed position, cellular, spine		⇑	↑	⇑				⇓				
Types of material handling systems – capacities			↑	⇑		⇑		⇓				

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	**1**		**2**		**3**		**4**		**5**		**6**	
P. FACILITY DESIGN, LAYOUT AND MATERIAL HANDLING												
Waste handling					↑	⇑		⇓		⇓		⇓

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Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN												
Assembly processes - welding, brazing, soldering, bonding, press/snap fits, etc.			↑	⇑	↑	⇑		⇓				
Automation concepts	↑	⇑	↑	⇑		⇑		⇓				
Basic shop practices	↑	⇑	↑	⇑	↑							
Blueprint interpretation	↑	⇑	↑	⇑	↑	⇑						
Bulk deformation processes – forging, rolling, bending, deep drawing, etc.						⇓		⇓				
Casting processes - sand, die, investment, etc.						⇓		⇓				
Coating/curing/pretreatment		⇓				⇓		⇓		⇓		⇓
Computer Numeric Control (CNC) programming		⇓						⇓		⇑		
Concurrent engineering								⇓				
Cutting tool design		⇓				⇓		⇓				⇓
Design for assembly			↑	⇑	↑	⇑						
Design for cost			↑	⇑	↑	⇑		⇓				
Design for distribution				⇑		⇑						
Design for environment				⇑	↑	⇑				⇓		
Design for manufacturing	↑		↑	⇑	↑	⇑				⇑		
Design for performance				⇑		⇑				⇑		
Design for product				⇑		⇑						
Design for reliability				⇑		⇑						
Design for safety			↑	⇑	↑	⇑						
Design for usability				⇑		⇑					↑	
Economics - per unit cost under various demand rates, machine selection				⇑		⇑		⇓		⇑		
Flexible Manufacturing Systems (FMSs)						⇑				⇑		
Gauge design		⇓				⇓		⇓		⇓		⇓
Geometric dimensioning and Tolerancing (GD&T)				⇑		⇓		⇓				⇓

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	**1**		**2**		**3**		**4**		**5**		**6**	
Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN												
Heat transfer		⇓		⇓		⇓		⇓		⇓		⇓
Hydraulics and pneumatics		⇓				⇓		⇓				⇓
Jig and fixture design		⇓	↑	⇑		⇓		⇓				⇓
Just-in-time manufacturing implementation		⇑	↑	⇑		⇑				⇑		
KANBAN/Pull versus CONWIP/Push	↑	⇑	↑	⇑						⇑		
Kinematics of machine tools		⇓						⇓		⇓		⇓
Lean manufacturing implementation	↑	⇑	↑	⇑				⇓	↑	⇑		
Line balancing techniques	↑	⇑	↑	⇑				⇓		⇑		
Logistics		⇑		⇑			↑			⇑		⇑
Machine production performance characteristics								⇓				
Machine tool elements design		⇓						⇓				⇓
Machining formulas		⇓						⇓				⇓
Machining processes - turning, facing, milling, drilling, etc.		⇓		⇑				⇓				
Material removal rates - feeds, speeds, depths of cut		⇓				⇓		⇓				⇓
Materials - selection, properties		⇓						⇓				
Modular tooling		⇓						⇓		⇓		⇓
Number of machining/people equipment selection			↑	⇑				⇓				⇓
On-line gauging systems		⇓		⇑				⇓		⇓		⇓
Polymer processing processes - extrusion, injection molding, blow molding, thermoforming, etc.		⇓						⇓		⇓		⇓
Powder metallurgy processes		⇓				⇓		⇓		⇓		⇓
Process mapping - route sheets		⇑								⇓		

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Q. MANUFACTURING PROCESSES AND SYSTEM DESIGN												
Product recycling						⇑		⇓		⇓		⇓
Sensoring		⇓						⇓		⇓		⇓
Sheet metalworking processes - blanking, punching, drawing, stretching, etc.		⇓						⇓		⇓		
Stress analysis		⇓						⇓		⇓		⇓
Surface integrity		⇓				⇓				⇓		⇓
System capabilities										⇓		
Tool design		⇓		⇑		⇓		⇓		⇓		⇓
Tool materials		⇓				⇓				⇓		⇓
Tool wear		⇓				⇓		⇓		⇓		⇓
Total predictive maintenance						⇓						⇓
Traceability of design		⇓						⇓				⇓
Tradeoffs between manufacturing processes	↑											
Troubleshooting	↑	⇑	↑	⇑	↑	⇑				⇑	↑	⇑
Types of manufacturing processes - forming, casting, joining, machining				⇑								
Work holding principles		⇓				⇓		⇓		⇓		⇓

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R. MANAGEMENT												
Annual report reading		⇓		⇓			↑	⇑			↑	⇑
Bill of materials	↑		↑		↑				↑		↑	⇑
Billing		⇓		⇓		⇓		⇓		⇓	↑	⇑
Business plan development	↑		↑						↑	⇑	↑	⇑
Distribution							↑			⇑	↑	⇑
Financial justification	↑	⇑	↑	⇑		⇑	↑		↑	⇑	↑	⇑
Forecasting of technology						⇑				⇑	↑	⇑
Job design			↑	⇑		⇑						⇑
Job evaluation	↑	⇑	↑	⇑			↑				↑	⇑
Labor/management relations	↑	⇑				⇑				⇑		
Liability										⇓		
Marketing impact		⇓								⇓		⇑
Mentoring of personnel	↑	⇑				⇑	↑	⇑	↑	⇓	↑	⇑
Mission statement development	↑			⇓							↑	⇑
Negotiating and arbitrating				⇓						⇑		⇑
Organizational structure	↑	⇑				⇑	↑	⇑			↑	⇑
Patent process		⇓		⇓		⇓				⇓		⇓
Pay structure – wage payment methods		⇓		⇓						⇓		
Project management - scheduling, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM)	↑	⇑	↑	⇑	↑			⇑	↑	⇑	↑	⇑
Proposal preparation	↑	⇑	↑			⇑		⇑	↑	⇑	↑	⇑
Purchasing				⇓	↑						↑	
Resource deployment											↑	
Strategic plan development	↑		↑	⇓		⇑	↑		↑	⇑	↑	⇑

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S. PERSONAL AND PROFESSIONAL SKILLS												
Accountability	↑	⇑					↑	⇑	↑		↑	⇑
Active listening	↑	⇑	↑	⇑		⇓	↑	⇑	↑	⇓	↑	⇑
Assessing performance	↑	⇑		⇑		⇓	↑	⇑		⇑	↑	⇑
Conclusion drawing	↑	⇑		⇑		⇓	↑	⇑	↑		↑	⇑
Conflict resolution	↑	⇑	↑				↑	⇑		⇑	↑	⇑
Consensus building	↑	⇑	↑	⇑			↑	⇑			↑	⇑
Creativity and innovation	↑	⇑	↑	⇑	↑			⇑	↑	⇑	↑	⇑
Documentation	↑	⇑	↑	⇑	↑		↑	⇑	↑	⇑	↑	⇑
Empowerment	↑	⇑	↑	⇑			↑	⇑			↑	⇑
Facilitation	↑	⇑		⇑		⇑	↑	⇑			↑	⇑
Followership						⇓				⇓	↑	⇑
Global awareness	↑		↑				↑	⇑			↑	⇑
Information gathering, researching, and organization	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑
Leadership implementation	↑	⇑		⇑			↑	⇑	↑		↑	⇑
Non-technical communication	↑	⇑	↑	⇑			↑	⇑	↑		↑	⇑
Predictive/anticipation of problems	↑	⇑		⇑				⇑	↑	⇑	↑	⇑
Presentation	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑
Problem solution implementation	↑	⇑	↑	⇑		⇑		⇑	↑	⇑	↑	⇑
Process thinking	↑	⇑	↑	⇑		⇑	↑	⇑	↑	⇑	↑	⇑
Resource identification	↑	⇑				⇑			↑	⇑	↑	⇑
Risk management	↑	⇑			↑	⇑	↑	⇑	↑	⇑	↑	⇑
Role identification	↑					⇑		⇑		⇑	↑	⇑
Shape/scale visualization						⇓						
Social and cultural awareness	↑					⇓	↑	⇑		⇓	↑	⇑
Supervision	↑	⇑	↑	⇑	↑	⇓	↑	⇑	↑	⇑	↑	⇑
System perspective	↑	⇑				⇑	↑	⇑		⇑	↑	⇑
Teamwork implementation	↑	⇑	↑	⇑		⇑	↑	⇑	↑	⇑	↑	⇑
Technical communication	↑	⇑	↑	⇑	↑	⇑		⇑	↑	⇑	↑	⇑
Time Management	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑
Values/ethics	↑	⇑		⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑

OSU Industrial, Welding and System Engineering Undergraduate Core Classes	1		2		3		4		5		6	
T. DISCIPLINES												
Biological sciences		⇓		⇓		⇓		⇓	↑	⇓		⇓
Chemistry		⇓		⇓	↑	⇓		⇓		⇓		⇓
Computer Science	↑	⇑		⇑	↑		↑	⇑		⇑	↑	⇑
Electrical		⇓			↑	⇓				⇓		
Foreign languages		⇓				⇓				⇓		
Linguistics		⇓		⇓		⇓		⇓		⇓		⇓
Materials			↑			⇓		⇓		⇑	↑	
Mathematics	↑	⇑		⇑	↑		↑	⇑	↑	⇑	↑	⇑
Mechanical				⇑						⇑		
Metrology – science dealing with measurement												
Neuroscience		⇓		⇓		⇓		⇓		⇓		⇓
Philosophy		⇓		⇓	↑	⇓				⇓		⇓
Physics					↑							⇓
Psychology					↑	⇓				⇓	↑	
Statistics	↑	⇑		⇑	↑	⇑	↑	⇑	↑	⇑	↑	⇑
Thermodynamics		⇓				⇓		⇓		⇓		⇓
Tribology - friction, lubrication and wear of interacting surfaces		⇓				⇓		⇓		⇓		⇓

1. Manufacturing Managers, Stage 46
2. Manufacturing Engineers, Stage 43
3. Safety Engineers, Stage 14
4. Operations Research Personnel, Stage 57
5. Cost Analysts, Stage 13
6. General Managers, Stage 41

↑ = Top 100 Job Applicability (JA) / ↓ = Bottom 100 JA

⇑ = Top 100 Ideal Emphasis (IE) / ⇓ = Bottom 100 IE