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The Carnegie Mellon University Master of Software Engineering Specialization Tracks

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Abstract

There is an increasing demand for domain-specific software. For example, the software to control a machine on a factory floor is different in significant ways from the software to manipulate large databases. The software engineer building real-time systems software to control a motor that powers a piece of machinery needs some understanding of the motor's servo system; whereas a software engineer who designs the software to manage large databases for the NASA Space Station needs specific knowledge about database models as well as the types of data handled on a long-term space vehicle. Specialization tracks within the Master of Sofrware Engineering (MSE) Program at Carnegie Mellon University enable students to gain application domain knowledge while developing fundamental software engineering skills. The MSE Program currently offers specialization tracks in real-time computing, human-computer interaction (HCI), and business. This paper overviews these tracks.

Keywords: *Donzain-specific software engineering education, graduate software engineering programs, specialization tracks.*

1 Introduction

There is an increasing demand for software engineers who are experts in developing software for specific types of applications. For instance, software to control a machine on a factory floor is characteristically different from software to manipulate large databases. Software that directs the movement of a lathe performs complex mathematical calculations and communicates in real time with custom hardware; whereas database software involves algorithms to format, correlate, and store data efficiently as well as to guarantee data consistency and integrity.

The authors use the term *application domain* to denote a set of applications with common properties that mandate the type of software designed for applications in the domain. Problem-based and solution-based application domains decompose the world of application domains in different ways. Problem-based domains consist of applications with similar requirements and common designs; whereas solution-based domains focus on applications which employ particular computer technologies. For instance, the domain of machine control applications includes those applications with basic servo control requirements. On the other hand, the domain of database ap-

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plications involves problems which are solved using database technology. Subdomains, such as the set of problems solved using distributed databases, decompose more encompassing domains, such as the database domain.

The demands of a professional work environment often do not provide software engineers sufficient time to acquire in-depth, domain-specific knowledge. In the case of the solution-based domains, the software engineer becomes an expert by developing a thorough understanding of the underlying computer technology and its application. Software engineers with expertise in problem-based domains have in-depth knowledge about the requirements and software solutions for problems in the application domain. For instance, software engineers must understand basic control theory essential to the movement of factory automation equipment before they can specify and design software for machine control.

To help meet industry's demand for software engineers with domain-specific knowledge and skills, the Master of Software Engineering (MSE) Program at Carnegie Mellon University offers ***specialization tracks.*** **A** specialization track is a directed course of study to enable graduate software engineering students to acquire and apply knowledge geared towards a chosen domain of applications or related to a particular technology. For instance, a student may specialize in the real-time domain. Section 3 contains more detail about the selection of an application domain for a specialization track.

In this paper, the authors overview the three specialization tracks defined for the MSE Program: the ***Real-Time Specialization Track*** (Section ***6),*** the ***Human-Computer Interaction*** *(HCI)* ***Specialization Track*** (Section ***7),*** and the ***Business Specialization Track*** (Section 8). They briefly describe the goal-oriented process used to design these tracks. Details of this process can be found in [Hoover 93]. More extensive information about the MSE specialization tracks appears in [Hoover 95a, Hoover 95b, Hoover 95c].

2 Rationale

In her discussion of computing education for the 1990s and beyond, Shaw identifies an industrial demand for computer specialists with core expertise in computer science as well as in a specialty area such as architecture, astronomy, chemistry, or psychology. She describes the need for joint degree programs that not only enable students to develop core competency in computer science and another field but also integrate the two fields. One way she says this can be done is by teaching specific computational models and selected techniques from areas of computer science which depend on relevant applications in the joint field [Shaw 90].

In a similar manner, tracks in a graduate software engineering program enable students to develop expertise in specialization areas as well as in software engineering. **A** specialization track integrates the computing theory and practice with the application domain knowledge needed to develop domain-specific software. Because of the increase in software applications and the growing emphasis on quality and productivity, companies producing applications software prefer to hire software engineers who already have domain knowledge and software engineering skills. The authors hypothesize that, in general, software engineering graduates who pursue a specialization track may more easily obtain jobs in these application-specific fields than students who do not. Section 10 provides more detail about students who have completed specialization tracks.

In a 1987 article published in Computerworld, Allman surveyed hiring trends for computer-related research and development positions. She reported that companies prefer to hire people who have graduate educations and can easily become specialists in a company's area of interest. According to Allman, staffing personnel at Sandia National Laboratories in Albuquerque, New Mexico, seek people with interdisciplinary backgrounds in computer engineering or computer science and mathematics. Sandia needs people with both software development and mathematical expertise to develop computational and cryptographic systems [Allman87].

The trend in specialization seems to be holding for the 1990s. Despite layoffs and downsizing, high-tech companies in Massachusetts seek people who are hands-on, sharp, individual contributors with specialized skills, Guisbond wrote in a 1990 Computerworld article [Guisbond 90]. McMahan, a recruiting director quoted in Guisbond's article, states that those being sought are people with substantial experience in relational databases, workstation software, graphical user interfaces, software engineering, and applications programming in C.[3] He thinks it is very important that people, early on in their careers, pick an area of specialization and develop in-depth skills in that area.[4]

In an article about training, Moore and Purvis discuss Texas Instruments' desire for software engineering graduates knowledgeable in real-time applications. The company's Defense Systems and Electronics Group (DSEG) assessed the background and capabilities of 250 newly hired software engineers and found that very few had any course work which covered embedded real-time systems. DSEG recommended that universities help by offering elective courses that cover the basic concepts of real-time computing.

Furthermore, Moore and Purvis suggest that on-the-job training (OJT) is not always a very good means of learning information. They say that, in contrast to formal training programs and courses, OJT tends to be hit-or-miss, may not be well organized, and is often incomplete. They also suggest that it may take an employee longer to learn fundamental concepts through OJT than by taking a course about these topics. The awareness of DSEG of these shortcomings has led to the creation of training courses to replace OJT [Moore 88]. Just-in-time software process workshops now help project teams identify their specialized training needs [Fortin 95].

Specialization tracks in a graduate software engineering program are value-added features. The student not only acquires expertise in the principles of software engineering but also in a particular application area. The opportunity to pursue a specialization track should enhance the value of a graduate software engineering program. Hopefully, companies will be more willing to fund the graduate education of employees who propose to follow a specialization track which matches the needs of the company.

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3. The trend in the nineties may actually be towards C++.

4. Guisbond based her article for Computerworld on interviews with directors and managers of recruiting firms and information systems departments. At the time Guisbond's article was written, Steve McMahan was the managing director at the Boston office of the recruiting firm Source EDP. [Guisbond90]

3 Selecting Specialization Areas to Become Tracks

Our selection of specialization areas is based on the industrial need for expert knowledge in an area; on the backgrounds and past/present career goals of our students; and, most importantly, on areas of specialized expertise at Carnegie Mellon University. Some of the guidelines that we generally follow in the selection of specialization tracks are

- The application domain knowledge and/or computer related knowledge needed to design software for an application in the proposed area is extensive or difficult to obtain on the job.
- The application domain knowledge is significantly different from that of other existing specialization areas.
- Faculty or guest lecturers from industry with expertise and an interest in teaching courses in the specialization area are available.
- The list of approved courses provides the student sufficient background to design software for applications in the area.
- The courses fit into the time frame of the graduate program.

Unlike the other predefined tracks, the ***Business Specialization Truck*** does not focus on software design. Therefore, most of the approved courses for this track do not target software design skills. Later in the paper we address how specialization track courses fit into the time frame of the MSE Program

4 A Structured Approach to Defining a Specialization Track

Defining a specialization track is an evolutionary process. We focus on behavioral objectives that clearly state what the student should be able to do after successfully completing the track. These educational objectives evolve from the target knowledge and skills that we identify using the TAP-D Model [Hoover 93]. We map the educational objectives to elective (and sometimes MSE core) courses to create a list of approved courses for the track.

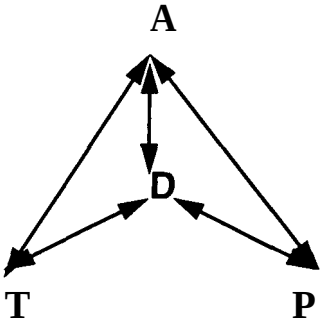

Figure 4-1: The TAP-D Model[5]

5. The idea of using a triangular structure to model three interacting components which contribute to the actualization of the center component was inspired by Bonnie John's model for human-computer interaction (HCI). In her model, interactions between the human, the available computer technology, and the task influence the design of a human-computer interface [John 92].

- **T** -Theory
- **A** - Application Domain Knowledge
- **P** -Practice
- **D** - Development of a Software System for a Particular Application

In the TAP-D model, **(T)** represents computing theory used to solve problems in the domain. For instance, software engineers use Petri Nets to specify timing constraints in real-time systems.

Application domain knowledge **(A)** includes non-computer related theoretical and practical knowledge drawn from the application area. An example is digital signal processing theory used in the design of industrial controllers. Likewise, an understanding of geometry and linear algebra is helpful to develop computer graphics algorithms. *An* understanding of the psychology of learning is required for the development of computer-based tutors.

Practice (P) refers to software development techniques geared to the application domain, for example, the use of commercial tools to support the specification and design of real-time systems.

Software development (D) involves the application of domain knowledge, computing theory, and software development techniques to specify, design, and evaluate software for a particular application. Interestingly, the use of knowledge from one component of the triangle affects the use of knowledge from another component. In Example 1 which follows, a software engineer uses both theoretical and application domain knowledge to generate a more complete requirements specification for a motorized wheelchair.

> **Example 1:** A software engineer formally specifying the requirements of a motorized wheelchair for the blind realizes that no one has defined what the software should do if the motor which powers the chair stops running. After speaking to experts in the use of mobile devices for the handicapped, the developer determines that the speech and vision systems should continue to monitor the surrounding environment, should notify the user of the power failure, and should activate emergency flashing lights.

Identifying the knowledge and skills needed to develop high-quality software for applications in a specialization area is not as simple as it may seem. The specifier of a track must not only be knowledgeable in the application domain but must also be well informed about advances in state-of-the-art computing theory and software development techniques.

Educational objectives for a specialization track should be behavioral in the sense that they should clearly define the way in which students will be expected to demonstrate the target knowledge and skills. For example, a high-level educational goal may be to have the student understand and apply formal specification methods suitable for real-time applications. Requisite knowledge includes an understanding of ways to model requirements of real-time applications software. Example 2 is a behavioral objective to demonstrate that a student understands a set of specification methods.

> **Example 2:** Given text descriptions of the requirements of various real-time systems, the student will identify appropriate specification method(s) for each application and explain why the chosen specification method(s) is/are appropriate for the corresponding application.

The accomplishment of this objective can be measured by giving the student text descriptions of requirements of real-time applications and evaluating the student's selections and explanations. The student would be expected to recognize a case in which none of the specification methods studied in class were appropriate for a particular application.

In general, we map educational objectives to existing courses. Elective courses in the graduate software engineering program provide application domain knowledge. Examples given through lectures and class assignments for these electives help students to understand and apply theoretical concepts and techniques to the design of software for the chosen application. Likewise, theories and methods presented in the MSE core courses often include application examples that satisfy specialization track objectives. At least one elective course, independent study, or project course should require the student to design and implement application software.

When educational objectives cannot be met by existing courses, we fill the gap with new courses or modifications to existing courses. For instance, we created a survey course that broadly covers topics related to the development of software for real-time applications [Hoover 95d].

Below is a summary of the four basic steps we use to define a specialization track.

1. Define the requisite knowledge and skills.
2. Formulate educational objectives.
3. Map the educational objectives to courses.
4. Target opportunities for students to develop application software.

5 General Track Requirements

In addition to the six core courses[6], an MSE student takes a minimum of 6 full-semester, 9-12 unit electives for a total of 54-72 credit units. We require a student pursuing a track to take 4 or more of these electives in his or her specialization area.

Students select approved courses that correspond to their career and educational objectives. The tracks are quite flexible in that students can select from a list of approved courses for each track.[7] The program allows tracks to be adopted to the needs of individual students. Under the supervision of their advisors, students may define their own tracks by applying the TAP-D Model discussed in the previous section.

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6. The MSE core courses include ***Models of Software Systems. Methods of Sofhvare Development, Management of Software Development, Analysis of Software Artifacts, Architectures of Sofhvare Systems,*** and *Software* ***Development Studio*** *I-V.*

7 Required track courses include: ***Introduction to Real-Time Software and Systems*** for the real-time track; ***Special Topics in Computer Science: Human-Computer Interaction*** for the HCI track; and ***Financial Accounting*** and *Managerial* ***Accounting*** for the business track.

Preferably students should have the prerequisite knowledge and skills for their track courses before entering the MSE Program. **As** a result, each track need not be accessible to all students. Occasionally a student can acquire a minimal number of prerequisite skills for a particular track course while pursuing an MSE.

In the next three sections, the authors present the rationale, knowledge and skills, educational objectives, and approved course list for each predefined track.

6 Real-Time Computing Specialization Track

Real-time computing is the type of computing in which the correctness of the system depends not only on the logical result of the computation but also on the time at which the results are produced. Examples of real-time applications include air traffic control, factory automation, patient monitoring systems, and video conferencing. Software engineers who develop real-time software need to understand the functional constraints such as timing, fault tolerance, and reliability that distinguish real-time from non-real-time applications.

The *Real-Time Specialization Track* enables MSE students to acquire knowledge about real-time applications, to obtain an understanding **of** fundamental principles of real-time computing, and to gain experience in the development of real-time software. Students who pursue this track should develop a broad view of the role of the software engineer in real-time software development. They should be able to identify common characteristics of real-time applications and to distinguish between applications which require real-time solutions and those which only require adequately fast response times. In addition, they should be aware that real-time applications often involve reliability, safety, and fault tolerance requirements.

In Table 1, we overview the knowledge and skills that students pursuing this track can acquire. Corresponding columns display the mapping between the knowledge and skills, educational objectives, and approved courses that satisfy the educational objectives. **All** students in the *Real-Time Specialization Track* take the course *Introduction to Real-Time Software and Systems.*

Table 1: Real-Time Specialization Track: Mapping Between Knowledge and Skills, Educational Objectives, and Approved Courses

Knowledge and Skills	Educational Objectives	Approved Courses
Real-time software systems: requirements/design, scheduling theory, languages, operating systems, software architectures, and integration.	Acquire and demonstrate fundamental knowledge and skills related to real-time computing and software development.	Introduction to Real-Time Software and Systems (required course)
Methods to design, implement, and evaluate real-time software.	Select and apply methods to design, implement, and evaluate real-time software.	Real-Time Software Design

Knowledge and Skills	Educational Objectives	Approved Courses
State-of-the-art techniques used to develop real-time operating system and multimedia applications software.	Apply state-of-the-art techniques to the development of real-time operating system and multimedia applications software.	Special Topics in Computer Science: Multimedia Systems
Properties of operating system support for real-time applications such as multimedia.	Design and implement operating systems support for real-time applications. Summarize and critique literature in the field.	Advanced Topics in PS: Operating System Support for Real-Time Systems
The technology of media representation, storage, and communication. Digital processing of audio, still images, and video.	Apply concepts of media technology to the design/implementation of human-computer interfaces.	Special Topics in Computer Science: Media Technology
Knowledge and/or skills in an individually selected area of real-time computing.	Acquire knowledge and/or skills in an individually selected area of real-time computing.	Independent Study of Real-Time Computing Issues
Quantitative analysis and design of high-performance, real-time computing systems.	Analyze the performance of real-time system components and devices.	High Performance Computing Systems
Digital filtering techniques and the design of software to implement digital filters.	Design and implement digital signal processing software.	Digital Signal Processing I

7 HCI Specialization Track

There is an increasing demand for software to implement human-computer interfaces. Software engineers who develop these interfaces need an understanding of the interactions between the human, the available computer technology, and human tasks. They should also understand empirical methods used to evaluate the usability of existing human-computer interfaces. The *HCI Specialization Track* enables graduate software engineering students to obtain knowledge and skills related to the design, implementation, and evaluation of interactive computing systems. They will become knowledgeable about the usability of human-computer interfaces and methods for evaluating usability. Students can explore computer technology to support individual users as well as group interactions. After completing a specialization in HCI, students will be able to apply their understanding of the interactions between the human, the available computer technology, and human tasks to the design of software to support an interactive computer system.

In Table 2, we overview the knowledge and skills that students pursuing this track can acquire. Corresponding columns display the mapping between the knowledge and skills, educational objectives, and approved courses that satisfy the educational objectives. All students in the *HCI Specialization Track* take the course *Special Topics in Computer Science: Human-Computer Interaction* or an equivalent.

Table 2: HCI Specialization Track: Mapping Between Knowledge and Skills, Educational Objectives, and Approved Courses

Knowledge and Skills	Educational Objectives	Approved Courses
Definition and evaluation of usability. Validation of interface design with respect to requirements.	Explain how humans interact with computers to complete tasks. Apply techniques for evaluating human-computer interfaces.	Special Topics in Computer Science: Human-Computer Interaction (required course)
Nature of group communications and computer technologies to support group interactions (groupware).	Show understanding of group interactions and of technology to support these interactions.	Advanced Topics in HCI: Computer Supported Cooperative Work
The comparison of HCI methods for evaluating the usability of human-computer interfaces.	Compare HCI methods for evaluating the usability of human-computer interfaces.	Advanced Topics in HCI: Comparative HCI Analysis Techniques
Computer technologies used to design and implement human-computer interfaces.	Design and implement interface software using state-of-the-art software development methodologies and tools.	User Interface Software
The technology of media representation, storage, and communication. Digital processing of audio, still images, and video.	Apply concepts of media technology to the design/implementation of human-computer interfaces.	Special Topics in Computer Science: Media Technology
Knowledge and/or skills in an individually selected area of HCI.	Display knowledge and/or skills in an individually selected area of HCI.	Independent Study of an HCI Topic
Impact of information technology on organizational procedures. Office automation and computerized decision-support.	Analyze and propose solutions to problems of using computer information systems.	Human Interface to Business Computer Systems
Visual aspects of designing user interfaces such as color, shape, and spatial location.	Demonstrate skill in the visual aspects of designing human-computer interfaces.	Human Computer Interaction Design
Designing/implementing interactive systems to meet user requirements.	Design and implement a human-computer interface to satisfy an industrial customer.	Industrial Design Project
Psychological factors which affect the usability of a design for a human-computer interface.	Show an understanding of the interaction between humans and their designed environments.	Human Factors

8 Business Specialization Track

MSE students who aspire to obtain business management positions within a computer-related technology company, to specialize in the development of software to support production and operations, and/or to start their own technical companies will need fundamental business skills and expertise. The *Business Specialization Track* is intended to help students acquire basic business **slulls** while completing their masters degrees in software engineering. The completion of this track is similar to obtaining a minor in business.

All students who complete this track should be able to read and interpret primary financial statements such as the balance sheet, the income statement, and the cash flow statement. They should understand basic cost and budgeting concepts used to analyze and report the performance of business operations and to make intelligent financial decisions regarding these operations. Other knowledge and slulls that they will acquire depend on the courses that they select to match their career goals and educational objectives.

We have targeted four example career goals and have developed a sub-track of the *Business Specialization Track* for each goal. The targeted career goals are (1) executive-level management in a computer technology company, **(2)** information management, *(3)* production and operations, and **(4)** entrepreneurship. **All** students in the *Business Specialization Track* take the courses *Financial Accounting* and *Managerial Accounting.* Students pursuing *Executive-Level Management in a Computer Technology Company* (sub-track 1) also take *Finance* and *Marketing Management. Finance* and *Management of Information Systems* are additional required courses for *Information Management* (sub-track **2).** *Quantitative Methods for Management Science* and *Production/Operations Management* are also required courses for *Production and Operations* (sub-track **3)** as are *Entrepreneurship I and II* for *Entrepreneurship* (sub-track **4).**

In Table *3,* we overview the knowledge and skills that students pursuing the *Business Specialization Track* can acquire. Corresponding columns display the mapping between the knowledge and skills, educational objectives, approved courses that satisfy the educational objectives, and sub-tracks. The sub-track numbers in the fourth column correspond to those shown in the preceding paragraph.

Table 3: Business Specialization Track: Mapping Between Knowledge and Skills, Educational Objectives, Approved Courses, and Sub-tracks

Knowledge and Skills	Educational Objectives	Approved Courses	Sub-tracks
Preparation and interpretation of financial statements. Calculation of asset value, inflation, depreciation, and interest.	Interpret financial statements. Reconstruct, analyze, and interpret economic events from financial statements.	Financial Accounting	Required for all sub-tracks.

Knowledge and Skills	Educational Objectives	Approved Courses	Sub-tracks
Cost concepts and accounting controls. Analyzing and reporting performance. Financial modeling.	Analyze costs and report performance.	Managerial Accounting	Required for all sub-tracks.
Financial concepts such as time value of money, capital budgeting, risk and return, and capital structure.	Demonstrate an understanding of the financial problems faced by firms and the models used to address them.	Finance	Required for sub-tracks **1** & 2. Approved for sub-track **4.**
Concepts related to marketing principles, analysis, and strategy.	Analyze and propose solutions for situations that marketing managers encounter.	Marketing Management	Required for sub-track 1. Approved for sub-tracks **2** & **4.**
Issues associated with the external political, social, and legal environment of the firm.	Demonstrate an understanding of political, social, and legal issues important to managers.	Managerial Environment	Approved for sub-track **1.**
Frameworks for analyzing the interactions between government and business.	Formulate strategic goals based on analytical models of the interaction between government and business.	Business, Government and Strategy	Approved for sub-track **1.**
Microeconomic theory applied to business problems.	Apply microeconomic theory to the solution of optimization problems such as pricing and project selection.	Managerial Economics	Approved for sub-tracks **1**& **4.**
Economic principles applied to macroeconomic problems.	Develop analytical models of macroeconomic problems such as the changes in productivity and economic growth.	Changing Global Environment: Wealth of Nations	Approved for sub-tracks **1** & **4.**
Concepts related to managerial communication, both oral and written.	Apply techniques that managers use to achieve their communication goals.	Business Communications	Approved for sub-tracks 1, 2 & **4.**

Knowledge and Skills	Educational Objectives	Approved Courses	Sub-tracks
Issues that managers face in managing human organizations and techniques for resolving these issues.	Diagnose the causes of organizational problems and suggest solutions based on judgment and understanding.	Human Behavior in Organizations	Approved for sub-tracks 1, 2 & 4.
Computer technology trends. Analysis of computer companies along dimensions of technology and marketing.	Analyze computer companies along dimensions of technology, manufacturing, and marketing.	Technology, Development, Management, and Marketing in the Computer Industry	Approved for all sub-tracks.
Organizational structure, management, strategy, finance, and innovation in computer companies.	Analyze computer companies along dimensions of organization, management, finance, and strategy for innovation.	Organizational Structure, Strategy, and Innovation in the Computer Industry	Approved for all sub-tracks.
Rigorous and responsible reasoning about ethical aspects of managerial decisions.	Demonstrate an understanding of ethical issues that managers face.	Ethical Issues in Business	Approved for sub-tracks 1, 2 & 4.
Theory and processes of negotiation practiced in a variety of settings.	Apply negotiation techniques to problems faced by the professional manager.	Interpersonal Negotiation	Approved for sub-tracks 1 & 4.
Concepts and methods of organizational management.	Identify, apply, and evaluate techniques for resolving managerial problems in public and private organizations.	Organizational Wanagement: Theory and Practice	Approved for sub-tracks 1 & 4.
Role and behavior of leaders in public and private institutions. Models of leadership and change.	Show an understanding of organizational leadership issues and guidelines for affecting change.	Leadership: nnovation and Organizational Change	Approved for sub-tracks 1 & 4.

Knowledge and Skills	Educational Objectives	Approved Courses	Sub-tracks
Requirements for organizational leadership and ways to promote creative thinking and innovation.	Explain leadership requirements and problems. Suggest ways to lead others towards creativity and innovation.	Advanced Topics in Leadership	Approved for sub-track **1.**
Issues related to the strategic use and management of information systems.	Analyze and solve problems of managing information systems.	Management of Information Systems	Required for sub-track 2.
Selection and use of information technologies from a managerial viewpoint.	Describe types and use of information and communication technologies as well as related managerial issues.	Information & Communications Technologies in Manufacturing	Approved for sub-track 2.
Managerial techniques for choosing from various telecommunications options.	Discuss telecommunications options and apply managerial selection techniques.	Telecommunications for Business	Approved for sub-tracks 2 & 3.
Fundamentals of database management from technological, managerial, and organizational perspectives.	Demonstrate understanding of database management fundamentals.	Information Resources Management	Approved for sub-track 2.
Information systems development project via a managerial or technical role.	Implement solutions to information systems development problems.	Information Systems Project Course	Approved for sub-track 2.
Ways to effectively exploit information technology for productive purposes.	Evaluate the feasibility and effectiveness of proposed information systems.	Information Systems Development	Approved for sub-track 2.
Fundamental concepts and programming issues in expert systems.	Develop an expert system as a team project.	Expert Systems	Approved for sub-tracks 2 & 3.
Case study analysis of information system/networking technologies used in industry.	Discuss issues and compare different approaches to applying network technology.	Information Network Implementation	Approved for sub-tracks 2 & 3.

Knowledge and Skills	Educational Objectives	Approved Courses	Sub-tracks
Impact of information technology on organizational procedures. Computerized offices and decision-support.	Analyze and propose solutions to problems of using computer information systems.	Human Interface to Business Computer Systems	Approved for sub-tracks 2 & 3.
Techniques for quantitative analysis in economics and the management sciences.	Use quantitative techniques to analyze economic and managerial problems.	Quantitative Methods for Mng. Science	Required for sub-track 3.
Basic techniques for managing materials, technological processes, and people.	Apply resource management techniques to the production of manufactured goods.	Production/ Operations Management	Required for sub-track 3.
Mathematics for operations research.	Develop operations research models to solve management problems.	Introduction to Operations Research	Approved for sub-track 3.
Characteristics of computer integrated manufacturing (CIM) technologies.	Analyze operational problems and propose appropriate CIM solutions.	Computer Integrated Manufacturing I, II	Approved for sub-track 3.
Characteristics of computer-aided design (CAD) tools.	Use CAD tools to design of products and manufacturing processes.	Computer-Aided Design Tools	Approved for sub-track 3.
Principles and techniques of knowledge-based technology. Application to CIM	Apply to the solution of production and operations problems.	Knowledge-Based Systems for Manufacturing	Approved for sub-track 3.
Risks and rewards of entrepreneurial careers and issues related to entrepreneurial management.	Show an understanding of the role of the entrepreneur and of the issues that they face.	Entrepreneurship I & II	Required for sub-track 4.

9 Track Supervision

Offering specialization tracks requires supervision. As with most graduate programs, the student must assume responsibility for determining and completing track requirements. Students use the track descriptions as well as information acquired during the MSE Program orientation to select and/or define a track [Hoover93, Hoover95a, Hoover95b, Hoover95c]. Students can discuss the track option with their advisors but usually one student advisor and the program

administrator keep students informed and record progress towards completion, As the track option becomes more established, we expect other student advisors to become more active in providing information about tracks.

In addition, we encourage students to work with domain experts in their chosen application areas. These may be industrial sponsors, industrial mentors, professional contacts, or academic faculty. Students talk to Carnegie Mellon University faculty or Software Engineering Institute (SEI) staff members about domain-specific career options. Many students pursue independent study courses with these domain experts to acquire individually defined knowledge and skills.

An important aspect of supervision is the ongoing curriculum development for tracks. As technical directions, industrial demands, and course offerings change, a faculty member responsible for track development needs to define new educational objectives and to select new courses for the tracks. This involves using courses developed for other purposes as well as creating new courses.

Currently, the MSE Program recognizes track completion in two ways: (1) designation on the diploma as a Master of Software Engineering in the Field of *<name of track>* (e.g., *<name of track>* could be Human-Computer Interaction), or **(2)** a letter from the department acknowledging the fact that the student completed a specialization in a domain-specific area of software engineering. The diploma designation is available only for the predefined tracks.

10 Lessons Learned

As of December 1995, one student has completed the ***Real-Time Specialization Track*** and two students the ***HCI Specialization Track.*** One of these students is taking a lead role in proposing improvements to the way in which his company architects real-time radio systems. As the manager for the CMU Psychology Department's computing systems, another student not only applies his background in HCI to the evaluation of user interfaces for the software that he selects but also has continued his research in this area. With respect to the other MSE graduate who completed the HCI track, there is no direct correlation between the completion of a track and the job selected by the student upon graduation.

We have several students currently pursuing or planning to pursue specialization tracks: one in real-time, one in HCI, and seven in business. Just recently, a student expressed an interest in defining his own track in distributed computing. At least three students planned to pursue specialization tracks at the beginning of their MSE studies but later opted to take a broader selection of electives. Another interesting case is a student who originally planned to define a specialization track in software process and who is now excited about software architectures. Not surprisingly, a student's interests can change with exposure to new ideas and areas of study.

In offering tracks, we have encountered issues such as the feasibility of creating new courses and fluctuations in the availability of existing courses. The number of students pursuing a track impacts the decision of whether or not to create a course for the track. We have found that our introductory real-time course (which we created for the ***Real-Time Specialization Track)*** attracts interest from students outside the track. Courses that cover interesting and specialized topics with high-market demand can attract sufficient numbers of students from different but related fields. For instance, we co-supported the offering of the ***Human*** *Factors* course with the psychology and design departments. Another way to reach a broader audience would be to provide

alternative methods of delivery. Mead suggests consideration of alternatives such as video, educational software packages, tutored video, and satellite delivery [Mead 95].

We have learned to prepare for fluctuations in course availability. As faculty commitments and interests change, so do the courses they teach. We try to provide a flexible list of approved courses to accommodate course unavailability. The developer of a track can select existing courses (including those from other departments) that cover key educational objectives. This helps to increase the number of available courses and reduces the cost of creating a specialization track.

There can be some complications in basing tracks on the selection of existing courses from other departments. In the case of the ***Business Specialization Truck,*** our students are having difficulty being admitted into courses offered by the Graduate School of Industrial Administration (GSIA), the graduate business school at CMU. Core GSIA courses are being filled by graduate business students. This situation has made us rethink the feasibility of requiring specific GSIA courses for the business sub-tracks. We are currently studying the situation.

11 Conclusions

In conclusion, we note a study by the Conference Board that evidences the shift away from the paternalistic and protective, employer-provided career management of the past towards employee self-management. This shift of responsibility for career management is a result of factors such as corporate downsizing and restructuring, uncertain business and job market conditions, and limited opportunities for career advancement.*

Though we firmly believe that employers have a responsibility to provide their employees with sufficient training to do their jobs well, we see the need for individuals to take a more proactive role in choosing educational endeavors that help them reach their career goals. We think that specialization tracks offer the graduate software engineering student the opportunity to customize their education to the specialized needs of industry. This **is** important not only for enhancing individual career options but also for strengthening career management capabilities.

The ability to seek help from domain experts, to identify requisite knowledge and skills, and to delineate meaningful educational goals as well as the discipline to complete a chosen course of action are essential to the management of one's career. Many companies today like to hire software professionals with broad software engineering expertise as well as domain-specific knowledge and skills. Software professionals must continually and actively seek information about career opportunities and must manage their own careers.

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8. The Conference Board is a nonprofit, bipartisan organization founded in 1916 to improve business enterprise systems and to enhance the contribution of business to society. Researchers in this organization conducted a study of trends in career management and financial planning during the fall of 1990. The study included **28** interviews with **14** corporations and one large accounting **firm.** The corporations included older companies in major industries as well as younger firms in high-technology businesses. The interviews were conducted with people within these corporations who were in charge of human resource planning, benefits, training. and development. The study also included discussions with career development consultants as well as executives. In addition, the researchers reviewed recent literature in the business press which discussed these topics [Dennis 91].

Defining and/or following a specialization track should help MSE students prepare for self-managed, software engineering careers with enhanced opportunities to develop software for chosen application areas. **As** Guisbond wrote in 1990, specialization is a dominant trend that requires people to take an informed and directed approach to managing their careers. Those people with the best job opportunities are those who prepare for anticipated technology trends and who tailor their job preparation and searches accordingly [Guisbond 90].

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