Engineering Management for Undergraduates

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Abstract

Upon completion of the educational requirements needed to obtain a B.S. in engineering, many students enter directly into the working world with little background in the business of engineering and limited knowledge of how projects are managed. To address this problem, The Citadel offers a technical elective, Civl 411-Engineering Management, aimed at helping students develop an understanding of the competitive environment, in which they are likely to be employed, as they conduct engineering work for private companies and public agencies. A major objective of the course is to introduce students to management issues and to expound on techniques that are essential in managing real-world engineering projects. The course focuses on three primary aspects of management including traditional business school topics, organization of integrated engineering design and construction teams and analytical tools needed to support effective decision-making. A large portion of the course centers on a discussion of industrial type projects and aspects of integrating mechanical, electrical and civil design activities. Numerous real world project materials are incorporated into the classroom instruction pertaining to marketing plans, operational plans, technical proposals, project budgets, progress reports and contract agreements.

Introduction and Course Overview

Engineering Management, Civl 411, is offered twice a year as a 3-hour credit course to both evening and day students. This course is one of three technical elective courses routinely offered each year through the civil engineering curriculum. Undergraduate students typically take one of the three elective courses. In the evening student program, the course is one of only two electives offered. As a result, on a year-to-year basis approximately 50% of the students obtaining a civil engineering degree at The Citadel have taken the course described in this paper. The purpose of this paper is to provide an overview of the course and presentation of techniques used to motivate and instruct students in this important subject. ABET objectives for students completing the course, as identified in the course syllabus, are as follows:

1. Knowledge of terminology used in business and engineering management.
2. Understanding of management organization, motivational theories and leadership models.
3. Application of planning, organizing, staffing and controlling to engineering management.
4. Ability to utilize decision making and problem solving techniques including fault tree analysis, linear programming, economic analysis, and matrix evaluation.
5. Understanding of project scheduling and network analysis through use of CPM/PERT methods.
6. Knowledge of engineering marketing and business development with respect to pre-qualification, project advertisement, proposal submittal, selection criteria and project award.
7. Understanding of engineering costs, design documents, legal agreements, construction contracting, and construction management.
8. Understanding of value engineering techniques.
9. Understanding of technical applications for total quality management.

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Course Topics

The course is generally divided into four primary course topic areas including: traditional business management, engineering project management, construction management and use/application of analytical tools in decision making. Materials for the course have been gathered from a wide variety of texts and technical sources. No single textbook is used in the course, rather an extensive set of instructional notes are utilized and distributed to the students through campus bookstore. In addition, students are required to read "The 7 Habits of Highly Effective People" by Stephen R. Covey [1]. Topics from the book are integrated with materials contained in the course notes and several questions are included on tests to insure students are completing the reading assignments. An outline of topics addressed throughout the course is summarized in Table 1. In addition a more detailed discussion of course materials organized according the four primary course topic areas. Finally, this discussion is concluded with an overview of a multi-part student assignment related to technical proposal preparation and evaluation.

Table 1 – Summary of Course Topics

I.	**BUSINESS MANAGEMENT** 1. Planning, Organizing, Staffing, and Controlling 2. Motivation Theories 3. Leadership Styles 4. Productivity and Incentives 5. Professional Ethics 6. Total Quality Management (TQM)
II.	**ENGINEERING MANAGEMENT** 1. Business Development & Marketing Strategies 2. Engineering Selection Process and Project RFP's 3. Engineering Qualifications, Technical Proposals & Cost Proposals 4. Manpower forecasting and staffing plans 5. Engineering Labor Costs, Overhead, Profit & Direct Expenses 6. Agreements and Change Orders 7. Engineering Management, Fast Track Design 8. Design Build Teams and EPC Projects
III.	**CONSTRUCTION MANAGEMENT** 1. Construction Management 2. Construction contracts & Documents 3. Bidding and Estimating 4. Quality Assurance / Quality Control 5. Bonding
IV.	**ANALYTICAL TOOLS** 1. Decision Tree (Expected value) 2. Linear Programming 3. CPM Network Scheduling Analysis 4. PERT Network Scheduling Analysis 5. MS Project (scheduling software exercises) 6. Value Engineering

Business Management

The initial portion of the course is dedicated to traditional business school type subjects including basic functions of management, motivation theory, authority, controls, organizational theory and development of strategic/tactical plans [2,3,4]. A wide variety of business school texts were referenced in developing the course notes. This portion of the course includes discussion of the five basic functions of management and system interaction, which are depicted in Figure 1 and briefly summarized as follows:

> **Planning** is the process of determining enterprise objectives and selecting a future course of action to accomplish them. Usually higher-level management activities require longer planning periods.
>
> **Organizing** is the process by which employees and their jobs are related to each other to accomplish the objectives. Establish the activity-authority relationship of the organization.
>
> **Staffing** is the process of assuring that competent employees are selected, developed and rewarded for accomplishing objectives.
>
> **Directing** (leading) is the process of inducing individuals or groups to assist willingly and harmoniously in accomplishing enterprise objectives.
>
> **Controlling** is the process of assuring the efficient accomplishment of the objectives. In this function the manager must establish standards of performance, measures performance against standards and deals with deviations from establish standards.

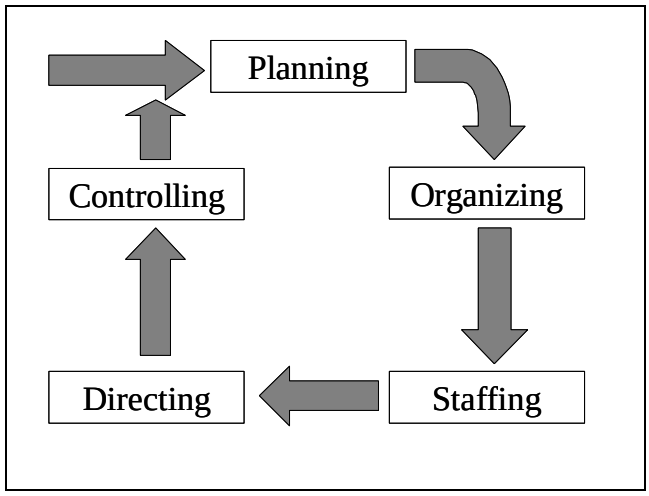

Figure 1 – Five Functions of Management [2]

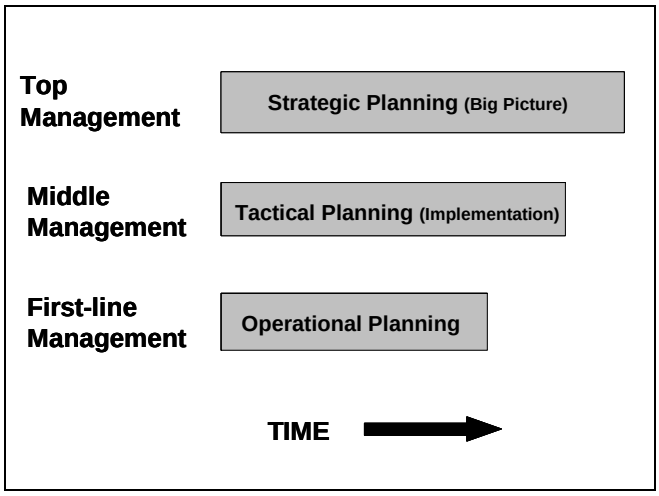

Figure 2 – Management Planning Emphasis [2]

Other business concepts related to management structure, basic skills of a manager, organizational structure and system/contingency approaches for performance evaluation are presented and discussed. Students are introduced to a variety of upper, middle and front line management issues. Figure 2 provides a graphical representation of management levels and their respective planning related activities. As depicted in Figure 3, topics related to control systems are introduced and discussed with respect to prevention, feed forward and feedback. Control system parameters for specific business fields are evaluated with regard to management operations, data aggregation/flow and quality assurance. Furthermore, topics related to span of control, delegation, authority, managerial/technical standards and theory X, Y and Z leadership styles are presented and discussed. A graphical summary of leadership styles is shown in Figure 4. All of these issues are tied in with the concepts from "The 7 Habits of Highly Effective People" especially with respect to the maturity continuum production/production capability (P/PC) balance.

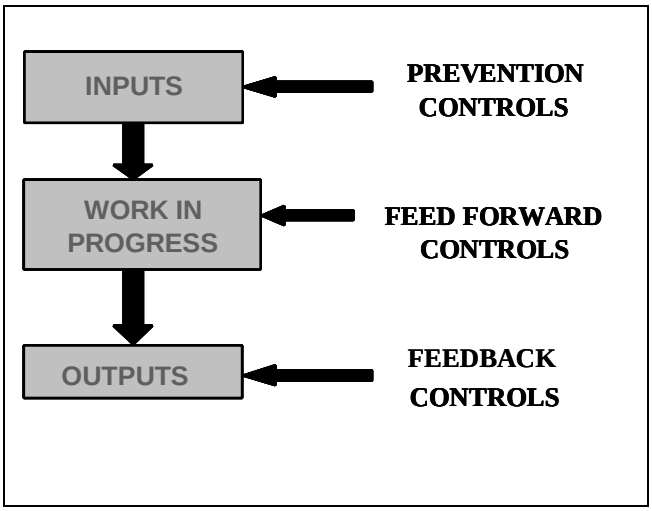

Figure 3 – Types of System Controls

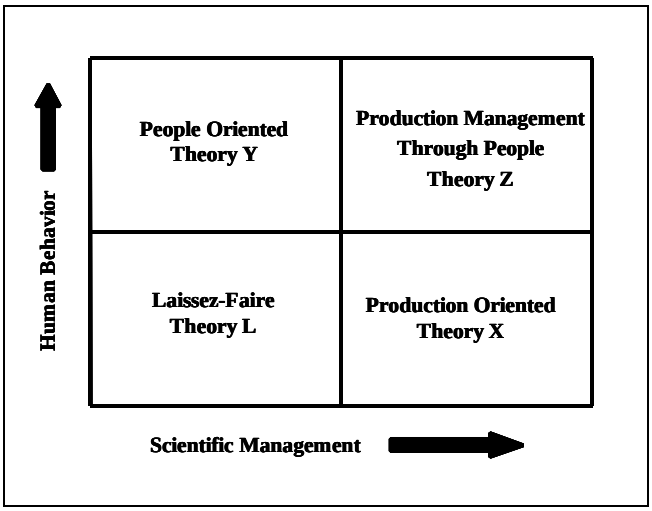

Figure 4 – Two Dimensions of Leadership

Engineering Management

A major component of the course is centered on business management issues, which are unique to the engineering, design and construction fields. Business development strategies, competition and project marketing are evaluated at length. A real-world engineering business plan founded upon a $700,000 marketing budget across multiple design disciplines including industrial, environmental, transportation, power and construction type projects is reviewed and analyzed in detail [5]. Target values for business development funds, expended per number of project hours booked, are evaluated with respect to required up-front investment and reasonable target value ranges. Engineering staffing and work force projections are analyzed against firm and forecasted workloads. Numeric and graphical tools are demonstrated which are useful in the formulation of human recourse action plans.

Management of the design process is covered with regard to adaptive, developmental and new design work [6]. Procedural steps useful in establishing an effective design process were emphasized. Specific emphasis is placed on development, evaluation and optimization of alternative solutions. Additional discussion on engineering management focuses on information sources, standards, design data, procedures, dissemination, administration and coordination. The effects of constraints and requirements on the design process are discussed with respect to operational related constraints, cost constraints, functional requirements, manufacturing limitations and environmental constraints. The need for designs to be creative, constructible, reliable, profitable and timely is stressed.

Project scheduling is presented and discussed in detail with respect to multi-discipline design and integrated construction. Design/build, engineering-procurement-construction (EPC) and fast-tract design projects are reviewed with emphasis on important linkages, progress tracking, milestones, review periods, permits and completion incentives/penalties. Many formats for developing and tracking project schedules are analyzed [7]. An example Gantt chart for a design-build industrial project is provided in Figure 4 [8.]

Project budgets are reviewed and evaluated in the course curriculum and include direct labor costs, overhead, profit and direct expenses. Project multipliers and average hourly rates for loaded labor costs are determined for varying project types including studies, design and construction engineering/inspection [9]. Students are required to determine project budgets and identify reasonable ranges of profit, overhead and labor costs given various components related to project cost. An example project design budget is provided in Table 2. Fee estimation for design services on architectural projects is discussed with respect to the use of fee curves and project complexity [10].

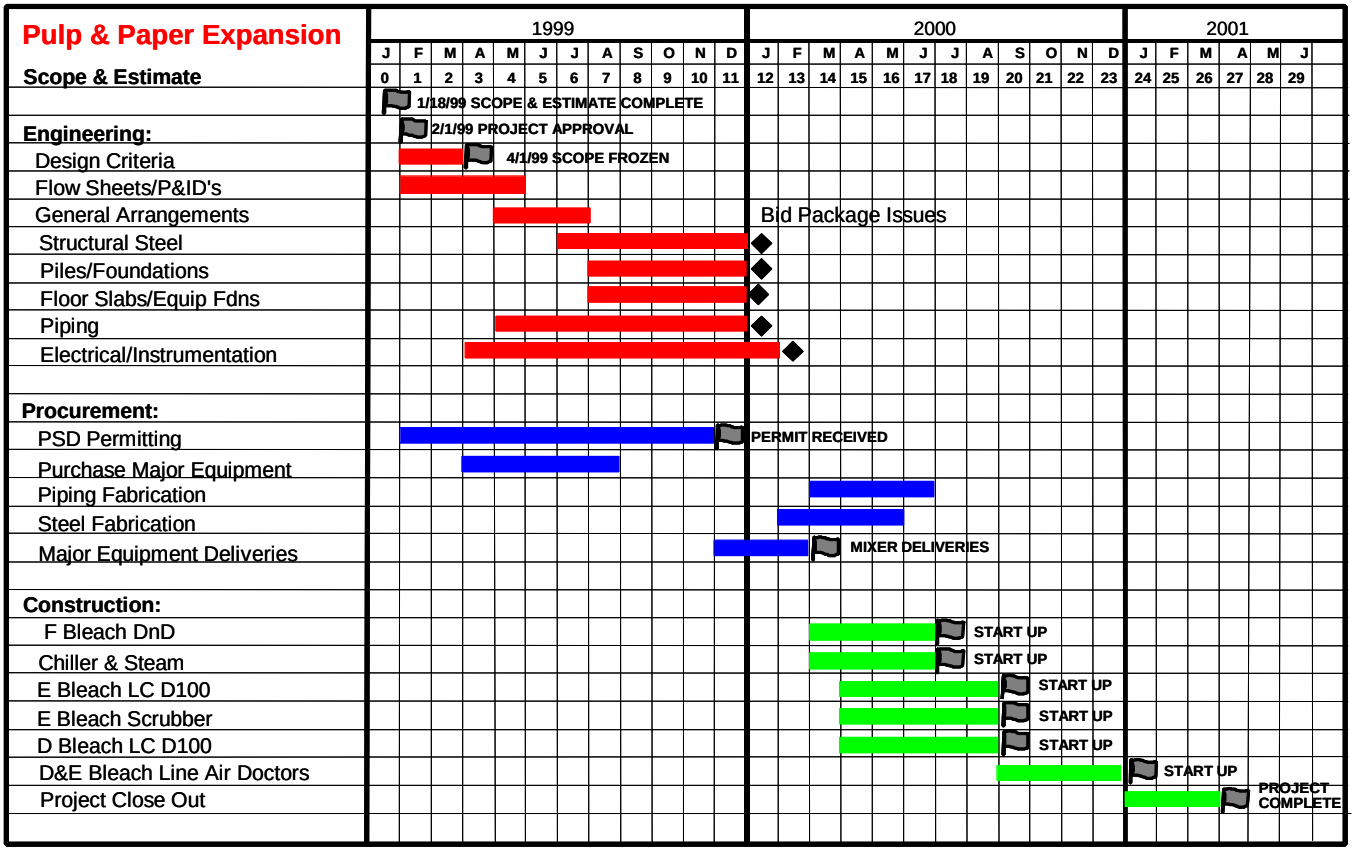

Figure 4 – Design/Build Project Schedule [8]

Table 2 – Example Design Budget [9]

Direct Labor Costs (6,200 hrs)		$136,981
Overhead (137.89%)		$188,884
Subtotal Labor + OH		$325,865
Profit (12%)		$ 39,104
Direct Costs	Subconsultants	$224,283
	Computer Charges	$ 48,220
	Travel/Comm./Repro	$ 15,334
Subtotal Direct Costs		$307,837
Total Project Budget		**$672,806**
Multiplier ($364,969/$136,981)=		2.664
Avg. Hourly Cost ($364,969/6,200)=		$58.86

Table 3 – Example Construction Budget

Project		Murray Barracks
Prime Contractor		Newton Builders
Construction Manager		Davis & Floyd
Winning Bid		$12,099,472
Project Duration		20 months
No. of Subs/Vendors		54
Change Orders	No. 1	$ -4,854
	No. 2	$ 115,518
	No. 3	$ 46,196
	No. 4	$ 17,312
Total Project Cost		**$12,273,644**

Construction Management

Relationships between owners, architects/engineers and contractors are evaluated to help students gain an understanding of which type arrangements are best suited for specific projects and project parameters [11.] Examples and advantages/disadvantages of design-bid-build, design-build, force accounts, construction management and program management are discussed from the differing perspectives of the parties involved. [12,13,14] Establishing efficient relationships between the general contractor and subcontractors

is discussed at length from the view of incentives, risk, and leverage in facilitating timely project completion. The role of an independent construction manager and the need for field/office engineering on complex industrial and public works projects are discussed.

The use and preparation of an engineer's estimate for project construction is covered in this section of the course. Disaggregation of the project into individual bid items, determination of bid item quantities, application of unit costs and calculation of the engineer's estimate are emphasized [15]. The need for good documentation is stressed along with the ever-changing nature of cost estimates and necessity of constant revisions. Advantages and disadvantages of using lump sum items are addressed along with unbalanced bids and administrative treatment of cost overruns. A variety of sample documents are utilized to familiarize students with the level of detail and legal aspects necessary to produce a successful end product in a timely and efficient manner.

A wide range of contracts and agreements are reviewed and discussed to identify which are the most useful in meeting the requirements for specific project conditions [16,17]. The sequence of bid package preparation, project notification, contactor bidding, bid evaluation and project award is analyzed through the use of a number of sample documents taken from real-world engineering and construction projects [18.] The discussion of bid package components includes, plans, specifications, proposal forms, general conditions and special provisions. Additional discussion is focused on the need for clear identification of materials, construction methods, measurement and payment for each bid item. Factors related to determination of responsible bidders are listed and include technical competence, experience, financial solvency, bonding capacity, current commitments, past history with claims/litigation and defaults on previous contracts. The importance of pre-bid meetings, use of project addendum and focus of pre-construction meetings are emphasized to students gain an appreciation of equitable and best practice procedures that should be used within the context of a comprehensive project approach. Issuance of notice to proceed and typical project start-up activities are identified, followed by construction sequence activities, monthly reporting, periodic payments, punch list items, project closeout, retainage, warranties, final inspection and final payment.

Analytical Tools

A number of analytical tools that are useful in project management and decision-making are demonstrated and numeric problems are assigned to help students become familiar with the methodologies. Decision trees are presented and utilized in decision-making by determining either maximum expected values or minimum variance given assigned values to various alternatives or sequence of alternatives [19.] Simple two factor linear programming applications are used to optimize the best combinations of factors against given constraints for the purpose of maximizing profit values. These two methods are demonstrated though examples pertaining to oil drilling scenarios, manufacturing, and mining. The simple examples demonstrated in class and given as student assignments are discussed within the context of more complicated, analytically rigorous problems.

Critical Path Method (CPM) and Project Review Evaluation Technique (PERT) are both extensively demonstrated for their use in determining project schedules, tracking project progress and assessing levels of uncertainty [6]. An example of a 13-activity CPM diagram is presented in Figure 5. This particular project has a 60-week duration and included activities B, D, J and N in the critical path. Numeric exercises related to this procedure are further demonstrated through the use of the Microsoft Corporation computer program Project 98, which uses task activity duration and logic definitions to determine a project CPM. Other options allow display of CPM information in a Gantt Chart and other useful formats. The topic of project schedules is expanded via PERT analysis to deal with uncertainty, variance and expected project completion as related to probabilities. The basis for this method is founded on use of optimistic, most likely and pessimistic task durations. A single-tailed cumulative distribution plot is used to determine probabilities associated with various expected project durations. Lastly, analytical methods related to value engineering and total quality management are also included in this portion of the course.

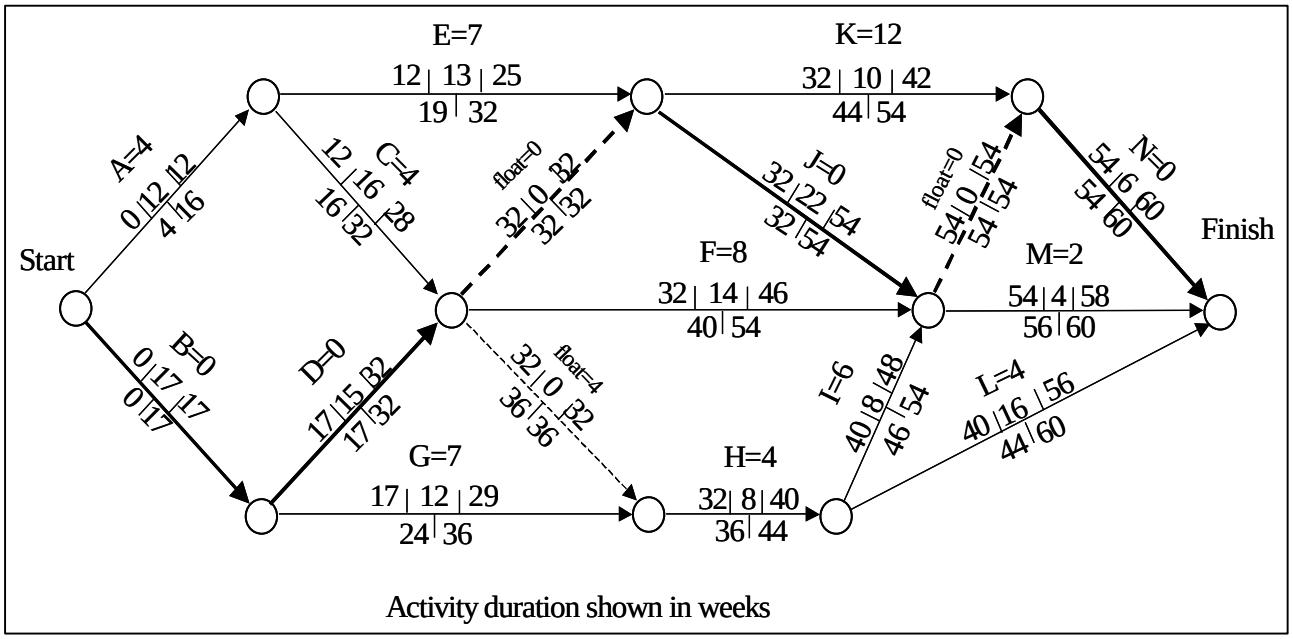

Figure 5 – Critical Path Method

Technical Proposal Exercise

One of the most demanding assignments during the course involves an extended multi-part exercise requiring students to develop a technical proposal, engineering schedule, budget and staffing plan to conduct a concept study of a real-world transportation project. Upon completion, the proposals are evaluated and ranked by a student selection committee, a project award is announced and a debriefing session is held to discuss the basis of the selection. This exercise closely emulates the consultant selection process used by many public works agencies. The projects are actual studies that have been conducted. Upon completion students are debriefed as to the scope, budget and findings from the real-world projects [20,21]. Students are required to apply some limited knowledge of engineering gained from other courses taken as part of the engineering curriculum. Aspects of this assignment are summarized in Table 4.

Conclusion

This type of course is useful in producing engineering graduates with a well-rounded background and more prepared to successfully enter the working world. In addition, this type course is helpful in addressing ABET criteria related to Criterion 3 (d) ability to function on multi-disciplinary teams and (k) ability to apply techniques, skills and tools to engineering practice, and Criterion 4 in applying knowledge towards engineering practice with respect to industry standards and realistic constraints. Feedback from the course has been very positive and students are able to significantly contribute to course discussions based on their work experiences in the engineering and construction fields. The possibility of including this course as part of the required curriculum is under consideration.

Table 4 – Technical Proposal Exercise

1. Teams prepare technical proposals for one of the following two projects:
   - Project 1 – Involves preparation of a Feasibility Study & Preliminary Design of a Downtown Transit Circulator for Chattanooga, TN.
   - Project 2 – Involves preliminary design of a transportation network for a 7,000-acre land development project located east of Chattanooga, TN. The site was formally an U.S. Army base. The western half of the site has some existing facilities, while the eastern half is undeveloped.
2. Evaluation criteria to be used by the Selection Committee in evaluating proposals is provided to proposing teams
3. The technical proposals are evaluated individually by members of the Selection Committee, using point assignment criteria as follows:
   - Project Understanding 25
   - Technical Approach 20
   - Proposed Staffing & Management Plan 15
   - Proposed Schedule 15
   - Estimate for services provided 15
   - Reviewer Discretion 10
4. Selection Committee meets to aggregate point totals for each proposing team.
5. Based on point totals and committee discussion, Selection Committee ranks proposals and determines winner.
6. Selection Committee meets with proposing teams to announce winner and to provide debriefing report to all proposing teams.
7. Proposing teams are provided with an opportunity to address questions to the Selection Committee during the debriefing report.
8. Selection Committee rankings of proposing teams are used in conjunction with professor evaluation to determine an aggregate grade for the assignment, typically 40% for ranking and 60% for professor evaluation of submitted materials.

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