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A Framework and Practices for Cost-Effective Engineering in Capital Projects in the A/E/C Industry

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Georgia Institute of Technology

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A Framework and Practices for Cost-Effective Engineering in Capital Projects in the A/E/C Industry

by

**Jorge A. Vanegas
Makarand Hastak
Annie R. Pearce
and
Francisco Maldonado**

**A Report to
The Construction Industry Institute
The University of Texas at Austin**

**Under the Guidance of the
Cost Effective Engineering Research Team
Number 112**

**from
Georgia Institute of Technology
Atlanta, Georgia**

May 1998

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EXECUTIVE SUMMARY

A perception within the construction industry, which is reinforced by limited data, holds that current engineering practices are not cost effective. In contrast, some companies such as NUCOR have reported using innovative or non-traditional practices that result in achieving overall business objectives at much lower engineering and capital costs, and with faster schedules, than are normally experienced in the construction industry. CII Research Team 112 was formed to identify, compile, assess, and provide objective information on the context of application, possible benefits, and possible risks associated with such practices, especially those which have a potential to improve the competitiveness of an owner organization.

This research was performed with the following specific objectives:

- Identify innovative or non-traditional practices that have contributed to successful projects in NUCOR and other selected organizations using apparently low cost engineering.
- Evaluate qualitatively each practice and the various potential implications of its use (e.g., risk, schedule, costs, value, content of engineering deliverables, rework, appropriate projects, company culture, and contractual issues).
- Determine various drivers that play a role in determining the use of these practices within an organization.
- Develop an organizational scheme to associate, qualify, and assess these practices, their implications, and their drivers.

The methodology used to achieve the research objectives included the following tasks:

- Identify and select a group of owner organizations (including NUCOR, a selected sample of its design, equipment and construction contractors, and other companies), perceived to be pioneering innovative or non-traditional project implementation practices that have led

to successful projects relative to their individual business objectives, particularly those with apparent low engineering costs.

- Identify and describe specific practices within the selected organizations, from global approaches, strategies and mechanisms to competition, partnering/alliances and contracts, to specific project management practices within the different phases of a capital project, both at the corporate and capital project levels.
- Document and analyze, to the extent allowed by each organization studied, the specific context, potential benefits and risks, and implementation requirements on the project or the organization, of each practice identified.
- Report the findings.

This report contains an in-depth analysis of the overall context for cost effective engineering, which provides the background for an integrated framework for cost-effective engineering in capital projects in the A/E/C industry. This analysis includes a general overview of the context for the delivery of a capital project; a discussion of the life cycle phases, stakeholders, and general context for capital projects; a discussion of the various roles that engineering plays, the importance of engineering, and the engineering costs within this process; and an analysis of various external influences and factors on engineering costs. The report also provides an overview of 20 innovative or non-traditional practices for cost-effective engineering identified within the interviews conducted in the twelve companies selected and that agreed to participate in this investigation, and describes in detail 10 specific practices that form the core of Nucor's approach to capital projects.

An important aspect of this investigation is that nature of the data collected in direct interviews which provided the basis of these findings was primarily qualitative; most quantitative data was treated with the appropriate level of confidentiality established by each organization being studied, or was not available to the research team.

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CHAPTER 1.– INTRODUCTION

This research report is the result of an investigation sponsored by the Construction Industry Institute (CII) at the Georgia Institute of Technology (Georgia Tech), under the guidance and supervision of CII Research Team 112 – Innovative Practices for Cost Effective Engineering (RT112), under the direction of Dr. Jorge Vanegas, Principal Investigator (PI), and with the support of several research associates and assistants from the Construction Engineering and Management Program (CEM) of the School of Civil and Environmental Engineering (CEE) at Georgia Tech, who served as members of the Academic Research Team (ART) in various capacities at different stages of the investigation.

1.1 Background

In 1993, at the CII Annual Conference, John D. Correnti, President and Chief Operating Officer of Nucor Corporation (Nucor), Charlotte, North Carolina, challenged the CII member companies to refocus their approach to capital projects, and in particular, to reassess the manner in which engineering for capital projects is performed to make it less expensive, and focused on producing a lower cost/higher value end-product. He revealed that Nucor was typically completing successful projects with engineering costs below 2% of Total Installed Costs (TIC). This claim, in conjunction with Nucor's reputation at that time for being a highly successful company, and its rank as the largest steel minimill operator in the U.S., and the fifth-largest of all the nation's steelmakers, caught the immediate attention of most members in the audience, particularly representatives from CII Owner organizations.

1.2 Original Charter of the Investigation

In response to Correnti's overall challenge and specific claim about Nucor's engineering costs below 2% of TIC, the CII decided to establish RT112 in February 1994, under the name: *"Low Cost Facility Engineering."* Its original purpose was *"...to study and make recommendations to facilitate cost effective construction and operations by optimizing the engineering design."*

The original scope of RT112 was to:

- Identify alternative engineering and construction approaches for building facilities.
- Develop processes where the engineer, constructor, and owner identify opportunities to optimize construction and eventual operation of a facility.
- Evaluate the opportunities and pitfalls to engineering optimization brought on by computer applications, including computer models.
- Make recommendations for eliminating non-value added efforts from capital projects.
- Make recommendations concerning when to utilize engineering in the field.
- Evaluate potential risks resulting from different engineering approaches.
- Consider differences between new projects and retrofit projects.

The original name, purpose, and scope of RT112 were later changed. These changes are described later in Chapter 2.

1.3 Research Team 112

Eighteen CII member companies and one academic institution were represented in RT112 during its existence: from its formation in February, 1994, to its sunset in February, 1997.

1.3.1 Industry Members

Thomas W. Carnes, from International Paper, served as the Chair of the team. Other industry members of RT112 included:

- Members who remained active until the team sunset:
 - James V. Bartlett, Jr., Navy Facilities Engineering Command

- Michael A. Beach, Stone & Webster Engineering Corporation
 - Ian D. Burdett, Union Carbide Chemicals and Plastics Co., Inc.
 - Dennis E. Lajevic-Augustine, Eichleay Engineers, Inc.
 - David L. Mays, Mobil Research & Development Corporation
 - Mark S. Meunier, Aker Gulf Marine
 - David O. Montano, Glaxo Wellcome Inc.
 - William Myles, Eli Lilly and Company
 - John R. Paul, Watkins Engineers & Constructors, Inc.
 - Ted R. Taylor, Eastman Chemical Company
 - I. Andrew Warren, The Parsons Corporation
 - Morris Wolf, Bechtel Group, Inc.
- Members who had to withdraw for various reasons from the team at various stages of the investigation:
 - Abdullatif Al-Othman, Aramco Services
 - Robert G. Langlois, Rust International Corporation
 - Kenneth J. Leach, Sordoni Skanska Construction Company
 - Christopher M. McDonald, The M.W. Kellogg Company
 - Lyndon Morgan, ALCOA

- Jon Vanden Bosch, Associate Director of CII, served as liaison between the research team and CII. His guidance, overall contribution, and specific input and suggestions were invaluable for the investigation.

1.3.2 Academic Research Team

Dr. Jorge A. Vanegas, from Georgia Tech, served as the academic member of RT112, and acted as the PI for this investigation. He was supported by several members of the ART, as follows:

- Dr. Makarand Hastak, past Post-Doctoral Fellow in CEM/CEE and currently an Assistant Professor in the Department of Civil Engineering at Brooklyn Polytechnic in New York. He participated in the investigation as a full time research associate during the initial phase of the project. He specifically contributed to the definition of the problem, and to the preparation of the funding proposal by RT112. He also managed the work of several of the student research assistants in conducting the general literature review, and collecting data used for identifying and selecting the companies that were studied.
- Dr. Rita Gregory, Assistant Professor in CEM/CEE. She participated actively in several meetings of RT112, and contributed her extensive expertise in cost management resulting from an illustrious career in the Air Force.
- Annie Pearce and Francisco Maldonado-Fortunet, Doctoral Candidates in CEM/CEE. They contributed to the general literature review, and in data collection efforts for the identification and selection of the companies that were studied.
- Banjo Babatunde, Lina Baron, Oscar Herrera, Andrés Pinzón, and Jennifer Werner, M.S. students in CEM/CEE. They contributed to the general literature review, and to the processing of data resulting from the interviews and RT112 meetings.

- Betty Gordon and Lisa Baxter, administrative coordinators in CEE. They provided administrative support to the investigation, including organizing all travel arrangements, and managing all the interfaces with the Business Office.

1.3.3 Acknowledgments

This investigation was possible as a result of the financial support provided by CII, and of the commitment, the active participation, the guidance, and the support provided by the Chair, the industry members of RT112, and the members of the ART to the research effort.

1.4 Companies Studied

As explained in more detail in Chapter 2, one of the objectives of this investigation was to identify and study companies that were perceived to have unique, non-traditional or innovative practices that result in achieving overall company business objectives of their projects at much lower engineering costs (and sometimes even capital costs), and at times, faster schedules than normally experienced in the Construction Industry.

As shown in Figure 1.1, a total, twelve companies agreed to participate in this investigation, including Nucor and three of its selected subcontractors. They are:

- Abbott Laboratories, Abbott Park, IL
- ALCOA, Knoxville, TN
- Allied Signal, Morristown, NJ
- Disney – Reedy Creek Energy Services, Inc., Lake Buena Vista, FL
- Eastman Chemical Company, Kingsport, TN
- Nucor Corporation, Charlotte, NC
 - D&L INC., Pittsburgh, PA

- SMS Concast, Pittsburgh, PA
- H. B. Zachry Company, San Antonio, TX
- Schering-Plough Corporation, Union, NJ
- Texas Instruments Incorporated, Dallas, TX
- Visy Board, Conyers, GA

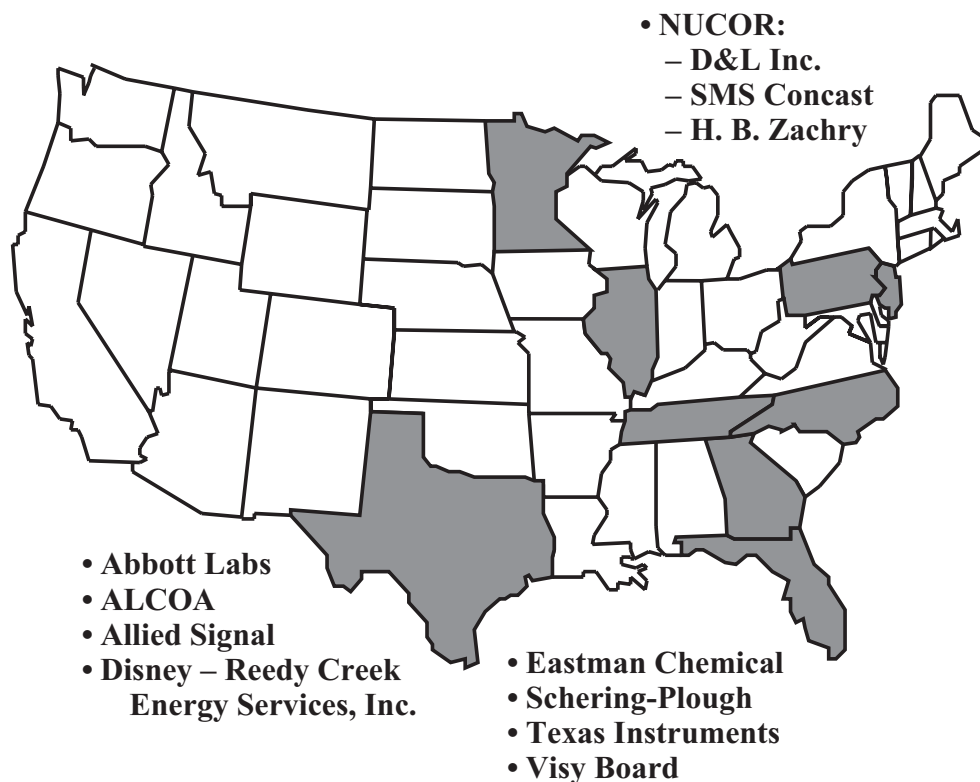


Figure 1.1— Companies Interviewed

On behalf of RT112, the ART, and the CII, the authors of this report want to thank the representatives from these organizations (see Appendix A), for sharing with the PI valuable insights and experiences about different practices within their organization that are used in the delivery of capital projects.

1.5 A Reader's Guide

This report contains six main chapters. Chapter 2 provides an overall description of the different phases and key milestones of the investigation; a discussion of the background and problem statement for the research, and the revised research purpose, objectives, and scope; and a detailed description of the methodology followed in the investigation. Chapter 3 provides an in-depth discussion on the overall context for cost effective engineering, which provides the background for an integrated framework for cost effective engineering in capital projects in the A/E/C industry. This chapter includes a general overview of the context for the delivery of a capital project; a discussion of the life cycle phases, stakeholders, and general context for capital projects; a discussion of the various roles that engineering plays, the importance of engineering, and the engineering costs within this process; and an analysis of various external influences and factors on engineering costs. Chapter 4 presents an overview of the state of the art in cost-effective engineering strategies and practices in the A/E/C industry, resulting from an in-depth examination of existing literature. Chapter 5 focuses on the findings of this investigation. The chapter provides an overview of 20 innovative or non-traditional practices for cost effective engineering identified within the interviews conducted in the twelve companies selected and that agreed to participate in this investigation, and describes in detail 10 practices that form the core of Nucor's approach to capital projects. Chapter 6 contains a summary and the principal conclusions of the investigation, and reflects on possible future extensions to this investigation.

Finally, there are five appendices:

- Appendix A contains the list of companies and people interviewed for this investigation.
- Appendix B contains the initial version of the Data Collection Interview Guide. It contains the complete set of questions developed jointly by RT112 and the ART. Although it resulted too complex to actually be used in the investigation, the guide provides a good synthesis of

the types of questions that were considered by the research team as important contextual issues surrounding innovative practices for cost effective engineering.

- Appendix C contains the final version of the Data Collection Interview Guidelines developed jointly by RT112 and the ART for the interviews conducted as part of this investigation. These guidelines provided a flexible framework for the identification and categorization of innovative practices for cost effective engineering.
- Appendix D contains a specific case study on Nucor.
- Appendix E contains a synthesis of an integrated framework for cost effective engineering in capital projects in the A/E/C industry developed by the principal author of this report, within this and other research efforts funded by the National Science Foundation, the GE Fund, and the Georgia Research Alliance.

CHAPTER 2.– METHODOLOGY

This chapter begins with an overall description of the different phases and key milestones of the investigation. A detailed description of the revised research charter follows, which includes the definition of the background and problem statement for the research, and the revised research purpose, objectives, and scope. The chapter concludes with a discussion on the methodology followed in the investigation, and a synthesis of key issues associated with the research process.

2.1 Chronology of the Investigation

As shown in Figure 2.1, this investigation had several distinct research tasks and four key milestones. As mentioned in Chapter 1, RT112 was officially launched in February, 1994. The first meeting of the team was held in Mobile, Alabama, on March 7, 1994. The team was fully established within two months. After the first meeting, the team met on a regular basis for the complete duration of its life.

During Phase 1, the focus of the RT112's efforts was to understand the problem, define research objectives, scope, and methodology, develop research strategies and a proposed course of action, and prepare the topic and funding proposals. A comprehensive literature review was also launched in this phase. After many discussions, revisions, and unsuccessful attempts, topic and funding approval were finally obtained from the CII Board of Advisors in November, 1994. At this point in time, the original name, purpose, and scope of RT112 were changed to better reflect the expectations of CII for this investigation, as opposed to the broader scope being pursued by the research team. These changes are explained in more detail in Section 2.2.

During Phase 2, the focus of RT112's efforts shifted to the identification and selection of the companies that would be studied within the investigation. Progress in this phase was slow and frustrating as a result of lack of agreement among the research team members about the criteria and methodology to be used in the selection of the companies, and what type of data that was needed. After many discussions, false starts, and efforts wasted by the ART in preparing lists of candidate companies according to a wide range

of metrics, RT112 members finally agreed on a short list of companies listed in Section 1.4 to formally study through direct interviews. These interviews, the analysis of the data collected, and the development of the principal findings of the investigation were conducted during Phase 3.

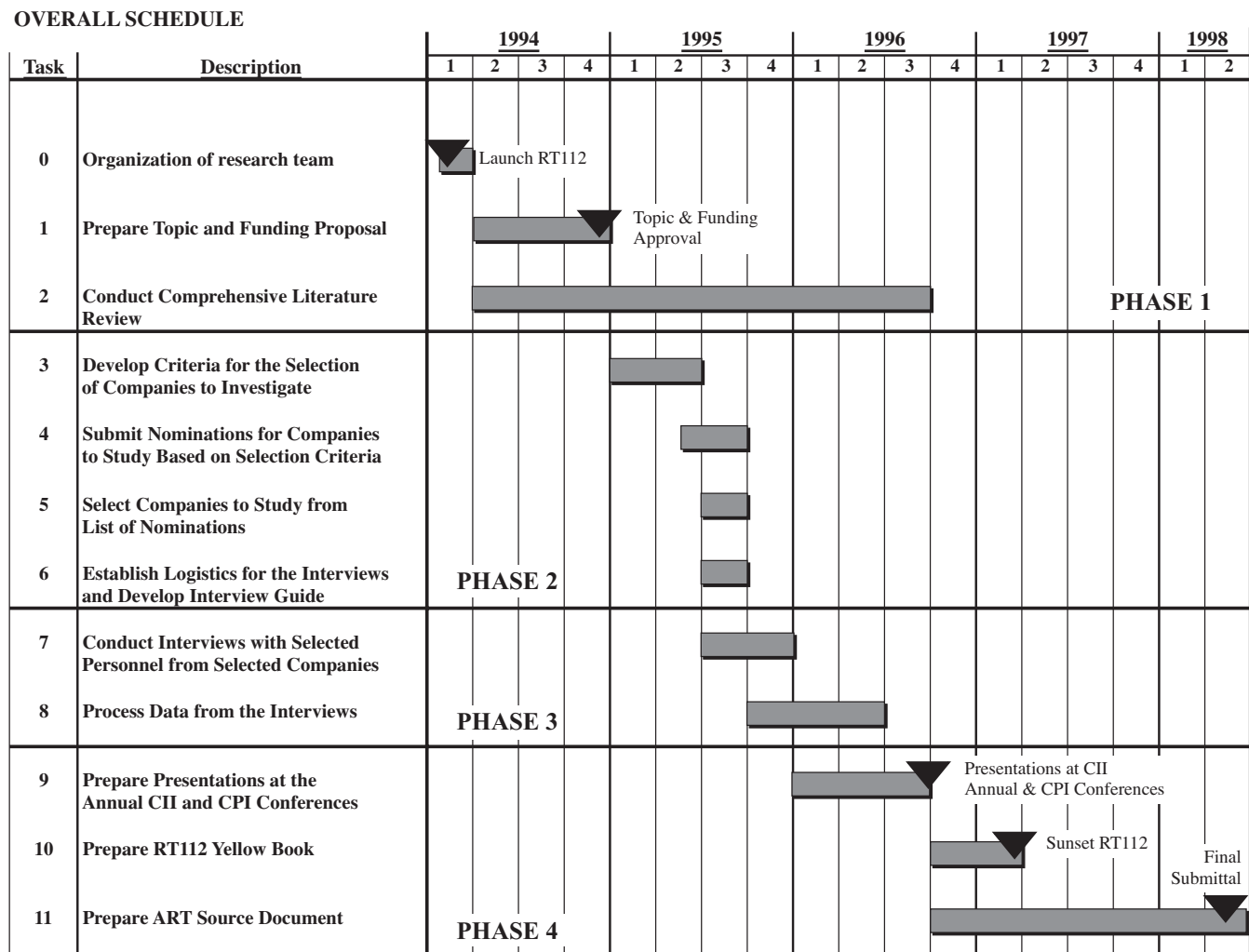


Figure 2.1.– Principal Phases, Tasks, and Milestones of the Investigation

Phase 4 focused on dissemination and reporting activities. The first task was the preparation and delivery of the presentation “2% Engineering – Can It Work For You?” This presentation was given at the CII 1996 Annual Conference held August 6-8, 1996, in Toronto, Ontario, Canada, and at the Seventeenth Annual Construction Project Improvement (CPI) Conference, held September 29-October 1, 1996, in Austin, Texas. The last formal meeting of RT112 was held in Austin during the CPI conference. The second important task in this phase was devoted to the preparation of the yellow book, which contained

the summary of the principal findings of the research team. A final briefing on the experiences of RT112 was given to the CII Research Committee on January 28, 1997, in Houston, Texas. Finally, the last task of the investigation was the preparation of the ART source document. This task extended much longer than originally anticipated as a result of circumstances beyond the control of the principal author of the source document. The investigation formally closed with the final submittal of the source document in May, 1998.

2.2 Revised Charter for the Research Team

The final topic and funding proposal prepared by RT112 during Phase 2 and approved by the CII Board of Advisors established a revised charter for the research team. This charter is explained next.

2.2.1 Background and Problem Statement

There is a wide spread perception among Owners within the construction industry at an industry, corporate and project levels, that current engineering practices are not cost effective from an overall project life cycle and from specific engineering design phase perspectives, and consequently, they offer an opportunity for improvement. This perception is reinforced by limited existing data that supports or refutes it. However, regardless of the factual veracity of this perception, Owners tend to agree that several factors are currently affecting current engineering design practices, and as a result, they may be potentially increasing engineering costs in capital projects. The existence of these factors, which can be grouped into two main categories — external and internal, strongly suggests that there are opportunities for reducing engineering costs that merit further exploration.

External factors affecting engineering design in a capital project include:

- current government regulations, corporate culture, standards, and codes impose constraints on engineering;
- the lack of definition and communication of project scope and objectives to all parties involved in a project affects engineering;

- current project risks and liabilities impose constraints on engineering; and
- current contractual approaches impose constraints on engineering because they do not support project objectives, distribute risks unevenly among the parties involved in the project, create poor working relationships among these parties, and do not promote cost effectiveness and/or efficiency.

Internal factors affecting engineering design in a capital project include:

- the role and culture of engineering is not aligned with the business objective of organizations, and is not well defined among the various parties involved across the different phases of a project;
- although there is no clear definition of the value of engineering, and engineering costs fall within a wide range as a result of the specific nature of projects, there is a general perception that the value-added of engineering is low, and the engineering costs are high; and
- current engineering practices are conducted in too much isolation, are inefficient and take too long, are not enhancing project schedules, are not innovative, are inflexible, creating too much documentation, are using standards and specifications that are outdated and gold-plated, and are not proactive in reaching an understanding of project objectives.

In contrast to the perception described above, some companies have reported unique, non-traditional, or innovative practices that result in achieving overall company business objectives of their projects at much lower engineering and capital costs, and faster schedules than normally experienced in the Construction Industry. A specific example is Nucor with its assertion that it typically completes successful projects with engineering costs below 2% of TIC.

However, before openly embracing innovative practices, there is a need to identify what type of practices exist, and then develop a research-based, objective assessment of them. This would provide factual information upon which companies can make informed decisions about their application to

potentially improve their competitiveness. This need was the main driver behind the establishment of RT112.

Owners and Contractors were initially identified by RT112 as the principal beneficiaries of the results of this investigation. The team considered that the specific value-added of this investigation for Owners and Contractors would be a compilation and objective assessment of non-traditional or innovative practices that would provide them with information that could be used to improve their competitiveness. However, given the different and important roles that engineering plays across all phases of a project (preliminary engineering, engineering design and field engineering), the close relation of engineering with all the other parties involved in or who have an influence or stake on a project (the Owner, Procurement, Construction, Operations and Maintenance personnel), and the focus on cost effectiveness and increased efficiency, all other members of the project team were considered to potentially have something to gain.

2.2.2 Revised Purpose, Specific Objectives, and Scope of the Investigation

As mentioned previously, when the CII Board of Advisors approved the topic and funding proposal submitted by RT112, the original name was changed. Instead of a focus on *“Low Cost Facility Engineering,”* the team was charged with the investigation of *“Innovative Practices for Cost Effective Engineering.”* In addition, the purpose, and scope of the research team also were changed to better reflect CII’s expectations for this investigation (as opposed to the broader scope that the research team initially wanted to pursue). However, the revised purpose, specific objectives, and scope remained consistent with the intent of the one assigned originally.

The revised purpose of this investigation became: *“...to identify, analyze and evaluate non-traditional, innovative project practices with respect to their applicability and associated implications (such as risks, schedule, costs, value, content of engineering deliverables, rework, appropriate projects, company culture, contractual issues, etc.).”* Consequently, the specific research objectives became:

- identify unique, non-traditional, or innovative practices that have contributed to successful projects;

- evaluate the various implications (risk, schedule, costs, value, content of engineering deliverables, rework, appropriate projects, company culture, contractual issues, etc.) of using each practice;
- determine various company drivers which play a role in determining what non-traditional practices to use; and
- develop a matrix to associate, quantify and assess these innovative practices, their implications and their drivers.

These objectives led to a revised scope of the investigation. An in-depth study of Nucor's practices became the focal point of the investigation. A study of one of Nucor's design, one of its construction, and one of its equipment subcontractors, complemented the information provided by Nucor and found in the literature. In addition, eight other companies were studied to identify additional practices for cost effective engineering. Section 1.4 contains the complete list of companies studied in this research. In addition, Appendix A contains the list of people interviewed for this investigation.

Finally, to guide the ART in its research efforts, RT112 established the following specific guidelines for the investigation:

- the investigation should focus on an objective identification and description of specific non-traditional or innovative practices for cost effective engineering within the selected owner organization, both at the corporate and capital project levels (with the exception of Nucor's design, construction, and equipment subcontractors);
- the range of the practices studied could span from global approaches, strategies and mechanisms to competition, partnering/affiances and contracts, to specific project management practices within the different phases of a capital project, as long as they related in some way to cost effective engineering;

- for each practice identified, the ART should document, to the extent possible, specific the context, potential benefits and risks, and implementation requirements for the project or the organization of the practice;
- the nature of the data/information collected in direct interviews with selected personnel involved in the capital project delivery process should be primarily qualitative;
- in the event that quantitative data/information was discussed, the ART should treat such data/information with the appropriate level of confidentiality established by the organization being studied (a standard non-disclosure agreement signed by Georgia Tech was provided, when requested by the company studied);
- the total number of people interviewed and the time allocated for individual interviews within each company selected would be determined at the discretion of the contact person for each company;
- any documents published as a result of this investigation should not associate the names of any company visited or people interviewed with a specific practice unless the company specifically authorized it and all material collected and/or generated as a result of the interviews was submitted to the contact person within the organization for review, comments, and approval prior to its use.

Since some of the companies interviewed requested confidentiality, RT112 decided that for consistency, the final source document and yellow book would not associate any of the practices found with a specific company, with the exception of Nucor, which had agreed to disclosure since it was the focus of the investigation.

2.3 Research Methodology

This investigation was a true collaborative research effort between the industry members of RT112 and the ART. All industry members of the team actively participated in the research process, and

provided guidance and support to the ART as needed. Figure 2.2 shows the overall research roadmap used by the team.

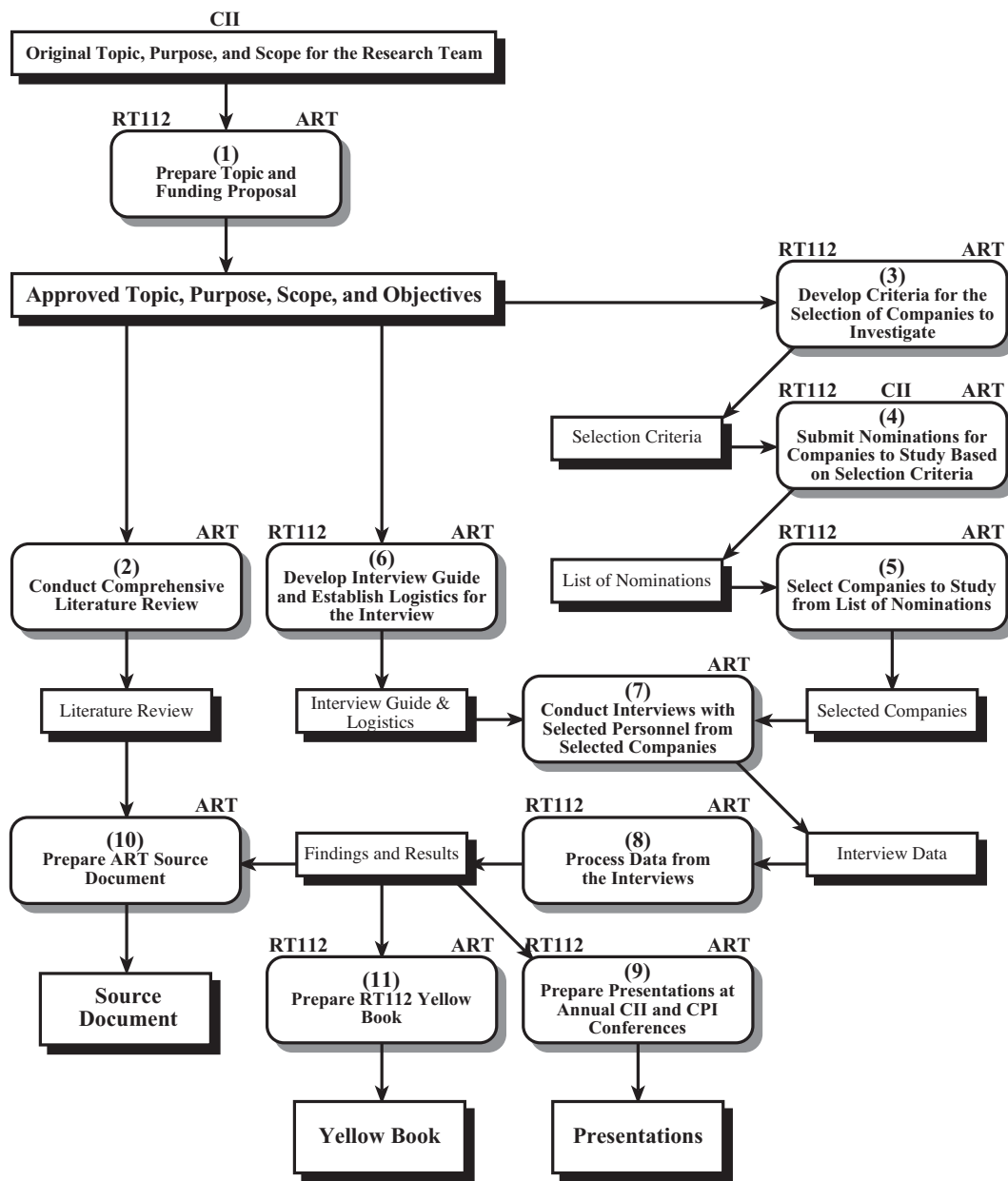


Figure 2.2.– Research Roadmap

The unique driver and nature of the topic pursued in this investigation forced RT112 to define the research typology for the investigation early in the process. After consultation with CII and much internal debate, the team decided that this investigation would be a qualitative assessment of practices identified within Nucor and a select number of owner companies through direct interviews. Consequently, the

most research projects funded by CII, this research is not quantitative-oriented or statistically-based investigation, nor did it produce a clearly-defined “product” or “tool.” Rather, it should be taken as an initial effort towards establishing a solid foundation for the definition of a framework for cost effective engineering in capital projects; an effort that is based on an exploratory study of a selected sample of owner companies in various industries implementing practices that fall outside the conventional approach to capital projects, with Nucor as the starting point.

2.3.1 Topic and Funding Proposal

Preparing the research topic and funding proposal was the first task of RT112. Using the original charter for the team as a starting point, the team struggled over several months to define the problem to address in the research, understand the mission of the team, and identify general areas and specific topics to study. These three challenges are discussed next.

Defining the problem.— When a large group of people (19), from very different organizations including owners, engineering and construction firms, and an academic institution, in very different industries (e.g., chemical, metals, pulp and paper, pharmaceutical), with very different professional backgrounds, and at very different stages of their careers (i.e., early, middle, late), is brought together to investigate a given topic, it should not come as a surprise that the first question asked is: what is the problem?

This may seem like a simple question to answer, specially given the diversity and wide level of experience of the research team members, but the fact is that during (and even after) three years of working together, members of RT112 were able to reach consensus, but never agreement, on what problem the team was supposed to address. One reason is that from the beginning of the investigation, team members had very distinct personal points of view and strong opinions on what the problem was, depending on what type of organization and industry they represented. These are some examples from various team members:

- *“...There is a perception that engineering costs are not optimized on projects, and the cost versus value is not where it should be. Cost effective engineering provides all services and products (and no more) required to meet the project cost, life and process objectives. These deliverables are for all project customers including client facility, the contractor, check out, start up, operations and maintenance...”*
- *“...There is a need to define the level of engineering that an Owner requires for construction, operations and maintenance...”*
- *“....There is a need to eliminate wasteful use of capital in the Design-Engineer-Procure-Construct cycle of industrial projects...”*
- *“...Engineering design decisions are not always linked/aligned with project financial criteria...”*
- *“...There is a need to reduce total installed facility cost without affecting required functionality or reliability...”*
- *“...There is a need to determine the optimum amount of detailed engineering required to build a most economical facility, balancing the cost of engineering effort versus lost field productivity and/or a compromise of facility requirements...”*
- *“...There is a need to develop clearly defined and measurable activities to take place during engineering which will lead to a more efficient design of facilities...”*
- *“...A fabricator has no control over the design of the structures they build. On rare occasions, they are asked to participate in the development of design concepts and joint details, but mostly, they are forced to work with a completed design without prior input...”*
- *“...Design firms are in the business of selling manhours, and of producing a quality product. It may not be in their best interest to be cost effective to their client. However, they should be cost effective to maximize their own profits...”*

- *“...Cost effective engineering connotes a highly communicative environment that involves the client, designer and builder. This team would be established at the start of a project to intensely plan to meet the client’s objectives. This not only results in cost effective engineering, but a lower cost product. This is not done as often as it should...”*
- *“...Facility engineering, although its cost is small compared to the TIC, is one of the critical phases for the successful execution of a project. However, the low cost of engineering coupled with the desire of engineering firms to maximize their profit, has allowed engineering to evolve into a bureaucratic process that produces deliverables with little or no value to the subsequent phases of the project (i.e., procurement and construction phases)...”*
- *“...Long durations for engineering activities have reduced the profitability of major projects...”*

In addition, the research team identified some specific problems within four specific project management activities:

- In the definition of a project, the scope of work is finalized too late in the project. Also, the initial scope of work is determined without accurate construction costs, and the basic concept and scope of work is determined without input from operating people or engineering specialists and without adequate understanding of construction techniques and cost. Finally, Total Quality Management concepts are not used adequately in developing basic project concept designs, which results in less than optimum cost/benefit.
- In developing the project schedule, engineering is performed on a very tight schedule, activities are performed out of sequence, and procurement of material and services takes too long.
- In coordinating the project, projects are increasingly complex and involve many participants, and every owner coordinates his projects in a different way. Also, information formats have changed very little (drawings, bills of material, specifications, etc.). Finally, information is not available on a timely basis.

- In establishing contracting methods, traditional methods tend to create adversarial relationships. Contracting methods should also take into account poor documentation for existing plant and facility, and many scope changes during detail design phase. Finally, they should not preclude early construction input.

Understanding the mission of the team.— The next key question that the members of RT112 asked themselves was: “...so, what is our team’s mission?”

Again, this was an apparently simple question to answer, but since the research team members represented diverse businesses, had different backgrounds, and did not speak necessarily the same language, the process of aligning their individual interpretations of the team’s mission included many seemingly unproductive and long discussions. This left many members of RT112 disheartened, but eventually, they came to realize the need to define a clear common mission.

Some examples of how various team members interpreted the mission of the research team include:

- *“...Optimize engineering for cost effective construction and operations...”*
- *“...Develop a cost effective/best value engineering approach for projects through study and research on capital processes and practices across various industries for the purpose of making U.S. industry more competitive in global markets...”*
- *“...Use Owner, Engineering, Construction, and Vendor knowledge and experience to optimize cost effective engineering...”*
- *“...Reduce facility engineering and construction costs...”*
- *“...Recommend design approaches that positively affect total project economics...”*
- *“...Develop a systematic plan for examining the key elements that make up a completely engineered project, and determine if they are critical to the successful completion of the project...”*

- *“...Evaluate and make recommendation as to means and methods which should be incorporated in to all engineering design efforts which will help produce a more efficiently designed and constructed facility...”*
- *“...Based upon historical data from recent projects and client feedback analyze and summarize design considerations and improvements which would lead to a more cost effective construction phase, and a more user friendly operations phase of a capital project in any industry. (The key here is to analyze what has been done wrong in the engineering phase that has adversely affected the construction/operation phases and to learn from past mistakes.)...”*
- *“...Develop an engineering design process, which enables a 25% reduction in TIC and cycle time of capital projects...”*
- *“...Review the current engineering process, and identify areas where it can be streamlined and made more effective at optimal costs and schedules without compromising quality. The product would be typical engineering deliverables required for the various contracting strategies (i.e. Lump Sum Turnkey, Lump Sum Procurement Build, Lump Sum Construction and Reimbursable Cost Construction)...”*
- *“...Completely study the concept of what cost effective engineering means, and provide the industry with insight as to how to attain it...”*

Identifying the general areas and specific topics to study.— Once a consensus was reached on the problem and the mission of the team, the next key issue that surfaced in the team was: so, what do we study, and how deep do we want to go?

A review of the initial list of general areas and specific topics to study within the investigation proposed by the different members of RT112, reveals a broad and ambitious research agenda that was not feasible with the limited budget and time available for the investigation. However, an important contribution of this agenda is that it highlights the diversity, complexity, and magnitude of problems,

needs, and opportunities that knowledgeable industry practitioners consider are important to pursue to fully address the problem, and which could be addressed by other research efforts.

The general areas and specific topics proposed included the following issues grouped by project phase: planning and contractual environment; engineering; and procurement, construction, and operations. The complete list of topics is shown in Table 2.1.

After several intense meetings, RT112 reached a consensus on the problem, the team's mission, and the topics it would pursue in the research, prepared and submitted a proposal to the CII Board of Advisors, and received approval and notice to proceed in November, 1994. The approved topic, purpose and specific objectives, and scope defined in the proposal, became the cornerstone of the investigation and the starting point for the research roadmap followed by the research team and the ART.

2.3.2 Comprehensive Literature Review

An on-going effort of the ART throughout the investigation was a review of periodicals, journals, and books. The principal results of the literature review are included in Chapter 3. This literature review had four distinct thrusts.

- The investigation began by identifying articles about Nucor on its organization, its managerial and employment practices, and most importantly, its construction procurement and project practices.
- At the same time, during the development of the background and problem statement for the investigation and in support of the preparation of the topic and funding proposal, the ART tried to obtain published information on the principal external and internal factors that currently affect the engineering design in capital projects according to RT112 members (see Section 2.2.1). This information was supposed to provide a solid foundation to quantify the impact of these factors, and thus establish a clear baseline for the investigation.

Table 2.1.– Research Topics Initially Proposed by RT112

Planning and Contractual Environment Topics
• types of projects and their characteristics, e.g., greenfield versus retrofit projects; or classes of plant quality • Owner's role and effect in the capital project delivery process, and its ability to affect cost • Owner's approach to risk, e.g., risk management funding or risk versus lower material equipment costs • alignment of design decisions with business and financial criteria • processes where owner, engineer, and constructor identify opportunities to improve project economics, and continually improve • funding approach • impact of various compensation scenarios on design/cost effectiveness, e.g., lump sum vs. workhour paradigms • use of strategic planning, e.g., project measures/goals; meaningful metrics; • project organization, e.g., early cross functional involvement, teamwork, and communication; home office versus field engineering activities; or outsourcing of selected services • alternative approaches to engineering and construction, the different types of contacts and relationships, and how contract type effects costs, e.g., E/P/C, EP/CM, EPC, Turnkey, Modified turnkey • Owner/Engineer/Constructor roles, relationships, and working atmosphere, e.g., motivational systems; team building sessions at the start of engineering; or integrated contractor/client project task force, with construction managers and plant operations personnel on the task force from the start of engineering • identification and elimination of non-value added activities and waste in capital projects • systems for handling interdisciplinary requirements, issues, coordination, interfaces, and interferences • use of corporate memory, e.g., examination of past projects for typical costs and percentage cost breakdowns, particularly projects with a relatively small percentage of engineering; or data collection from past projects on change order logs, lessons learned" summaries, post construction audits, client surveys after one year of operation • definition of project objectives and scope, e.g., standards and specifications; reliability; duration reduction; front end loading; zero-base deliverables; or scope freeze/change management • evaluation of alternatives, e.g., technology selection; conceptual estimating; optimization and Value Engineering; or innovation • implementation of constructability, operability, and maintainability
Engineering-Related Topics
• definition of the amount of engineering on typical projects devoted to cost control, scheduling, pipe design, civil, structural, power, process controls, material takeoff and purchasing and staff – by percentage of TIC for each category – to allow critical review of where money goes • maximize client/owner input and relationships prior to and during engineering, e.g., design/procurement/operations data; project's design conditions, utilities and scope; sending teams of designers to the jobsite early in the engineering phase to scope the work (especially important on revamp projects); having the owner's representative be a member of the design and construction teams from the start and be resident in the contractor's office to answer questions • strategies for engineering, e.g., design of facilities to use standard materials, building systems, equipment, and methods of construction whenever possible; optimization of constructability, schedule, and material cost through owner, engineer, and constructor involvement in schematic design; use of more cooperative design effort between engineers and material vendors; cost-effective engineering strategies and implementation mechanisms; or development of a project execution summary at the start of engineering which summarizes the scope, procurement strategy, and the construction execution strategy • engineering objectives and scope, e.g., type and amount of engineering currently provided on a typical project; creative ways to provide less expensive engineering and support; amount of engineering purchased from vendors; field engineering and its effectiveness versus home office engineering; construction scope checklists to improve the quality of the construction subcontract scope packages • engineering deliverables, e.g., optimizing engineering deliverables and determining their appropriateness; • engineering standards, e.g., minimum acceptable standards of materials to perform required facility operation/function for each element of the facility • engineering methodologies and processes, e.g., methodologies to eliminate non—value added engineering products/work which can be eliminated or performed by the contractor at reduced cost; use of Value Engineering and constructability throughout the design process; work processes in Facility Engineering and typical work flow diagrams • engineering costs, e.g., effect of engineering costs on TIC; percent of total cost of project currently consumed by engineering and field support; optimizing engineering costs • planning and scheduling of engineering tasks, e.g., system to control changes and to freeze the scope of a project as soon as possible during the design phase; establishing when detail engineering should start • technological support for engineering, e.g., opportunities and pitfalls due to engineering automation and computer-aided engineering; use of 3D CAD; development of models (especially for projects with heavy process); order bulk materials from CADD generated material takeoffs; create of non-violable volumes of space during the CADD design for future walkways, maintenance areas, etc.; finalizing piping specification, vendor dimensional data, and layouts prior to developing the CADD model piping database; or set up a CADD electronic link between the contractor and the client's offices and the field, to review the design and engineering drawings for accuracy and completeness
Procurement, Construction, and Operations Topics
• the effect of procurement on engineering • selection of equipment which have best life cycle costs • use of cost-effective material and methods of construction which may be readily available, accessible, and/or close to the site • optimization methodologies to identify opportunities for construction and operations • what is required in field to ensure compliance to operations requirements • Contractor-supplier alliances

Unfortunately, a lack of agreement or consensus on the metrics within these factors that should be used, combined with a lack of information in the literature on them, prevented the ART from fully achieving this objective. However, this review provided the research team with information that was used in the development of the criteria for the selection of the companies to study.

- Once the topic and funding proposals were approved, the literature review effort shifted towards two objectives:
 - identifying companies in various industries that met the selection criteria established by the research team; and
 - collecting data and information on these companies, as the basis of the evaluation and final selection of the group of companies to be studied in more depth within the investigation.

For this review three main references were consulted: Engineering News Record, Forbes, and BusinessWeek.

- Finally, in parallel with the interview process, the ART conducted a broad review to identify additional specific examples of unique, non-traditional, or innovative practices reported in the literature. Key words used in the literature search included, among others: progressive; innovative; cost effective engineering; low cost engineering; cost drivers; company drivers; leading edge; non-traditional practice; increased efficiency; successful construction practices.

2.3.3 Development of Criteria for the Selection of Companies to Investigate

Another challenge faced by RT112 was the definition of the criteria for the selection of companies to investigate. The initial goal was to develop a systematic quantitative-oriented set of metrics that would serve as the basis of the criteria to use in the selection of the companies to study under this investigation. Unfortunately the problem encountered by the team was, and still remains, a lack of a common set of fundamental operational definitions that apply across the different types of organizations, industries,

and projects. For example, the research team was unable to develop clear unambiguous answers to deceptively simple questions like:

- what are the attributes of a successful company, and what are the parameters or metrics used to measure its success relative to its peer organizations?
- what exactly is included in the TIC of a project from an owner's perspective?
- what is the actual role and scope of engineering in a project across the different phases of the life cycle of a project?
- what entity is responsible for delivering engineering services at the different phases of the life cycle of a project?
- how are engineering costs calculated within each phase and for each responsible entity?
- what does 2% engineering costs as a percentage of TIC really mean?
- what does a cost effective practice mean?
- what are the attributes of a unique, innovative, or non-traditional practice?
- what is the baseline or benchmark against which a unique, innovative, or non-traditional practice should be compared?
- in attempting to establish the cost-effectiveness of a practice, what parameters or metrics should be used?

RT112 did not reach a consensus on any answer to these questions in this investigation. When a team member proposed an answer to any of these questions, either he included a qualifying statement that limited the answer to a specific domain, he was immediately refuted by another member who was looking at the question from a completely different perspective, or a lively discussion ensued.

One example that illustrates this problem is the initial list of metrics for cost effective engineering developed by the research team, as shown in Table 2.2. In trying to understand what each of these metrics meant, establish what they encompass, and determine where and how can actual data on them be found within an organization for a specific project, the ART prepared a special form so each research team member could evaluate each of these 61 metrics from his own perspective, and define the following items for each one so a composite ranking could be developed:

- Priority: High, Medium or Low
- Brief Description: What does this metric measure?
- Rationale: Why is this metric important for cost-effective engineering?
- Methodology: What data sources are available, and how can we collect data for this metric?

After several attempts, RT112 concluded that this was not a feasible nor worthwhile task for many reasons, among others: there were too many variables involved; companies do not have mechanisms in place to collect or access easily some of these types of data or information; companies have their own way of doing things, making hard any comparison across companies; and some of these metrics addressed confidential or sensitive information that companies are not willing to disclose openly.

Consequently, after repeated attempts to develop a fundamental set of operational definitions, common metrics, and a systematic quantitative-oriented research methodology, the team decided to shift directions towards a more qualitative and subjective research methodology, with approval from CII. Consequently, companies to be studied had to meet at least the following two requirements:

- the selected company should be considered a leader or at least successful within its business niche by its peer organizations or industry analysts and observers; and
- the selected company should project a perception or have some indication that they engage in unique, non-traditional, or innovative practices that may lead to lower engineering costs or lower TIC costs at either a corporate or a specific capital project levels.

Table 2.2.– List of Metrics for Cost Effective Engineering

1.	Runability	2.	Availability	3.	Actual Throughput – Design Capacity
4.	Performance Factor	5.	Design Effectiveness	6.	Design Efficiency
7.	NPV	8.	MH/Dwg.	9.	Marketing/Bus. Dev.
10.	Stream Factor	11.	Engineering Costs/MH	12.	% Engineering Costs/TIC
13.	Automation	14.	CADD	15.	Rework Man Hours
16.	Average Number of Drawings Revised	17.	Information Provided vs. Information Needed	18.	Project Duration
19.	Material Acquisition	20.	Schedule Variation	21.	Cost Variance
22.	Scope Growth	23.	Change Management	24.	Change Orders/TIC
25.	% Rework	26.	Front-end Effectiveness	27.	% Engineering Completed at Construction Start
28.	% Engineering Completed at CID	29.	% Engineering Deliverables at CID	30.	Cost of Delivery Delays: Equipment/Materials
31.	Construction Cost	32.	Field Change Orders	33.	Engineering Change Orders
34.	TIC/Major Equipment Costs	35.	Safety	36.	Construction Complaints
37.	Operations Complaints	38.	Maintenance Complaints	39.	RIF's
40.	% TIC for Future Provisions	41.	Facilities, Space, etc. Costs	42.	Legal and "CYA"
43.	Insurance	44.	Number of Drawings with As-Built Revisions	45.	Reproduction
46.	Coordination	47.	Communication	48.	Factor Costs/# Product
49.	Capital Cost/# Product	50.	Procurement	51.	Inspection and Testing
52.	Checking	53.	Expediting	54.	Mgmt. and Admin.
55.	Labor Cost/TIC	56.	P ³	57.	Field Support
58.	Field Engineering	59.	Start-Up and Commissioning: Duration of Project and \$	60.	Customer (Owner) Satisfaction
61.	Employee Motivation				

2.3.4 Nominations for Companies to Study Based on Selection Criteria

The process for identifying companies to study had two distinct phases. In the first, prior to simplifying the selection criteria, the ART attempted to develop a short list of candidates to interview using a quantitative-based approach:

- From Engineering News Record, companies were identified in fourteen categories based on values of their plant, warehouses and other building structures added or improved during the years shown. A list of approximately five companies in each category was compiled.
- Forbes provided a second list of approximately five companies for each category, based on best economic performance using three percentage criteria: five year average return on equity, five year average earnings per share, and five year average sales. Listing was determined by examining the 1995 Forbes' Annual Report on American Industry, and focusing on the companies that quantitatively had the best prospects for growth and profitability.

Finally, a third list of companies for each category was generated using BusinessWeek's Corporate Scoreboard reports for the fourth and first quarters of each year since 1990. Companies were selected based on three criteria: percent growth in profits over 12 months, percent growth in equity over five years, and percent growth in earnings per share over five years. Formulae for these indices are shown in the footnotes of the spreadsheet containing the BusinessWeek list, and were slightly different than those used by Forbes. These measures were selected to reflect each company's success in investing in capital while continuing to grow in the market as well as keeping shareholders happy. In each category, a list was compiled for each year of the companies with the highest ratings for each of the three criteria. After generating an extended list of approximately ten companies per category, a short list was generated which contained no more than five companies per category, based on continued positive trends over the five years examined and absence of significant negative values for any of the indicators.

A multi-objective selection methodology was used to generate a list of candidates with no more than five companies per category for evaluation by the task force members. With the three lists generated from ENR, Forbes and BusinessWeek as contrasting input, a comparison of the top companies from each source was conducted using the other sources, to determine which companies had the highest and most consistent ratings across the three sources. Listing in ENR was a prerequisite for selection of companies not already familiar to the selection team, to ensure that each selected company regularly engaged in capital investment projects. Involvement in construction of new facilities was essential for the study.

since it is capital investment process which is under scrutiny in this research. The team considered each top company individually, and selected the best five in each category based primarily on growth in equity. In the case of conflicting data between sources, the size of investment in built facilities was used as a determinant. Each of the resulting companies was assigned a relative index to place it among the others in the same category, based primarily on percent growth in equity from Forbes. In the final selection, companies were ordered based on this subjective index.

This list of candidates included 64 companies from 13 industries:

- Chemical: Crompton & Knowles; Great Lakes Chemicals; Valspar; Sigma-Aldrich; Loctite; A. Schulman
- Commercial: Wal-Mart; Home Depot; Circuit City; Office Depot; Staples; May Department Stores; J.C. Penney Co.
- Electronics & Computer Hardware: EMC; Silicon Graphics; Hewlett-Packard; Motorola; Texas Instruments
- Entertainment: Walt Disney
- Healthcare: U.S. Healthcare; Stryker; Medtronic; Johnson & Johnson; Becton Dickinson; Health Trust
- Infrastructure: WMX (Waste Management); Montana Power; Pacific Gas & Electric; Duke Power; Enron
- Light Building: Clayton Homes; Pulte; Centex; Lennar; Valspar
- Metals: Nucor; Worthington Industries; Chaparral; Nichols Homeshield; North Star
- Mining: Freeport McMoran; Magma Copper; Phelps Dodge; Corning Inc.; Minnesota Mining & Manufacturing

- Petrochemical: Tosco; Valero Energy; Mitchell Energy & Development
- Pharmaceutical: Amgen; Schering-Plough; Abbott Laboratories; American Home Products; Perrigo; Marion Merrell Dow
- Polymers: Mark IV Industries; Goodyear Tire & Rubber; Aptar Group; Gates
- Pulp and Paper: Bemis; Louisiana-Pacific; Kimberly-Clark Corporation; Minnesota Mining & Manufacturing; Willamette Industries; Scott Paper Company

The ART anticipated several potential threats to the validity of this selection process, including a lack of available data for all companies over each of the five years examined; conflicting and sometimes unintelligible differences between Forbes and BusinessWeek data; and the potential for subjectivity in the generation of the initial lists and subsequent interim listings. However, since each of the companies on the list was rated among the top performers according to industry-accepted evaluations such as those found in ENR, Forbes and BusinessWeek, the final group of selected companies to be included in the study would certainly be among the most progressive and successful companies at the time. In any case, the final decision would rest on a final evaluation done by RT112 members.

The second phase of this research task used a completely different selection methodology, more compatible with the final qualitative and subjective nature of the investigation. First, each member of RT112 was asked to submit and defend their own nominations, based on their own individual knowledge and experience. Second, a request for nominations of companies to study was disseminated widely among CII member companies.

2.3.5 Selection of Companies to Study From List of Nominations

After much discussion, RT112 agreed on a short list of companies that were invited to participate in the study. Only 12 companies accepted the invitation. These companies included owners in the Chemical, Electronics and Computer Hardware, Infrastructure, Metals, Pharmaceutical, and Pulp and Paper industries, and one design, one construction, and one equipment supplier firms.

ALCOA, a company represented in the research team, volunteered to serve as a pilot interview. Nucor, and three of its contractors (a design, a construction, and an equipment supplier firms), were the focal point of the investigation. Of the 64 companies short listed using the first selection methodology, only Texas Instruments, Walt Disney (its Reedy Creek Energy Services, Inc.), Schering-Plough, and Abbott Laboratories accepted the invitation to participate in the study. In addition, from the companies nominated using the second selection methodology, Eastman Chemical Company, Allied Signal and Visy Board accepted the invitation to participate in the study. No selections were made from the responses to the broad request to CII member companies.

2.3.6 Development of Interview Guide and Logistics for the Interviews

The primary sources of data for this investigation were interviews with selected professionals from the companies that accepted to participate in the study. Therefore, a key component of the methodology used, was the interview guide.

The development of the interview guide began with a brainstorming of potential questions by the ART based on articles reviewed from the literature. In addition to general literature on successful business and construction practices which served as a source for questions (Ahlbrandt 1992a, 1992b, 1993), the ART also reviewed existing documents which contained discussions of interviewing techniques and protocols. (Russell 1994) In parallel, the industry members of the research team also generated a list of questions using brainstorming techniques, some of them associated with the list of metrics discussed in Section 2.3.3. The ART combined these three sources of questions into a master list of questions, which was further distilled into a basic set of questions, after review and comment from the research team members.

The first version of the interview guide is contained in Appendix B. The questions are divided into two primary categories:

- External Issues: This category was aimed at collecting data on

- the company’s contractual strategies and project management practices in capital investment projects;
 - its markets, customers, and competition; and
 - its principal suppliers and partnering agreements.
- Internal Issues: This category was aimed at collecting data on
 - the company’s organizational structure, personnel issues (e.g., labor force, labor relations, reward and compensation, and profit sharing), and communication;
 - its operational, product, and process-related practices for safety, quality control, environmental compliance, advanced technology research and development, and technology transfer;
 - its management practices, including corporate culture, management philosophy, approaches to decision making, problem solving, and strategizing, and strategies for performance enhancement; and
 - financial indicators of growth and profit.

To provide an initial pilot testing of this initial interview guide and protocol, and to compile a baseline set of data against which to compare data acquired from the final interviews, three baseline interviews were conducted by research team members within their own companies: Aramco Services, Mobil Research & Development Corporation, and the Bechtel Group, Inc. They used the data collection interview guide and tried to collect the requested data.

The results of this test run led to the conclusion that the guide was too complex to actually be used in an investigation of an actual company. Most of the data requested was not available, could not be found easily, collecting it would require a time-consuming effort, or was too sensitive or confidential. However, from a research perspective, the guide still provides a good synthesis of the types of questions

that were documented by the research team as important contextual issues surrounding innovative practices for cost effective engineering.

Consequently, the ART, jointly with the research team, developed a new version of the data collection interview guide. This new guide provides a higher degree of flexibility to the interview process, and enables the interviewer to customize his/her questions to the specific context of the company studied, and also, adapt and react quickly to new developments as an interview progresses. The final version of the interview guide is contained in Appendix C. It contains five categories of questions:

- General Corporate and Project Contexts: This category was used to document the type of company and types of project(s) studied, and their overall contexts, attributes and characteristics.
- Innovative Practices at the Corporate Level: This category was used to document specific innovative practices at a corporate level of the selected company interviewed, in terms of their attributes and characteristics and their specific context of application.
- Innovative Practices at the Capital Project Level: This category was used to document specific innovative practices at a project level within the selected company interviewed, in terms of their attributes and characteristics and their specific context of application. Further sub-categories included:
 - Competitive Approach, Strategies and Mechanisms
 - Partnering/Alliance Approach, Strategies and Mechanisms
 - Contractual Approaches, Strategies and Mechanisms
 - Project Management Approaches, Strategies and Mechanisms at the pre-planning/ conceptual, design/pre-construction, construction, start-up, and operations phases of a project

- **Innovative Practices within Other Organizations Involved in the Project:** This category was used to document specific innovative practices at a corporate and/or project level within other companies working for or with the selected company interviewed, in terms of their attributes and characteristics and their specific context of application.
- **Other Innovative Practices in the Industry:** This category was used to document additional practices in the industry of potential interest.

To provide an initial pilot testing of this revised interview guide and protocol, another research team member, ALCOA, volunteered to be interviewed by the PI. This interview validated well the new approach on the interview guide. A second pilot was conducted at another research team member, Eastman Chemical Company. The results of this second pilot were very positive and reinforced the flexibility and the “user-friendliness” of the interview guide. In addition, since some innovative practices emerged as a result of the interview, instead of staying as just a pilot, this interview became the first one within the formal data collection process for this investigation.

With the interview guide completed, attention shifted to the logistics of the interview process. Key challenges faced by the PI in this area, included:

- difficulty in identifying, within each company that would be studied, a specific person who would serve as the principal contact and liaison for the interviews;
- substantial amounts of time was wasted playing “telephone tag” while trying to establish telephone contact with all the contact persons once they had been identified;
- difficulty in identifying the proper sample of people to interview within a company, and coordinating their schedules to concentrate the interview process into the minimum possible number of days; and