



RE-ENGINEERING THE EPC PROCESS

by

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The Construction Industry Institute
The University of Texas at Austin

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EXECUTIVE SUMMARY

Reengineering as defined by Hammer and Champy includes a fundamental rethinking and radical redesign of a process to achieve dramatic improvements in performance. Under dramatic consequences, owners and contractors accomplish projects whose short schedules, tight budgets or technical complexity require adoption of extraordinary approaches to design and construction. We have labeled these projects, “crisis” or “exceptional” projects.

Crisis projects and their attendant requirement for unusual project execution strategies, arise for many reasons. Sometimes industrial accidents or acts of God cause damage to crucial manufacturing capacity. In other cases, changes in the economy or international markets cause us to speed a product to market. Often, these crisis projects are completed in record time, with superior quality or within a very low budget. It also is common on crisis project for strategies that are designed to (say) reduce schedule, to have collateral beneficial impacts on the project’s cost or quality. The fundamental question behind this research is:

Since we can achieve exceptional results on crisis projects by using extraordinary methods, what did we do differently to achieve exceptional results, and what can we learn from it.

This project investigated whether the techniques and methods used for special “crisis projects” could be adapted to permanently reengineer the existing EPC process. Fundamentally, this project is about adjusting the EPC paradigm to incorporate the ingenious, resourceful and

innovative approaches that we use on crisis projects to challenge the current approach to EPC projects.

Construction Industry Need

The Construction Industry faces the same competitive pressures and global marketplace issues that have spawned the recent spate of re-engineering in other industries. Increasing competition is forcing the industry to become more efficient and innovative. Owners, E/C contractors, subcontractors and material suppliers will benefit from a successfully reengineered EPC process.

Anticipated Value Added

This research identifies opportunities to improve the efficiency and effectiveness of the Construction Industry. Implementation of the results has the potential to reduce construction schedules, reduce project costs, diminish errors, and dramatically change the nature of the EPC process.

Objectives

The purpose of this research was to redesign and rethink the existing EPC process to:

- (1) Take advantage of existing methods used by owners and contractors in crisis situations.
- (2) Evaluate these methods by incorporating them in existing models of the EPC process.

The specific objectives of this research include:

- (1) To identify “crisis” approaches that can be effectively applied to the EPC process.
- (2) To cooperate with RT 125, Information Management, to validate their EPC model.

Approach

This project consisted of a series of 30 case studies of “crisis” projects. The goal of the case study analysis was to identify extraordinary approaches that are used by owner and contractor firms that achieved extraordinary results. Specifically, the cases studies:

- Identify the exceptional techniques or methods used on “crisis” projects,
- Assess whether the intended special project goals were achieved (shorter schedule, reduced rework, enhanced market penetration, etc.),
- Identify extraordinary good consequences of the techniques used (lower cost, better owner relationships, etc.),
- Identify unexpected “bad” consequences of the technique used (lower quality, more owner risk, increase disputes, etc.); and,
- Identify the principles of reengineering and how they should/can be applied to the EPC process.

Analysis of the case study data indicates that re-engineering processes produces significant reduction in originally projected project duration and cost. These reductions were achieved with no negative effects on safety and quality. Schedule reductions ranged from 12% to 85%. For example, one crisis project was completed in only 15% of the time (2 months) that a non-crisis project would require (13 months)! The cost impact associated with the schedule

reduction generally ranged from -40% to 52%. More significantly, 50% of all case studies demonstrated a DECREASE in cost with an associated DECREASE in schedule

Project safety performance included analysis of first aid cases, OSHA recordable incidents, and lost time accidents. The available data indicate that safety was not compromised on the case study projects. In fact, safety awareness during crisis project management is heightened to the extent that safety performance was generally excellent.

Owners associated with the case studies provided information on project quality. Quality data was collected for ease of startup, initial downtime, capacity, and maintainability. Quality on crisis projects was not compromised.

Although this research report does not provide a re-engineered EPC Process it does provide compelling evidence that fundamental changes can occur with dramatic results and delivers guidance for organizational re-engineering efforts.

Investigating crisis projects, our mission was to identify and investigate work process changes and their impact on cost and schedule, determine their sustainability, and offer guidance to organizations for implementing process level re-engineering efforts.

Our results illustrate that changing work processes and providing appropriate cultural environments can result in up to significant schedule reduction with no additional costs.

RT 124 is excited to offer valuable information to motivate and assist you in re-designing your work processes.

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CHAPTER 1

Introduction

1.1 Purpose

With increasing frequency, owners are demanding that the construction industry deliver projects within shorter and shorter time frames. Never did the old adage, "Time is money" ring truer than it does to today's owners and developers. Whether a computer chip manufacturer is pushing to get the next generation of chips to market (Tulacz and Daniels 1995), or a fire has ravaged a textile mill and interrupted specialty carpet production (Strassman 1995), every day of lost production results in significant lost profits for the owner. With the potential for huge business interruption losses and the possible erosion of a client base, corporate tends to demand the seemingly unachievable on crisis projects - a reduction in the overall duration of the EPC (engineering, procurement, and construction) process by 50% to 75%.

Attaining that level of schedule reduction necessitates not just fast-tracking, but "flash-tracking" (Fisher 1996). Although owners' demands may seem unreasonable, those companies that can respond will gain a distinct competitive advantage over their brethren. In fact, several proactive companies have found ways to meet incredible schedule constraints without jeopardizing worker safety during construction or sacrificing functionality of the completed facility. They have met those demands by challenging old assumptions associated with traditional project delivery procedures.

The procurement and administrative functions associated with the EPC process seem particularly ripe for "rethinking." In fact, many of the administrative procedures followed by owners and EPC contractors were adopted to mitigate perceived risks and may not be absolute necessities. For example, numerous formal design reviews are routinely performed, but the reviews probably provide only slight increases in design effectiveness or functionality. During the procurement phase, contracting authority is often held close to the home office to minimize improprieties. Hammer and Champy explored these type of process evaluations in conjunction with the manufacturing and service sector (1993). They coined the term "reengineering" and defined it as the "fundamental rethinking and radical redesign of a process to achieve dramatic improvements in performance." Reconsidering whether the many checks and balances within the traditional EPC process offset sufficient risk at the expense of time certainly falls within the purview of reengineering. With time such a critical factor in crisis projects, there appears to be adequate justification for "breaking the rules" and only doing what is absolutely necessary to complete the project.

With owners demanding dramatic improvements in performance (most notably schedule compression), and the availability of reengineering approaches for other business sectors, how can a construction firm change their traditional EPC process to attain a competitive advantage? What are the cost, safety, and quality impacts of delivering projects expeditiously? Can these changes be implemented on projects not precipitated by a crisis to deliver projects faster and realize increased profits for owners? The purpose of the research summarized by this report explores "crisis-driven reengineering" and the potential application of EPC process changes to both crisis and traditional projects.

1.2 General Research Approach

The research was conducted by a team of 17 industry professionals and three academics. The team first did an evaluation of specific projects selected as candidates for detailed case studies. Preliminary findings from the case study data were used to develop a questionnaire, which was sent out to each of the Construction Industry Institute (CII) member companies.

Initially, fifteen projects were selected as case studies for in-depth analyses. To qualify as a case study, each project had to meet the following criteria:

- The project was completed by one of the CII companies represented on the research team.
- The project was driven by a crisis, such as a fire, explosion, natural disaster, or market condition, that mandated a significant reduction in the EPC duration.
- The project was successfully delivered within a significantly abbreviated schedule compared to the industry norm.
- Schedule and cost data could be made available for review, and several project participants were available for personal interviews.

Specifics of the projects were obtained through a multi-step data collection process, which included an initial and supplemental questionnaire, a prioritization survey, and face-to-face interviews with project participants. The purpose of the data acquisition was five-fold:

1. To identify changes to the EPC process, as well as specific techniques, that enabled schedule reduction;
2. To evaluate the relative success of implementing those changes and techniques;
3. To estimate the aggregate cost implications of schedule-focused decisions;
4. To identify other positive and negative consequences of changing the traditional EPC process; and

5. To gather opinions on the potential use of schedule reduction techniques on future projects.

This data was analyzed using both a "macro" and "micro" approach. In the macro review, the researchers evaluated the combined effectiveness of implementing both proven and unproven process strategies on schedule reduction and its associated cost impact. To determine the schedule and cost parameters, the actual project was compared to a baseline project. The baseline project was defined as a project of similar scope to the actual project that was completed using traditional EPC methods. Since "traditional" approaches vary from company to company, "traditional" was defined as company-specific procedures that are followed on non-crisis driven, cost-sensitive projects.

The micro analysis involved the classification and prioritization of the various EPC processes, methods, and techniques that were implemented to reduce the duration of the overall schedule. The purpose of this analysis was to identify specific approaches that were most effective across multiple case studies, and to extract trends of effectiveness based on classification of the approaches.

Although the initial analyses suggested several trends and commonalities across case studies, additional data was deemed necessary to validate those findings. Consequently, a questionnaire was developed for Phase II data collection and disseminated to each of the CII member companies. The questionnaire surveyed 15 additional crisis-driven projects that were completed over a shorter-than-average duration. The combined analysis of the case study data and the questionnaire data (30 projects) form the basis of the conclusions presented in this report.

1.1 Report Format

The report is comprised of five chapters, including the Introduction. Chapter 2 discusses the research methodology in detail, both data collection and analysis. Chapter 3 describes the results of the analyses. Chapter 4 addresses the potential sustainability of the various approaches to both crisis and traditional projects. Conclusions are presented in Chapter 5, followed by references and appendices.

CHAPTER 2

Methodology

2.1 Case Study Profile

The 15 case studies and 15 questionnaire studies used in this research represent a broad range of EPC projects. Figures 2.1 and 2.2 below demonstrate the facility type and crisis driver for the case studies. Figure 1 shows a large amount of the data set (32%) represented refinery projects. This is consistent with CII member organizations supplying case studies. The research team anticipated a higher percentage of refinery related projects. The variety of projects types represented demonstrates that re-engineering is not limited to a particular type facility.

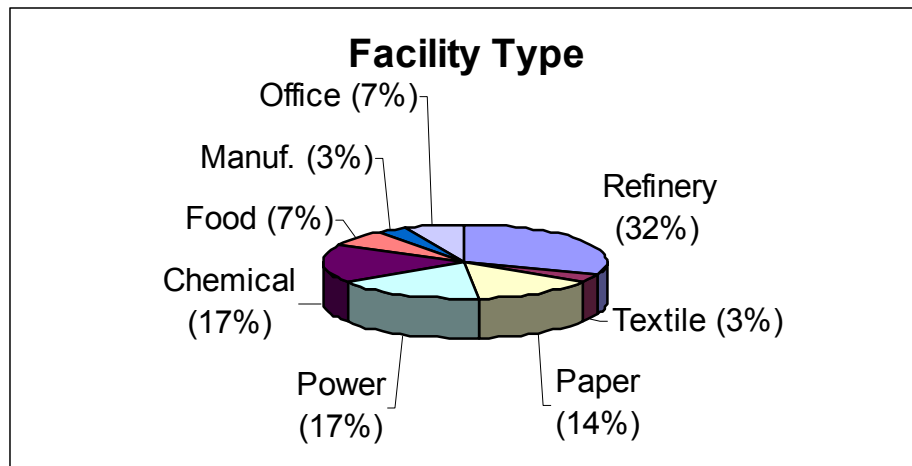


Figure 2.1 Case Study Facility Type

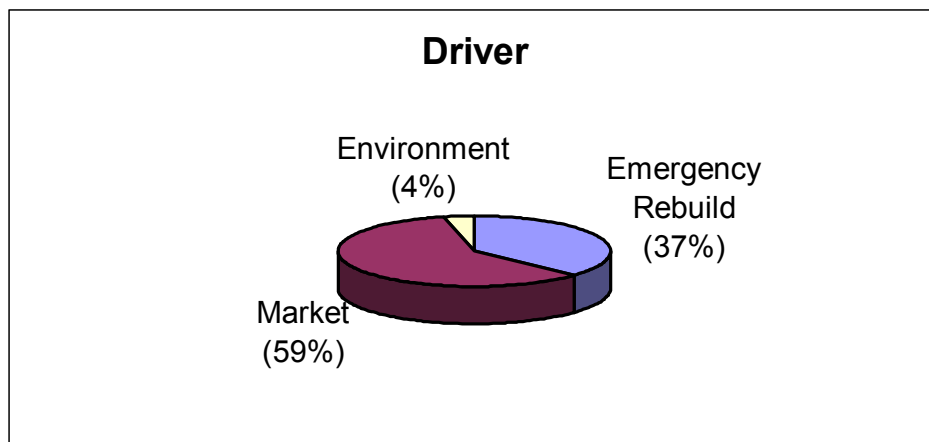


Figure 2.2 Case Study Drivers

Figure 2.2 illustrates the primary drivers which created exceptional or crisis projects. Drivers are the impetus which led organizations to change from traditional project processes. Note the primary drivers for initiating dramatic changes in processes were market factors and rebuilds caused by catastrophic events such as fire.

2.2 Project Selection

All of the 30 projects came from the industrial sector and were precipitated by a crisis. In each case, the owner made it perfectly clear that schedule was the first priority (although never at the expense of safety), and cost was a secondary consideration. (Some of the projects involved a lump sum contract for construction, so cost was still a consideration for the constructor). The degree of project acceleration varied, but in all cases the owner established a schedule that was indisputably shorter than if the project had been done in a more cost-sensitive manner. An additional project, constructed by a firm not represented on the research team, was selected because it offered outstanding examples of schedule reduction methods. Table 2.1 provides a list of the 30 projects, sectors, and drivers.

Table 2.1 General Case Study Facts

STUDY NO. (CS-)	TYPE OF FACILITY	REBUILD, ADD-ON, REHAB, NEW	CRISIS DRIVER	STUDY NO. (CS-)	TYPE OF FACILITY	REBUILD, ADD-ON, REHAB, NEW	CRISIS DRIVER
CS-1	refinery	rebuild	fire	CS-16	food proc	new	market
CS-2	power	rebuild	fire	CS-17	gas	rework	fire
CS-3	textile	rebuild	fire	CS-18	chemical	rework	market
CS-4	paper	mixed	market	CS-19	oil drilling	greenfield	market
CS-5	refinery	add-on	environ.	CS-20	refinery	greenfield	market
CS-6	refinery	rebuild	fire	CS-21	refinery	rework	market
CS-7	power	rehab	market	CS-22	paper	rework	market
CS-8	refinery	mixed	market	CS-23	manuf.	greenfield	market
CS-9	chemical	new	market	CS-24	office	greenfield	market
CS-10	chemical	unknown	unkown	CS-25	power	rework	fire
CS-11	refinery	rebuild	fire	CS-26	power	rework	fire
CS-12	paper	unknown	unknown	CS-27	chemical	rework	market
CS-13	chemical	rebuild	fire	CS-28	paper	unknown	market
CS-14	power	rehab	market	CS-29	office	greenfield	market
CS-15	food proc	rehab	market	CS-30	chemical	combo	market

2.3 Data Collection

The process of data collection consisted of a data collection guide, supplemental surveys, ranking surveys, and drill down interviews.

2.3.1 Data Collection Guide

The researchers developed the Data Collection Guide for Exceptional and Traditional Projects (DCG, Appendix A). The DCG is a questionnaire comprised of three sections: Project

Description, Project Outcomes, and Changes. Section I solicits general project information, Section II requests data on the impacts of deviating from the traditional EPC model, and Section III asks the responder to identify and discuss those deviations.

Besides general information such as project name, location, and construction sector, Section I asks the responder to provide broad schedule and cost data. In addition, there is space for the responder to describe the crisis that precipitated the project. Section II requests two sets of comparative data on various cost, schedule, quality and safety. The first set represents the measures associated with the exceptional (crisis) project selected for the case study. The second set involves data for a traditional project to establish baseline measures against which the exceptional project can be compared. Along with the request for two data sets, Section II solicits descriptions of the various methods of measurement represented by the raw data.

In Section II, data was to be provided by both the EPC contractor and the owner, depending on the measure. The contractor provided data on:

- Engineering productivity
- Construction productivity
- Procurement
- Rework
- EPC cost
- Safety
- Planning schedule
- Design schedule
- Construction schedule
- Contract strategy

- Incentives, and
- Claims

Owners were asked to provide data on:

- Initial downtime
- Capacity
- Ease of start-up
- Maintainability
- Owner's cost, and
- Client organization

The responder was required to follow a formal procedure to collect data for each of the categories. For example, the contractor would complete the "Safety" category by first defining a measure by which the company tracks safety performance, such as lost-time accidents. Next, the contractor would note the accident rate for the exceptional project selected for the case study. Finally, the contractor would note the "average" accident rate for similar projects completed in the traditional manner. Contractors queried their historical data bases to gather information on traditional projects.

Section III asked the responders to identify all the specific changes to the traditional EPC process that enabled the exceptional project to be completed so expeditiously. The responders were free to consider various areas where change occurred, including information technology tools, contract strategy, management strategy, resource (labor and equipment) utilization, activity sequencing, elimination or reduction of administrative procedures, and project documentation.

For example, "establishing a design office adjacent to the construction site" was a typical change. For each of those changes, the DCG asks standard questions to allow the responder to adequately describe the change, its impacts on the project, and its sustainability. Sustainability was defined as the potential for implementing a particular EPC process change on future projects to facilitate schedule reduction, and under what conditions.

In summary, the DCG solicited general project information, changes to the traditional EPC process that enabled a reduction in schedule, and the impacts of those changes on the project. The guide proved challenging for many of the project participants who were asked to fill it out. As a result, most of the guides were returned only partially completed. In some cases, project summary books or "Lessons Learned" documents were returned with the DCG to provide additional raw data. Only slightly discouraged, the researchers proceeded with the next step of Phase I data collection, the supplemental questionnaire.

2.3.2 Supplemental Survey

Upon receipt of the completed DCG, a memorandum was sent to the research member championing the collection of data for each specific case study. The generic version of the memo (Appendix B) was edited for each study in response to the quantity and quality of data that was contained within the DCG. In addition to clarifying cost and schedule data outlined in the DCG, the memo requested information on several key issues. First, the memo sought to extract details concerning the use of additional human resources throughout the project. In other words, were multiple shifts used, how long was the work week, and were crews oversized? Manhour graphs were requested for both the case study project and a traditional project of similar scope. When applicable, the memo also asked for the costs associated with establishing a design office

adjacent to the construction site and expediting equipment/materials to the site. General questions also inquired about procurement procedures, contractor involvement during design, and start-up procedures.

Lastly, the memo verified that all the critical changes to the EPC process had been identified. Participants in the exceptional project were asked to review and amend a list of EPC changes that were attached to the memo.

2.3.3 Ranking Survey

To establish the relative effectiveness of the various EPC changes on schedule reduction, a Ranking Survey was developed (Appendix C). Up to four people involved in the project were asked to complete the survey. To develop a project-specific survey, the researchers compiled a complete list of the EPC changes for each project; these lists varied in length from 9 to 59 changes. Next, the changes were classified into two mutually exclusive categories, quantifiable and nonquantifiable changes. A quantifiable change is one in which the schedule impact could be reasonably estimated or measured. For example, sole-sourcing a purchase to a preferred vendor may reduce the procurement cycle for a major piece of equipment by four weeks. The estimate is based on the average duration of that activity on a traditional project compared to the duration of that activity on the case study project. Nonquantifiable changes can be equally important to reducing the overall project duration, but their individual contribution is impossible to measure. Utilizing experienced project managers and establishing a "team" environment are two examples of nonquantifiable changes.

The quantifiable changes were randomly listed on the first page of the survey, while the nonquantifiable changes were listed on the second page. If there were more than ten changes in a

category, those people surveyed were given specific instructions to review the entire list of changes in each category and select the top ten changes based on their relative effectiveness in reducing the overall duration of the project. The ranking survey solicited the following detailed information:

Ranking Survey for Quantifiable Changes

- (a) Item No.: The number assigned to the EPC Change
- (b) EPC Change: Description of the EPC change (To reiterate, columns (a) and (b) were filled out by an academic, except when there were more than ten changes in each category)
- (c) Affected Critical Path Activity? (Y or N): "Y" indicated the change affected a critical path activity (ies), and "N" indicated the change affected a non-critical path activity. (Those changes that have a direct impact on critical path activities will have a direct impact on the duration of the overall schedule)
- (d) Relative Direct Schedule Impact (1-n): The changes were ranked from "1", most effective in reducing the overall project duration, to "n" (usually 10), least effective in reducing project duration. (This is the most important part of the survey)
- (e) Relative Direct Cost Impact (1-n): The changes were ranked from "1", largest net impact on project cost, to "n" (usually 10) least impact on cost.
- (f) Actual CP Schedule Impact (days): The actual reduction in the duration of the project solely attributable to the single EPC change.
- (g) Actual Cost Impact (+ or - Dollars): The magnitude of the cost increase or decrease of the project attributable to the change.

(h) Relative CP Schedule Impact (%): The relative schedule impact, in percent, associated with each change. The combined impact of all the changes is 100%.

(i) Relative Cost Impact (%): The relative cost impact, in percent, associated with each change. The combined impact of all the changes is 100%.

(j) Other Impacts: Other impacts, besides cost and schedule.

Ranking Survey for Nonquantifiable Changes

(a) Item No.: The number assigned to the EPC Change

(a) EPC Change: Description of the EPC change

(b) Relative Direct Schedule Impact (1-n): The changes were ranked from "1", most effective in reducing the overall project duration, to "n" (usually 10), least effective in reducing project duration.

(c) Relative Direct Cost Impact (1-n): The changes were ranked from "1", largest net impact on project cost, to "n" (usually 10) least impact on cost.

(d) Other Impacts: Other impacts, besides cost and schedule.

To summarize, the purpose of the Ranking Survey was to rank the deviations from the traditional EPC process in order of their effectiveness in reducing the project duration. Two separate rankings resulted, one for quantifiable changes and one for nonquantifiable changes. In addition, the survey solicited comparative schedule and cost effectiveness of the various changes. For example, is the No. 1 ranked change twice as effective as the No. 2 ranked change? Did the change that was most effective in reducing the schedule carry the largest cost premium?

2.3.4 Drill Down Interviews

The final step of data collection consisted of face-to-face interviews between one of the researchers and project participants. The personal interviews were referred to as "drill down interviews," since the purpose was to drill down into each critical change for increasing levels of detail. An agenda with enclosures (Appendix D) was sent to the research team member for dissemination to the project participants prior to the meeting. The first enclosure consisted of two tables which summarized the results of the Ranking Survey. The second enclosure consisted of a list of ten questions titled "General Drill Down Questionnaire." The third enclosure to the drill down interview agenda was a list of specific questions pertaining to the most important deviations from the traditional EPC process. The last enclosure was a copy of the precedence diagram that was simultaneously under development by CII's research team No. 125.

Drill down interviews varied in length from four to twelve hours. In most cases, representatives from both the owner and the EPC contractor were present at the meeting. The first order of business was to review the status of data collection for that case study, and gather any missing information. Next, the table listing the most critical quantifiable EPC changes was used to discuss the top ten most effective hard changes in regard to schedule reduction. For each change, the ten questions on the General Drill Down Questionnaire were addressed. These questions forced the interviewees to explain how the particular change represented a deviation from the traditional EPC approach, whether it eliminated steps (e.g., preparing a bid package once design was complete), if sequencing of activities was altered, what cost premium was associated with the change, if other impacts could be attributed to the change (e.g., rework), and the sustainability of the change. The RT125 precedence diagram was used, when appropriate, to

help explain the "traditional" approach to a project in comparison to the way a sequence of activities was performed in the crisis project.

The drill down interviews provided detailed information concerning the most important hard changes that enabled schedule reduction. Critical soft changes, those necessary to implement the hard changes, were also discussed. The formal data collection process was supplemented by the review of project books, "Lessons Learned" documents, and independent reports that were available.

2.4 Data Analysis

Data analysis was divided into two primary arenas, the macro evaluation and the micro evaluation. The purpose of the macro approach was to determine the aggregate schedule reduction and the corresponding cost premium associated with each case study. Once these parameters were identified for each case study, the results could be presented on a single graph to estimate a "best fit" relationship between schedule reduction and cost premium on crisis-driven projects. The global impact of schedule reduction measures on safety and quality were also considered. The micro analysis consisted of identifying critical changes in each project that were most effective in reducing the schedule, classifying the changes by several criteria, and seeking threads of commonality across all the case studies for both specific changes and classification trends.

2.4.1 Macro Analysis

Actual schedule and cost data associated with each case study project were documented on a project summary table (Appendix F). The data were classified into the three primary phases

$$\text{Schedule fraction(\%)} = \text{Case study duration} / \text{Traditional project duration} \times 100\%$$

of the EPC process: engineering (conceptual and detailed), procurement (permanent materials and equipment), and construction/startup. Next, schedule and cost data for a traditional project (the baseline project with similar scope but accomplished without the crisis-driven changes) were documented for each EPC phase. In terms of schedule, the actual duration of each phase of the exceptional case study project was compared to the estimated duration of the traditional project phases. The schedule fraction was calculated for each phase as follows:

A schedule fraction less than 100% indicates that the case study project had a shorter duration than would be expected under non-crisis conditions. Schedule reduction can be calculated from schedule fraction.

$$\text{Schedule reduction(\%)} = 100\% - \text{Schedule fraction(\%)}$$

Cost ratio was similarly calculated, by phase, as follows:

$$\text{Cost ratio(\%)} = \text{Case study project cost} / \text{Traditional project cost} \times 100\%$$

A cost ratio greater than 100% indicates that the case study project cost the owner more than would be expected under non-crisis conditions. The difference between the estimated cost of a traditionally delivered project and the actual cost of the case study project is defined as the cost premium, expressed either in dollars or as a percent. Cost figures represent payment made

by the owner to the EPC contractor (or engineer and constructor separately) and do not include the owner's internal costs.

2.4.2 Micro Analysis

2.4.2.1 Classification of EPC Changes

The first step in the micro analysis was to compile a list of the changes to the traditional EPC process that enabled the project to be completed quickly. Each change was then classified by three different criteria: phase, type, and quantifiability.

The following five phase classifications were selected to mirror the phases of the RT125 EPC process model (Back 1996):

- Preproject planning (PPP)
- Engineering/Design (D)
- Materials management and procurement (MM)
- Construction (C)
- Start-up and commissioning (SU)

Table 2.2 summarizes the classification criteria by phase.

Table 2.2 RT124 Classification Codes Summary

1. EPC Phase		Code
a. Preproject Planning		PPP
- Business Plan - Process Technical Plan - Facility Scope Definition - Project Execution Plan - Contract Strategy - Organization of Players - Project Management - Labor Strategy (e.g. union contracts) - Motivational Strategies (e.g. incentives, awards)		
b. Design		D
- Finalize Scope - Detailed Cost Estimate - Detailed Design - Prepare Work Packages		
c. Materials Management		MM
- Bulk Commodities - Fabricated Items - Standard Engineered Equipment - Specialty Engineered Equipment - Services (subcontracts) - Documentation - Field Equipment Management - Materials and Equipment Procurement		
d. Construction		C
- Pework - Execution		
e. Start-Up		SU
- Start Up Plan - Commissioning - Project Close-out		
2. Resource Classification of EPC Change		
- Resource		R
- Nonresource		NR
3. Quantifiable Classification of EPC Change		
- Quantifiable		Q
- Nonquantifiable		NQ
4. Impacts	Measures	
- Cost	Dollars	
- Time	Weeks	
- Quality	Startup, downtime, capacity, maintainability	

The "type" of change describes whether the change affected the quantity or quality of human resources used on the project. Quality factors include the ability of individuals to make decisions, such as empowerment and teaming. The changes were classified as resource changes or non-resource changes. Resource changes include:

- Significant craft overtime,
- Multiple shifts,
- Saturating the site with craftsmen,
- Increasing expediting efforts,
- Use of experienced project managers,
- Increasing the authority of field-level employees,
- Decreasing absenteeism and increasing productivity through incentive programs,
- Relieving project participants from other responsibilities.

Resource changes were identified because they tend to directly increase the cost of completing a process, whereas non-resource changes may not.

Finally, changes were classified by quantifiability. Quantifiable changes were defined as those whose schedule impact could be reasonably estimated. For example, doubling a crew size might reduce the duration of a critical path activity by 50%; this change would be considered quantifiable. Conversely, the impact of a nonquantifiable change can not be ascertained with any degree of accuracy. For example, a firm commitment by the owner to pay for all services certainly enables the constructor to make decisions primarily based on schedule impact, but assigning a discrete time savings of (say) two weeks is impossible. Table 2.3 was developed to facilitate the classification process.

Table 2.3 EPC Changes

ITEM	EPC CHANGE	PHASE(a)	TYPE(a)	QUANTI- FIABILITY(a)
------	------------	----------	---------	-------------------------

1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Note: See RT124 Classification Codes Summary for classification definitions.

2.4.2.2 Trends by Number of Changes

Next, the changes were sorted three different times to group changes by their common characteristics. A graph was developed for each case study to illustrate the distribution of the number of changes across the five EPC phases. Graphs were also prepared to compare the distribution of resource and quantifiability classifications across all sixteen case studies. Although these distribution graphs indicated some interesting trends based on the number of

changes to the traditional EPC process, they did not illustrate the effectiveness of the various type of changes. The results of the Ranking Survey were necessary to address effectiveness.

2.4.2.3 Comparative Effectiveness of EPC Changes

For each project studied, the ranking survey produced two sets of critical changes to the EPC process, a set of quantifiable changes and a set of nonquantifiable changes. Each change had been ranked by project participants in order of effectiveness in reducing the overall project duration. The researchers sorted the changes by rank order and matched the changes to classification codes. The first four columns of Table 2.4 were used to record the results. Nonquantifiable changes were sorted and recorded in the same manner in Table 2.5. To address the effectiveness of the various quantifiable changes, Table 2.4 includes four additional columns not contained in Table 2.5.

Column (e) of Table 2.4, titled "Schedule Impact," represents how effectively each critical hard change reduced the duration of the project. Ideally, there were ten such changes, and an allowance was made for the contribution of those changes not in the top ten. The total impact equals 100%. As rank order increased from one (most effective) to ten (least effective), the percent effectiveness assigned to the change progressively decreased. The allocation of schedule impact was extracted from column "h" of the Ranking Survey. When the schedule impact was not noted in the ranking survey, a nonlinear distribution was assumed.

The estimated schedule impact of each critical change (column "f", Table 2.4) was calculated by multiplying the percent impact in column "e" by the total schedule reduction.

Table 2.4 Most Critical Quantifiable EPC Changes

MOST CRITICAL QUANTIFIABLE EPC CHANGES							
CII RT 124, CS-							
EPC CHANGE (a)	EPC PHASE (b)	RESOURCE OR NON-RESOURCE (c)	SCHEDULE IMPACT RANK (d)	SCHEDULE IMPACT (% of total impact) (e)	ESTIMATED SCHEDULE IMPACT (weeks) (f)	SCHEDULE REDUCTION (% of trad proj. dur) (g)	CONTRACT PRICE IMPACT (+/-, %) (h)
			1				
			2				
			3				
			4				
			5				
			6				
			7				
			8				
			9				
			10				
Other							
Total				100			

Table 2.5 Most Critical Nonquantifiable EPC Changes

MOST CRITICAL NONQUANTIFIABLE EPC CHANGES				
CII RT 124, CS-				
EPC CHANGE	EPC PHASE	RESOURCE OR NON-RESOURCE	SCHEDULE IMPACT RANK	OTHER IMPACTS
			1	
			2	
			3	
			4	
			5	
			6	

Estimated scehdule impact in weeks was taken from the project summary table (Appendix F). Schedule reduction attributable to each change (column "g", Table 2.4) was calculated as

$$\text{Schedule`reduction (\%)} = \text{Estimated schedule impact (weeks)}/\text{Traditional`proj. duration(weeks)} \times 100\%$$

follows:

Finally, the net cost impact attributable to each change was noted in the last column of Table 2.4.

Once Table 2.4 and 2.5 were completed for each case study, all the necessary data were compiled and organized to evaluate the effectiveness of the critical hard changes based on various classifications. Graphs were generated for each case study to show the phase in which the most schedule impact was generated. To develop the first graph for a particular project, all the preproject planning changes were selected from Table 2.4, along with their corresponding schedule reduction value (percent of traditional project duration as report in column "g" of Table 2.4). The sum of these values represented the schedule reduction, as a percent of a traditional project duration, associated with the planning phase. This calculation was done for all five EPC phases, and the results were plotted on bar graphs. A similar exercise was conducted for nonquantifiable changes, except that rank values were used in reverse order instead of using schedule reduction percentages. If a case study had ten nonquantifiable changes, then a value of 10 was used for the most important soft change and a value of one was used for the least

important soft change. A comparison of resource and nonresource changes was also made using schedule reduction values.

To complete the micro analysis of the research, the results of the individual case study analyses were reviewed collectively. The purpose of this evaluation was to explore trends amongst change classifications and identify critical changes that were common to multiple exceptional projects.

To identify trends, the data used to plot the individual case study graphs discussed above were used to compare the effectiveness of phase-specific changes across all case studies. The data were plotted to discover if there was a correlation between the effectiveness of changes within a particular phase and the total schedule reduction of each project. The impact of resource changes and nonresource changes, based on actual effectiveness, was also plotted for all the projects on a single graph.

2.4.2.4 Commonality Amongst EPC Changes

Finally, a set of tables was developed to identify changes to the traditional EPC process which were common to multiple case studies. Five tables were developed for Quantifiable changes (one for each EPC phase) and five for nonquantifiable changes. The change did not have to be a critical (top ten) change to be considered a common change. (Appendix G)

CHAPTER 3

Analysis Results

A vast amount of information was collected and analyzed for each case study project. This chapter provides the principle findings assessed from the macro and micro analysis of collected data. Specifically, this chapter:

- provides a cost/schedule comparison summary of exceptional to traditional project;
- provides a safety impact assessment;
- provides a quality impact assessment;
- demonstrates the number of changes occurring for each project phase;
- discusses the primary categories of work process changes that occurred on exceptional projects;
- identifies common work process changes found throughout the sample of exceptional projects by phase;
- identifies the uncommon work processes changes found in projects by phase, and;
- illustrates the importance of non-resource work process changes in a project.

3.1 Macro Analysis Results

As noted, a macro analysis was performed to determine overall project trends. Specifically, Cost, Safety, and Quality premiums were determined for the dramatic reductions in schedule.

3.1.1 Cost Premium for Schedule Reduction

Analysis of the case study data indicates that re-engineering processes produces significant reduction in originally projected project duration and cost. These reductions were achieved with no negative effects on safety and quality. Schedule reductions ranged from 12% to 85%. For example, one crisis project was completed in only 15% of the time (2 months) that a non-crisis project would require (13 months)! The cost impact associated with the schedule reduction generally ranged from -40% to 52%.

Figure 3.1 illustrates the cost to schedule relationship for each case study project and each comparison project. Cost Fraction is the exceptional project total installed cost divided by the comparison (traditional) project total installed costs represented as a percentage. Therefore the vertical component for points on the graph illustrate the % cost of the exceptional project compared to a traditional project of similar scope and complexity. The horizontal line represents 100% costs for a traditional project. Therefore, any project falling below the horizontal line on Figure 3.1 demonstrates a lower cost for the exceptional project than the comparison project.

Schedule Fraction is the exceptional project total duration divided by the comparison project total duration represented as a percentage. Therefore, the horizontal component of the graph illustrates the % schedule duration of the exceptional project compared to a traditional project. Note that all case study projects were completed in less time than their comparison traditional projects.

A significant finding illustrated by Figure 3.1 is that 50% of all case studies demonstrated a DECREASE in cost with an associated DECREASE in schedule.

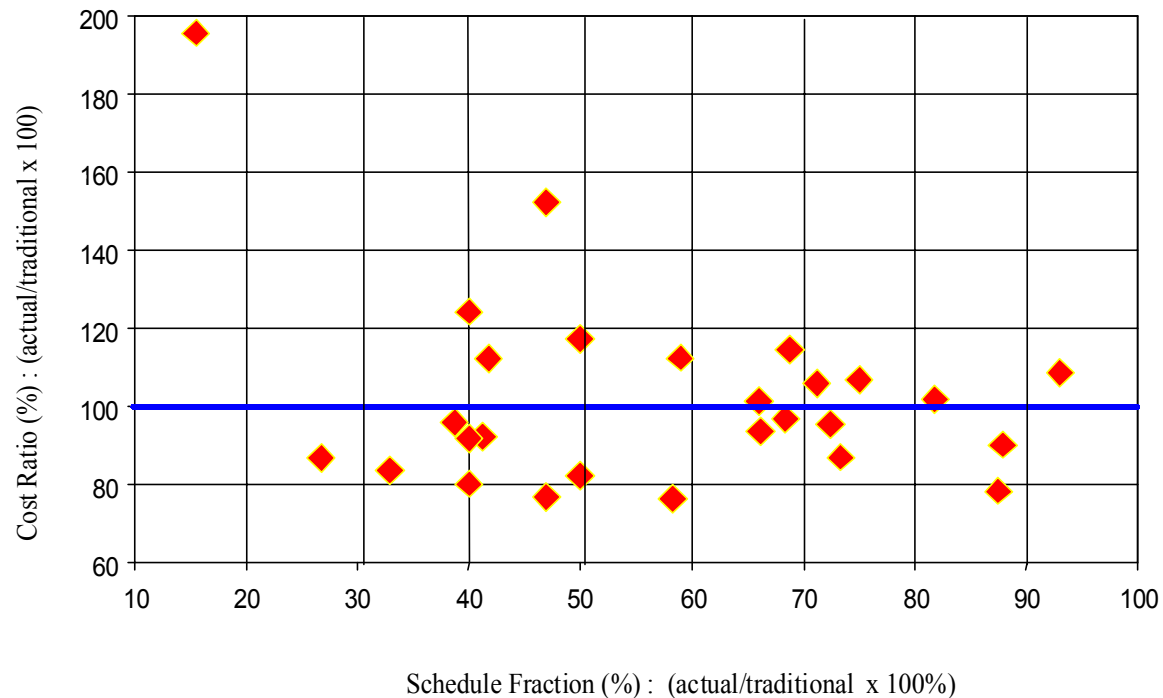


Figure 3.1 Cost Ratio vs. Schedule Fraction, Total Project

50% of all case studies demonstrate a DECREASE in cost with an associated DECREASE in schedule.

Cost ratio and schedule fraction values analyzed for engineering, procurement, and construction phases indicate no distinct correlation across multiple case studies. Schedule fractions and cost ratios were calculated for each project phase individually and tabulated on Project Summary forms (Appendix F). Data from those forms were consolidated onto Tables 3.1, 3.2, 3.3, and 3.4. Table 3.1 presents schedule and cost data associated with the planning and engineering phase of the EPC process, while Table 3.2 and Table 3.3 present data on the procurement and construction phases, respectively. Table 3.4 summarizes total duration and total project cost data for all projects.

Table 3.1 Schedule Impact and Cost Premium of EPC Changes on Planning/Engineering Phase

Case Study	Traditional ^(a) Durataion (months)	Actual Duration (months)	Schedule Reduction (months)	Schedule Fraction ^(b) (%)	Traditional Cost ^(a) (\$MM)	Actual Cost (\$MM)	Cost Premiu m (\$MM)	Cost Ratio ^(c) (%)
1	6	4	2	67	2.0	2.8	0.8	140
2	8	1.6	6.4	20	.42	0.08	(.34)	19
3					NA	NA	NA	NA
4	18	15	3	83	22.9	24.4	1.5	107
5	10	9.5	0.5	95		1.6		
6	15	10	5	67	24.7	20	(4.7)	81
7	7	3	4	43	0.5	0.41	0.09	83
8	12	12	0	100	5.75	6.1	0.35	105
9	14	12	2	86	9.9	10	0.1	101
10								
11	11	6	5	55	4.3	2.5	1.8	58
12	3	2.5	0.5	83	0.27	0.34	0.07	126
13	15.5	7.5	8	48	30.3	40.8	10.5	135
14						98		
15	9	8	1	89	3.3	3.0	(0.3)	91
16	4.75	3	1.25	63	0.68	0.33	0.35	49
Avg. ^(d)	10.6	8.1	3.9	62	15.7	21.3	1.74	115

^(a) A "traditional" project has the same scope as the actual project, but estimates of schedule and duration assume that the project was completed using traditional EPC processes.

^(b) Ratio of actual project duration to traditional project duration, x 100%.

^(c) Ratio of actual project cost to traditional project cost, x 100%.

^(d) Average does not include CS-14.96 values.

Table 3.2 Schedule Impact and Cost Premium of EPC Changes on the Procurement Phase

Case Study	Traditional Duration ^(a) (months)	Actual Duration (months)	Schedule Reduction (months)	Schedule Fraction ^(b) (%)	Traditional Cost ^(a) (\$MM)	Actual Cost (\$MM)	Cost Premium (\$MM)	Cost Ratio ^(c) (%)
1	4	3	1	75	0.5	0.5	0	100
2	5	1.5	3.5	30	1.62	2.16	0.54	133
3					NA	NA	NA	NA
4	18	15	3	83	110.4	115.9	5.5	105
5	12	12	0	100		2.1		
6	18	13	5	72	58.5	69	10.5	118
7	6.5	3	3.5	46	2.3	1.9	0.4	81
8	9	9	0	100	6.2	6.2	0	100
9	15	15	0	100	41.2	42.0	0.8	102
10								
11	6.5	6.5	0	100	3.4	3.8	0.4	112
12	4	1.5	2.5	38			0	100
13	8	9	(1)	113	169.7	174.8	5.1	103
14						152		
15		6				2.9		
16								
Avg. ^(d)	8.9	7.8	1.7	77	58.7	58.4	3.9	105.3

^(a) A "traditional" project has the same scope as the actual project, but estimates of schedule and duration assume that the project was completed using traditional EPC processes.

^(b) Ratio of actual project duration to traditional project duration, x 100%.

^(c) Ratio of actual project cost to traditional project cost, x 100%.

^(d) Average does not include CS-14.96 values.

Table 3.3 Schedule Impact and Cost Premium of EPC Changes on the Construction/Startup Phase

Case Study	Traditional Duration ^(a) (months)	Actual Duration (months)	Schedule Reduction (months)	Schedule Fraction ^(b) (%)	Traditional Cost ^(a) (\$MM)	Actual Cost (\$MM)	Cost Premium (\$MM)	Cost Ratio ^(c) (%)
1	9	5	4	56	22.5	24.7	2.2	110
2	4	2	2	50	1.83	5.34	3.51	292
3					NA	NA	NA	NA
4	17	12	5	71	85.7	93.4	7.7	109
5	10	7.5	2.5	75		3.5		
6	15	10.5	4.5	70	46.8	53	6.2	113
7	7	3.5	3.5	50	1.2	0.9	0.3	77
8	14	7	7	50	6.3	6.3	0	100
9	16	13.5	2.5	84	6.3	6.4	0.1	102
10								
11	11	7	4	64	11.3	13.1	1.8	116
12	4.5	4.0	0.5	89	5.04	5.6	0.56	112
13	24	14	10	58	29.4	52.9	23.5	180
14	18	32	(14)	178		395		
15	7	5	2	71	7.9	7.2	0.5	91
16	6.5	5	1.5	77	5.8	3.7	2.1	64
Avg. ^(d)	12.3	8.0	4.7	58	26.3	30.2	14.3	126

^(a) A "traditional" project has the same scope as the actual project, but estimates of schedule and duration assume that the project was completed using traditional EPC processes.

^(b) Ratio of actual project duration to traditional project duration, x 100%.

^(c) Ratio of actual project cost to traditional project cost, x 100%.

^(d) Average does not include CS-14.96 values.

Table 3.4 Total Schedule Impact and Cost Premium of EPC Changes

Case Study	Traditional Duration ^(a) (months)	Actual Duration (months)	Schedule Reduction (months)	Schedule Fraction ^(b) (%)	Traditional Cost ^(a) (\$MM)	Actual Cost, TIC (\$MM)	Cost Premium (\$MM)	Cost Ratio ^(c) (%)
1	12	5	7	42	25.0	28.0	3.0	112
2	13	2	11	15	3.87	7.58	3.71	196
3	24	6	18	25	NA	300	NA	NA
4	24	18	6	75	219.1	234	14.9	107
5	20	17.5	2.5	87	9.0	7.2	(1.8)	80
6	28	16.5	11.5	59	130	146	16	112
7	10	4	6	40	4.0	3.2	(0.8)	80
8	25	16.5	8.5	66	20.65	21	0.35	101
9	22	18	4	82	57.4	58.4	1.0	102
10	20	15	5	75		11		
11	16	7.5	8.5	47	19.0	28.9	9.9	152
12	8	5.5	2.5	69	5.3	6	0.7	113
13	30	15	15	50	230	269	39	117
14		56				790		
15	14	7	7	50	73	13.1	2.0	87
16	12	7	5	58	9	6.8	2.2	76
Avg. ^(d)	18.5	10.7	7.8	56	61.9	76	6.9	104

^(a) A "traditional" project has the same scope as the actual project, but estimates of schedule and duration assume that the project was completed using traditional EPC processes.

^(b) Ratio of actual project duration to traditional project duration, x 100%.

^(c) Ratio of actual project cost to traditional project cost, x 100%.

^(d) Average does not include CS-14.96 values.

3.1.2 Safety Impacts of Schedule Reduction

The DCG asked crisis project participants to identify accident rates for both the case study project and a typical project. Based on the responses contained in the DCG's, constructors commonly monitor safety performance by tracking the following measures:

- First aid cases
- OSHA recordable incidents, and
- Lost time accidents.

Generally, the raw number of incidents and the cumulative craft manhours are recorded. Using these values, incident rates were calculated for each category as follows:

$$\text{Incident rate} = \text{No. of incidents} \times 200,000 \text{ OVER } \{ \text{Craft manhours} \}$$

Table 3.6 summarizes the results of the safety performance on the crisis projects studied under this research. Although very little safety data were provided, the available data indicate that safety was not compromised on the case study projects. In fact, safety awareness appears to have been heightened to the extent that safety performance was generally excellent.

Table 3.5 Safety Performance on Crisis Projects

<u>8 Cases responded</u>
7 of 8 responded Safety Performance was Excellent
1 of 8 responded Safety Performance was Average
8 Cases no response or unknown
Safety was measured by: First Aid Cases, OSHA Recordables and Lost Time Accidents

3.1.3 Quality Impacts of Schedule Reduction

Owners associated with the case studies provided information on project quality. Since all the case studies came from the industrial sector, quality is generally defined with functionality measures and not aesthetic measures. Data concerning the following quality attributes was requested in the DCG:

- Ease of startup,
- Initial downtime,
- Capacity, and
- Maintainability.

Table 3.7 summarizes the results of quality performance on the case study projects. Again, data were not provided for every case study, but overall performance was generally average. Since "average" is defined as meeting owner performance criteria, "average" is certainly satisfactory. In one instance, difficulties were experienced during the first two months which degraded the performance rating. Once those initial problems were rectified, the plant proceeded to operate satisfactorily.

Table 3.6 Quality Performance on Crisis Projects

<u>8 Cases responded</u>
1 of 8 responded Quality Performance was Excellent
5 of 8 responded Quality Performance was Average
1 of 8 responded Quality Performance was Mixed
1 of 8 responded Quality Performance was Below Average
8 Cases no response or unknown
Quality was measured by: Ease of Startup, Initial Downtime, Capacity and Maintainability

3.2 Micro Analysis Results

The micro analysis entailed the identification of those actions taken by the EPC teams that enabled the projects to be delivered quickly. The results of the analysis are in four forms: trends based on the raw number of EPC changes, trends based on the effectiveness of those changes, a list of specific changes common to the case studies, and a list of uncommon yet effective techniques.

3.2.1 Trends by Number of EPC Changes

Using the various data collection methods, a list of changes to the traditional EPC process were compiled for each case study (Appendix G). Based on the classification of each change, a bar graph was developed for each case study to compare the relative number of changes that occurred across the five EPC phases. To identify trends, a summary graph was developed which presents the distribution of changes across the EPC phases (Figure 3.5). One can see that the predominant number of changes occurred in the Preproject Planning Phase (>40%). More importantly a majority of these changes were non-quantifiable changes in processes and methods. This suggests an important component of establishing productive reengineering are the early process changes that establish a foundation of improved cost and schedule performance and undoubtedly impact downstream project phases.