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Improving the design process with information management

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Abstract

This paper presents a method to quantify the time and cost impacts on Engineer, Procure, and Construct (EPC) projects resulting from information management driven process changes to the design process. Many engineering and construction companies have implemented information technologies and other changes, fully expecting to save time and cost, gain competitive advantage, improve productivity, better align project objectives, and improve product quality. Previous efforts to quantify benefits have been function or technology specific. The method described herein illustrates the value of evaluating process improvement strategies at the project level to avoid misleading conclusions regarding the actual benefit of investments. The research results strongly suggest that information management strategies applied to the design process may substantially improve total project performance. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Information management; Process modeling; Process improvement strategies; Simulation; Information technology

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1. Introduction

In large part, success in engineering and construction is measured by how firms effectively manage change. New systems, often created in response to competitive pressures in the marketplace, create change, often with unpredictable, or even undesirable results. Managing change, and predicting the ultimate impacts on work processes, is as important as managing any other aspect of the business enterprise. Today's leading edge organizations will only remain leaders in the future if they proactively, and continuously, improve their work processes to meet the advancing capabilities of competitors, and the changing expectations of their customers. It is therefore critical for the engineering industry to have the ability to evaluate potential work process changes to ensure that they produce desired results, improving the effectiveness and/or efficiency of corporate operations.

Companies within the engineering and construction industry have begun efforts to implement many forms of strategic change, including strategies for partnering, standardization, and electronic exchange of information. Unfortunately, justification for making these changes has primarily been qualitative. As a result, the likely impact to such quantitative measures as project cost and schedule is frequently unknown until after the process changes are already in place. In some cases, the resulting project impacts may not be known until after projects are fully

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executed. It is undesirable for the implementation of a work process modification, or any form of strategic change, to result in surprise consequences to the organization. Process changes are intended to improve, not hinder, the organization's ability to perform.

To date, a satisfactory method to quantify, and predict, the project level impacts of proposed process change has not been developed. This is undoubtedly due, at least in part, to the difficulty in capturing the performance variability inherent in executing construction engineering projects. By their nature, engineering, procurement, and construction (EPC) projects are typically complex, multidisciplinary and costly, constituting a major capital investment by owner companies. Such projects vary in scope, design, and execution strategy. As a result, the individual activities that comprise the design and construction work processes are themselves highly variable from project to project. The ability to predict, and quantify, the time and cost impact of any proposed work process change improves the likelihood of meeting, or exceeding, project performance criteria. Without such an ability, work process modifications may have unknown, or possibly even adverse, project impacts.

To correctly evaluate the time and cost impacts of proposed work process changes, the EPC process must be examined holistically. Failure to look at the entire EPC process, despite the multiorganizational complexity, can only result in suboptimization, as firms institute a piecemeal, discipline specific, approach to process improvement. Organizations must be alert to the potential for reaching misleading conclusions regarding time and cost savings that accrue from process improvement strategies when the analysis has failed to extend beyond a subprocess level of the project.

In response to these needs, this paper presents a method to quantify the time and cost impacts that are likely to result from proposed work process modifications. Such modifications may be driven by technological or organizational change. As a case study example, this paper summarizes a research project that evaluated the potential time and cost impacts that may result from strategically implementing information management strategies in the design phase of an EPC project.

2. Design background

The life cycle of an EPC project includes pre-project planning, design, materials management and procurement, construction, and start-up. Clearly, engineering design is only one phase in a much larger process. It is, however, a very important piece of the whole. Based on a recent study of 20 EPC projects, the engineering design process consumes approximately 28% of project labor costs and 22% of project activity time [1]. In addition to the time and cost resources consumed during the design process, the quality of the design product can also influence the project schedule and cost. The quality and accuracy of the design can influence the number of field interferences, the amount of rework required, the optimization of material resources, and the ease and efficiency of construction. The design product may even influence an owner's future operations and maintenance by providing an accurate history of design development decisions.

Despite the significance of the design process to the delivery of the constructed facility, the design process is still riddled with inefficiencies. While many engineering and construction companies have invested heavily in computing technology, the ability to integrate information across functional and organizational boundaries is generally limited. Research indicates that projects are still fragmented and highly dependent on information exchange in paper form [15]. Workman [16] cites works by Cooper and Kleinschmidt (1986), Dougherty (1992), and Workman (1993), who have all conducted field research to specifically review the interactions in engineering-driven organizations. Their studies indicate conclusively that personnel within engineering organizations frequently have communication difficulties. From field interviews with 80 individuals on 18 new product teams in five engineering-driven firms, Workman [16] found that people in various functional groups possess different information, tend to focus on their own part of a project, and define the entire process from their own perspective.

Parfitt et al. [12] identifies a significant contributor to poor communication in the engineering and construction industry to be the lack of an efficient means of disseminating information from one department to another. For example, plotted drawings are often used to transfer designs and reports of one project phase to another and to check the compatibility of the many design efforts. Additionally, any one person using the printed document may only need a fraction of the information contained within it [15]. The pertinent information is often extracted to produce new drawings and new reports.

Teicholz and Fischer [15] state that such paper-based design is difficult to coordinate and may fail under time constraints. They further state that elaborate procedures for logging and checking drawings, to ensure that the changes of one designer are completely and accurately added to other drawings and reports, adds both time and cost to the project. Other ramifications include processing or retrieval delays, lost documents, misrouted forms, and storage problems [7]. According to Taylor [14], 80% of an engineer’s time is spent accessing data to begin analysis. Conoco has stated that proper usage of data management could save 50% of this searching, collecting, and pre-processing time [14].

The current paper-based process is prone to errors since data is extracted, transferred, interpreted, and repackaged [9,15]. Kartam [6] refers to a study by Nigro (1984) who reported that more than half of the errors and omissions in construction drawings and specifications are due to poor coordination between design disciplines. Today’s paper-based exchange of information is also open to interpretation, since only outputs from each department are communicated, while reasons behind the designs remain in the minds of the designers involved [9].

The engineering industry has undergone changes in an effort to minimize the inefficiencies identified above, to reduce time and cost resources consumed during design, and to improve the accuracy and quality of the design product. Time to market has also become increasingly important, placing added emphasis on reducing turnover time from an engineering solution to an “approved for construction” status. The list of techniques and technologies used to improve the design process is lengthy, but includes such technologies as object oriented methodologies (OOM) for intelligent P&ID’s, automated pipe routing, and electronic bill of materials generation. The concept of 2% engineering has been introduced, and partnering during the early stages of the design process has become much more commonplace. Document management systems have also made contributions to the industry by enabling faster and easier access to engineering documents [5].

3. Need to quantify design process changes

There is clearly a need for changes to the design process, and broad changes within the industry are occurring, but on what basis are these process changes or technology implementations justified? Although the costs of implementation can usually be adequately ascertained, the benefits are much more ambiguous. The most common benefit cited in the literature is the perception that considerable time, effort, and cost savings accrue [2,3,8,11,12,14,15]. More specifically, authors have cited lower developmental costs, lower operational costs [13], and reduced downstream operation and maintenance costs [3].

Improved productivity, enabled by streamlining of the business processes, has been cited as a key benefit of some process and technology changes [4]. Improved flexibility in creating and storing project information has also been described as a benefit [12]. Miyatake and Kangari [11] suggest that integrated design processes, and the enabling technologies’ ability to facilitate concurrent performance of different departments, offers additional flexibility to the design and construction effort. Teicholz and Fischer [15] support the claim that timeliness, consistency, and completeness of communications can be improved.

Unfortunately, except for a few sources citing company specific case studies, there is limited literature that identifies benefits in quantifiable terms. Some studies addressing quantification of benefits have been completed after the fact, looking backward to see the actual results of the implementation. These benefits, then, were not used as justification for the initial investment for the change process. Other studies that have quantified benefits have been function, discipline, or technology specific. Even if the engineering function can be reduced in terms of time and cost, what does this really mean in terms of project level savings? Without a method to help predict the project benefits of the design process changes, prior to implementation, the initial investment will continue to be predicated on subjective criteria.

The methodology presented with this case study provides a means of testing and simulating the results of design process modifications without actually incurring the expenses associated with real world implementation. It provides predictive and quantitative information regarding the likely impacts to the measures of total project time and cost, even when the investigated changes are only considered within the design process itself. Such a methodology provides a useful tool to the construction engineering industry by enhancing the ability to quantitatively evaluate strategic initiatives. This is true whether the proposed work process changes are technological or organizational driven.

4. Research approach

A research study was recently undertaken to develop and demonstrate a method to quantify the time and cost impacts on EPC projects resulting from information management driven process changes in design-related activities. Many companies have implemented technologies expecting to save time and effort, gain competitive advantage, improve productivity, better align objectives, and improve product quality. The premise of this research is that these benefits can be quantified in terms of time and cost performance measures. While previous efforts to quantify benefits have been function, discipline, or technology specific, the method presented herein illustrates the importance of quantifying process improvements at the total project level.

To provide the reader with a better understanding of the scope and context of this research, the following definitions for "design", "cost", and "time" are presented below.

Definition 1 (Design definition). Design, as defined for this investigation, includes all activities required for an overall engineering function, including numerical engineering analysis required to produce design documents as a final product. The function includes all efforts of the designer, all necessary design disciplines, the owner, and suppliers that are required to finalize the project scope, complete detailed estimates and schedules, complete detailed design deliverables, and prepare work packages for project execution. More specifically, Fig. 1 identifies all activities that have been included in the definition of design.

Definition 2 (Cost definition). Costs, for the purposes of this research, include only those associated with labor hours dedicated to activity completion. Material and equipment costs were intentionally excluded. This restriction was necessary to compare and normalize projects of varying size and facility type. That is, certain facility types have higher equipment and material costs simply because of the nature of the production process within that facility. Similarly, facilities of the same type, with different capacities for production, may have significantly different material and equipment costs. Generally speaking, material costs are unaffected by improvements to the design work process.

Finalize Scope

- Finalize P&ID's and PFD's
- Finalize Facility Plans
- Define Major Equipment & Material Specifications
- Finalize Utilities and Offsite Scope
- Address Codes, Standards, HAZOP, & Environmental Impact Requirements
- Acquire Permits & Regulatory Approvals
- Conduct Site Evaluation

Detailed Cost Estimate

- Estimate Equipment Cost
- Estimate Installation Cost
- Estimate Support Services Cost
- Estimate Indirects Cost
- Estimate Materials Cost
- Estimate Other Costs: (Escalation / Spare Parts / Contingency)

Detailed Schedule

- Detail Design Schedule
- Detail Materials Management Schedule
- Detail Construction Schedule
- Detail Start-Up Schedule

Detailed Design

- Detail Engineering Discipline Drawings
- Finalize Drawings and Construction Specifications
- Conduct Cost and Schedule Review Analysis
- Design / Engineering Review
- Obtain Intermediate Owner Reviews and Approvals
- Review Changes & Approve
- Complete Constructability Review
- Complete QA/QC Review
- Conduct Scope / Estimate Review
- Coordinate Vendor/ Engineering Interface
- Distribute Documents

Prepare Work Package

- Draft Project Plan
- Prepare Material Requisitions
- Develop Bill of Materials

Milestones

- Preliminary Scope Definition Complete
- Detail Estimate Complete
- Detailed, Integrated Project Schedule Complete
- Detailed Design Milestone
- Owner Review & Approval of Detailed Scope and Estimate

Fig. 1. Activities included in design definition.

Definition 3 (Time definition). Activity time represents the total amount of effort expended over the life of the project for a given activity. While activity cost is associated with actual labor hours physically spent to complete an activity, activity time is associated with the total elapsed time from the point an activity starts to the time it is fully completed. Activity time, therefore, includes work time as well as time spent waiting or idle.

5. Methodology

The method described herein includes four major steps. The first step is the development of a baseline condition of the total project execution process to represent the present state. The second step is the development of the baseline conditions for specific design related activities investigated for process modification. The third step is the quantitative evaluation of the impacts resulting from changes to specific design activities accomplished by comparing a "path forward" state to the previously identified baseline condition. The fourth step involves incorporating the impacts identified on the design activities in step three into a "path forward" state for the entire project and then comparing this new model against the baseline identified in step one.

For each of these steps, a Monte Carlo simulation technique is employed. The simulation process permits the user to, in effect, "perform" the work process hundreds of times and observe the resulting variability with respect to time and cost. The simulation program executes the work process in strict accordance to the precedence logic prescribed by the user. Variability in the simulation output results from the randomness in the work process with respect to time and cost performance for individual activities. Additionally, there is often variability in the execution of activities such as when rework is required. When a work process is experimentally modified, the simulation process will produce a revised distribution of time and cost values that can then be used for comparative analysis. Modifications to a work process may be the result of technological, procedural, or organizational driven change. The following sections describe each step in greater detail, providing case study examples to illustrate the methodology.

6. Project baseline

To measure the impact of changes to any work process, it is first necessary to define the existing process, or the baseline condition. The baseline model used in this research was developed from a procedure described by Back et al. [1]. The following paragraphs summarize the process.

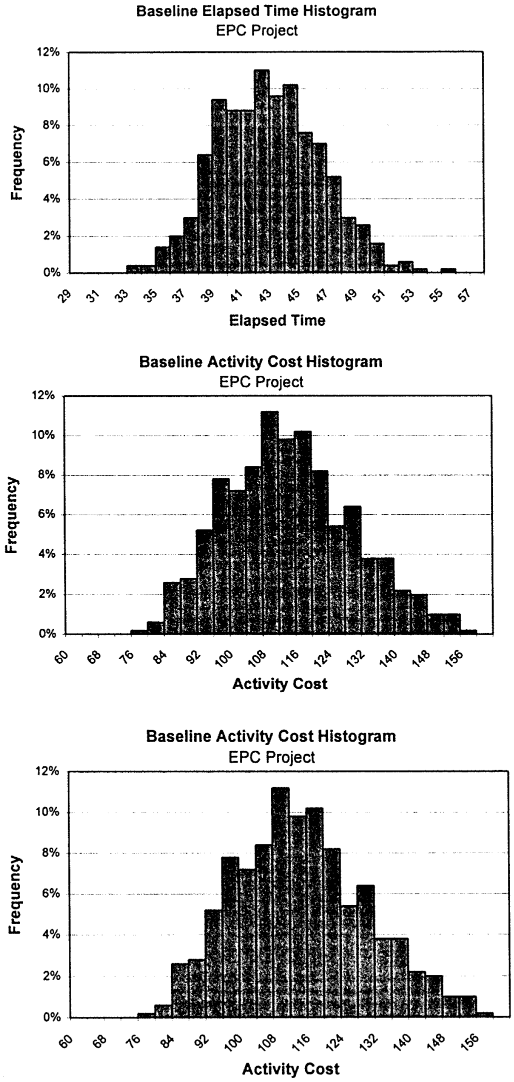
First, an industry team comprised of both owners and EPC firms jointly developed an activity list encompassing the "macro level" project activities typically included in the execution of an EPC process. These activities defined the phases pre-project planning, engineering design, materials management and procurement, construction, and start-up. The list included 164 activities and 16 specific milestones (see Fig. 1 for design activities and milestones). Second, the industry team developed a logic diagram identifying the activity relationships and interactivity dependencies. Over 40 US companies, including both owners and contractors, participated in the review of the activity list and logic diagram.

Time and cost information was then collected for each activity identified in the list and process diagram to compile a database of historical time and cost information. Data to support the baseline was provided from approximately 20 EPC projects completed between 1994 and 1997. After collecting time and cost data for each activity, the researchers then defined a probability distribution to represent the time and cost variability for each activity. A triangular distribution, using least squares minimization, was the primary distribution used to model the data in this research.

Finally, the researchers simulated the baseline condition using Monte Carlo simulation procedures. Activity Based Costing Simulation (ABC-SIM) was the simulation tool used to perform this process. ABC-SIM is a software product specifically developed to support this type of process modeling and analysis. When using ABC-SIM, the process diagram is modeled as a node and link network. The nodes represent the required activities and process resources, while the links provide the control mechanism to ensure the prescribed precedence logic is maintained during the simulation [10].

The simulation process yields output measures for the:

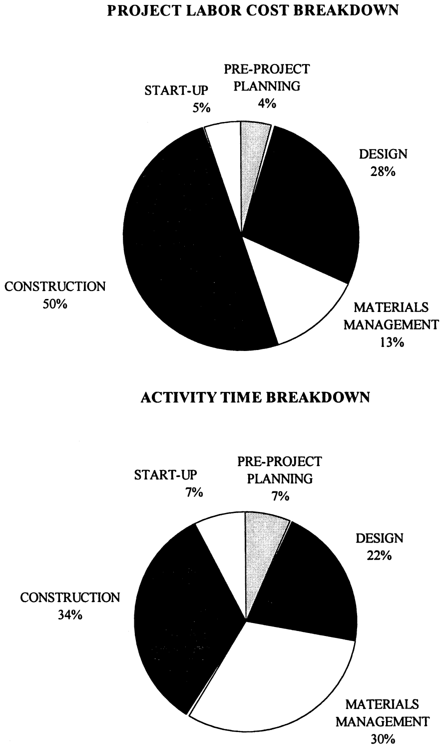
- Total elapsed time (calendar or clock time) required to fully execute the entire process with the defined precedence logic.
- Total activity time required to execute all activities defined in the process.


Baseline Elapsed Time Histogram
EPC Project

Baseline Activity Cost Histogram
EPC Project

Baseline Activity Cost Histogram
EPC Project

Fig. 2. Baseline histograms for EPC project.


PROJECT LABOR COST BREAKDOWN

ACTIVITY TIME BREAKDOWN

Fig. 3. Time and cost by project phase as a percentage of time and cost.

- Total activity cost required to execute all activities defined in the process.

Since every activity in the network model was represented by variable time and cost distributions, the simulation output was used to define the variable range for total time and cost at the project level of performance. This variability was represented in

Table 1
Time and cost by activity as a percentage of project time and cost

Activity	% Total activity cost	% Total activity time
Design	28	22
Finalize scope	5	4
Detailed cost estimate	1	2
Detailed schedule	2	2
Detailed design	19	12
Prepare work package	1	2

Finalize Scope

- Finalize P&ID's and PFD's
- Finalize Facility Plans
- Define Major Equipment & Material Specifications
- Finalize Utilities and Offsite Scope
- Acquire Permits & Regulatory Approvals

Detailed Design

- Detail Engineering Discipline Drawings
- Finalize Drawings and Construction Specifications
- Conduct Cost and Schedule Review Analysis
- Design/Engineering Review
- Obtain Intermediate Owner Reviews and Approvals
- Review Changes & Approve
- Complete Constructability Review
- Conduct Scope/Estimate Review
- Coordinate Vendor/ Engineering Interface
- Distribute Documents

Fig. 4. Design activities used in case study.

terms of a histogram illustrating the range and frequency of possible project values. The histograms shown in Fig. 2 illustrate the baseline project time and cost distributions resulting from the research.

7. Design activity baselines

The second major step of the methodology to quantify impacts of design process improvements involves developing a baseline condition for selected design related activities. One should first consider, however, the justification for investigating the design function at all. Design was chosen for detailed evaluation based on its potential for significant impact on the total project time and/or cost if improved. This potential for impact was based on total project time and cost resources typically dedicated to the design function during project execution, as shown in Fig. 3.

The methodology for quantifying impacts of process change in design can be utilized for changes to any design activity. However, similar to the selection of design for investigation, specific design activities for the case study were also singularly selected based on their potential to impact the total project time and cost. This potential impact was based on the relative amount of project resources dedicated to the specific design activity. Table 1 identifies the percentage of total project time and cost of specific design activities based on the data collected during the development of the project baseline condition described in Section 6.

Clearly, the detailed design activity consumes the greatest amount of time and cost resources in the design process with 19% of total activity costs and 12% of total activity time. Although second in usage of project resources in design, "Finalize Scope" consumes significantly less resources than detailed design with less than 5% of project costs and less than 4% project time. This activity was still selected for detailed analysis based on the project team's expectation that a clearer, more comprehensive and complete plan can have a significant impact on all

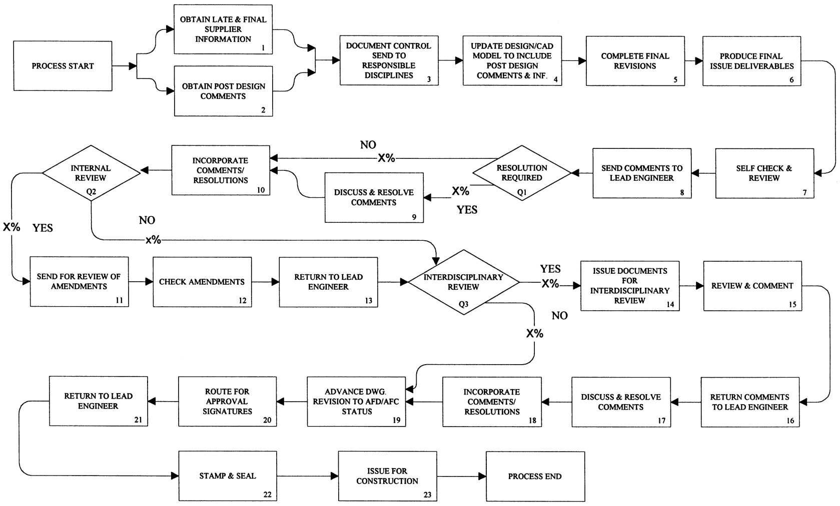


Fig. 5. "Finalize Drawings and Construction Specifications" logic diagram.

subsequent project activities. The activities included in these categories, as defined for the case study, are summarized below in Fig. 4.

Using steps similar to those necessary to develop the baseline condition for the total project, baseline conditions for each of the activities listed above were also developed. A task list was developed for each activity. Development of a logic, or precedence diagram for each activity illustrated task sequencing and interdependencies.

The diagrams and task relationships were derived by the consolidation of ideas, comments, and suggestions from research team members, company employees participating in the interview process, and technical literature. Fig. 5 illustrates the logic diagram developed for "Finalize Drawings and Construction Specifications" as a representative example.

Table 2
Time and cost distributions for "Finalize Drawings and Construction Specifications tasks"

	Baseline					
	Time			Cost		
	L	ML	H	L	ML	H
Task 1	16.00	40.00	130.00	$20.42	$110.83	$210.00
Task 2	11.00	22.00	56.00	$20.42	$64.17	$210.00
Task 3	10.00	17.50	32.00	$64.17	$128.33	$297.50
Task 4	38.00	69.00	110.00	$218.75	$320.83	$746.67
Task 5	38.67	54.67	104.00	$713.13	$726.25	$735.00
Task 6	41.33	60.00	78.67	$218.75	$253.75	$280.00
Task 7	24.00	38.67	53.33	$274.17	$309.17	$373.33
Task 8	10.33	10.33	15.67	$61.25	$75.83	$105.00
Q1	% yes 37.50			% no 62.50		
Task 9	14.67	22.67	36.00	$116.67	$157.50	$303.33
Task 10	14.67	22.67	36.00	$210.00	$250.83	$303.33
Q2	% yes 12.50			% no 87.50		
Task 11	7.33	8.00	14.00	$26.25	$29.17	$35.00
Task 12	11.00	16.33	17.67	$45.83	$63.33	$103.33
Task 13	5.67	5.67	11.00	$14.58	$17.50	$23.33
Q3	% yes 12.50			% no 87.50		
Task 14	18.67	18.67	24.00	$50.83	$51.67	$55.83
Task 15	16.00	26.67	42.67	$116.67	$151.67	$233.33
Task 16	6.00	6.00	11.33	$26.25	$40.83	$70.00
Task 17	11.33	14.00	19.33	$81.67	$87.50	$163.33
Task 18	9.33	14.67	22.67	$81.67	$134.17	$280.00
Task 19	21.33	26.67	32.00	$157.50	$166.25	$175.00
Task 20	16.50	21.50	30.50	$105.83	$106.67	$120.00
Task 21	12.00	12.00	17.33	$4.17	$5.00	$10.00
Task 22	6.67	6.67	12.00	$14.58	$17.50	$35.00
Task 23	17.33	22.67	30.67	$75.00	$83.33	$96.67

Data was collected from multiple completed projects to identify the variability in time and cost requirements for individual tasks. Stochastic distributions were developed to represent the variability at the task level. For example, Table 2 shows the time and cost distributions used for each task illustrated in Fig. 5.

Using these distributions as input to a simulation network modeled after the logic diagram, the processes were simulated in ABC-SIM to define the process variability in terms of total activity time or cost. As with the project baseline, each design activity had its own baseline histogram to represent the present condition. Fig. 6 shows these histograms for "Finalize Drawings and Construction Specifications".

8. Path forward design

The third step of the methodology is an evaluation of the impacts resulting from changes to specific design related activities. The evaluation is completed by comparing a "path forward" state to the baseline. The user of the methodology determines the path forward state. This step is the user's opportunity to model the potential future process based on anticipated changes and benefits.

The reader should understand that the simulation output is only as accurate as the information put into the model. Modeling the future state of an activity requires engineering judgment and forethought. Simulation programs are not designed to automatically modify a process network by simply selecting an improvement strategy or technology, such as the implementation of 3D-CAD, automated material take-offs or bill of material generation, electronic document approval routing, or any other type of process change. It should be noted that task level impacts for any specific type of work process change would certainly vary from one company to the next and be influenced by, among other factors, the corporate objectives of implementing the change in the first place. However, the chief advantage of simulation is that it allows companies to go beyond simple

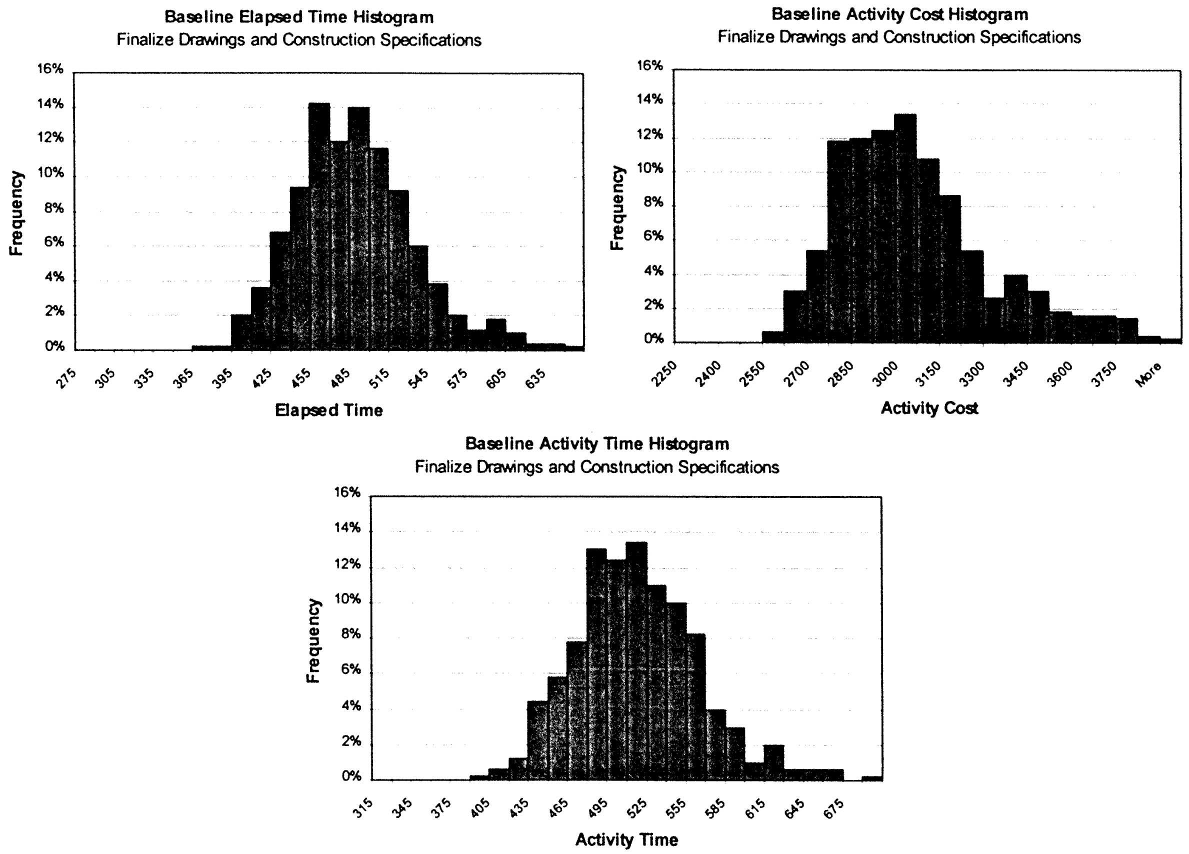


Fig. 6. Baseline histograms for “Finalize Design Drawings and Specifications”.

speculation; permitting the user to predict, and quantify, the total time and cost impacts to the EPC work process should the contemplated improvements be realized.

The process changes evaluated in this study were based solely on the potential improvements anticipated from the implementation of information management. Specifically, the research focused on the concept of information sharing. Information sharing includes the ability to access and exchange design information, and interpretations of that information, across functional and organizational boundaries.

Each design activity listed in Fig. 4 was evaluated, and redesigned based on changes anticipated from information sharing driven improvements. For example, information sharing improvements to “Finalize Drawings and Construction Specifications” were expected to impact tasks 3, 8, 11, 13, 14, 16, 21, and 23. Each of these tasks requires the transfer of information, or documents, from one person to another person or group.

It was assumed that the information exchange process went from one that was originally manual, and paper-based, to one that is electronic. Electronic transfer of information would enable information to go directly to its destination nearly instantaneously, without the clerical and physical delivery effort associated with a paper-based system. Although some effort would still be required to send the documents electronically, even that effort could be reduced with the use of certain workflow applications.

Time and effort associated with printing and photocopying information for records was also assumed to be minimized, or even eliminated, since the information may be copied and stored electronically. Additionally, these tasks had no significant external

Table 3
Estimated task level improvements enabled by information sharing

	% Estimated change			% Estimated change	
	Time	Cost		Time	Cost
Task 1	0	0	Task 12	0	0
Task 2	0	0	Task 13	95	85
Task 3	95	95	Q3	yes 13	no 87
Task 4	0	0	Task 14	95	90
Task 5	0	0	Task 15	0	0
Task 6	0	0	Task 16	95	90
Task 7	0	0	Task 17	0	0
Task 8	95	95	Task 18	0	0
Q1	yes 38	no 62	Task 19	0	0
Task 9	0	0	Task 20	0	0
Task 10	0	0	Task 21	95	40
Q2	yes 13	no 87	Task 22	0	0
Task 11	95	90	Task 23	99	95

constraints to hold up the time required to send information. That is, the exchange of the information was not typically dependent on an executive decision or prerequisite action.

Based on these assumptions, a reduction in the time and cost of each task was estimated. Table 3 identifies the estimated reduction in time and cost used in this case study for each individual task. It is important to remember that these are estimates based on engineering judgement and not guaranteed results. The intention is to determine, given the cost of implementing the process change, if the benefits outweigh the costs should the anticipated benefits be realized.

Based on the anticipated changes to each of the tasks in a given activity, the simulation network, and associated time and cost distributions, can be modified accordingly. In such analyses, task level modifi-

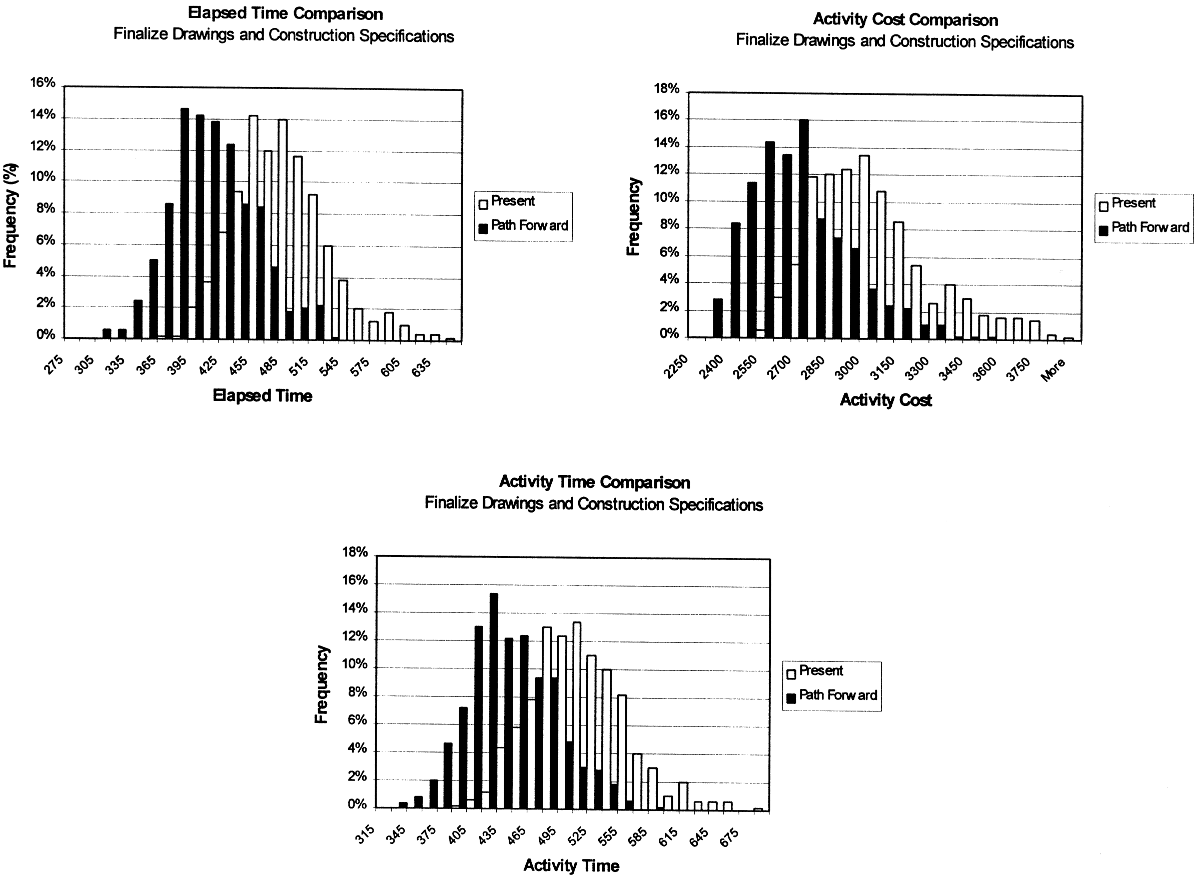


Fig. 7. Project time comparisons of present and path forward simulation output (activity level).

Table 4
Statistics comparison of present and path forward simulation output

	Elapsed time		Activity time		Activity cost	
	Present	Path forward	Present	Path forward	Present	Path forward
Mean	475	403	504	432	2996	2649
Standard error	2.1	1.9	2.1	1.9	11.8	9.7
Median	472	399	502	427	2961	2623
Mode	454	378	496	435	2966	2631
Standard deviation	46	42	47	43	263	217
Sample variance	2103	1742	2221	1864	69 040	46 894
Range	278	234	304	260	1447	1227
Minimum	360	295	378	316	2477	2269
Maximum	638	529	682	576	3924	3496

cations can be based on experience and judgement, speculation, or known fact. This process can be used to test a hypothesis about the likely impacts of implementing a new technology. In this case, task level modifications were predicated on industry interviews, technical literature, and qualified judgement.

For this particular study, the path forward distributions were developed by multiplying the present practice triangular distribution parameters (low, most

Table 5
Reduction in mean from present to path forward (%)

Design activity	Elapsed time	Activity time	Activity cost
Finalize P&ID’s and PFD’s	17	23	19
Finalize facility plans	18	20	9
Define major equipment and material specifications	25	25	14
Finalize utilities and offsite scope	30	34	24
Acquire permits and regulatory approvals	21	21	9
Detail engineering discipline drawings	10	23	1
Finalize drawings and construction specifications	15	14	12
Conduct cost and schedule review analysis	24	42	14
Design/engineering review	15	15	8
Obtain intermediate owner reviews and approvals	50	49	21
Review changes and approve	46	49	17
Complete constructability review	34	41	19
Conduct scope/estimate review	19	22	9
Coordinate vendor/engineering interface	23	24	12
Distribute documents	39	40	18

likely, and high; see Table 2) for each task by the difference of 100% and the percentage reduction in activity time and activity cost shown in Table 3.

Each modeled design activity was simulated for 500 runs. Evaluation of the resulting simulation identified the impact to the activity should these modifications to the design process be implemented. Fig. 7 and Table 4 compare the simulation output from the present model (see Fig. 6) to the path forward model for "Finalize Drawings and Construction Specifications".

The significance of this path forward simulation is to determine the percentage change in the mean activity time and activity cost from present practice to potential future practices. Based on the information presented in Table 4, the reductions in the mean value for elapsed time and activity cost were approximately 15% and 12%, respectively. This comparison was made for each of the present and path forward models developed for the design activities shown in Fig. 4. Table 5 identifies the reduction of the mean value of time and cost for all activities modeled.

9. Path forward project

The fourth and final step in the methodology is to incorporate the results of the design improvements into the overall project. The percent reduction in activity time and activity cost for each activity is used to adjust the baseline project triangular distributions. For the case study, the data values within each data set, used to create the present practice activity distributions, were multiplied by the percent reduction in the mean values for the same project activity. These values are summarized in Table 5. The result

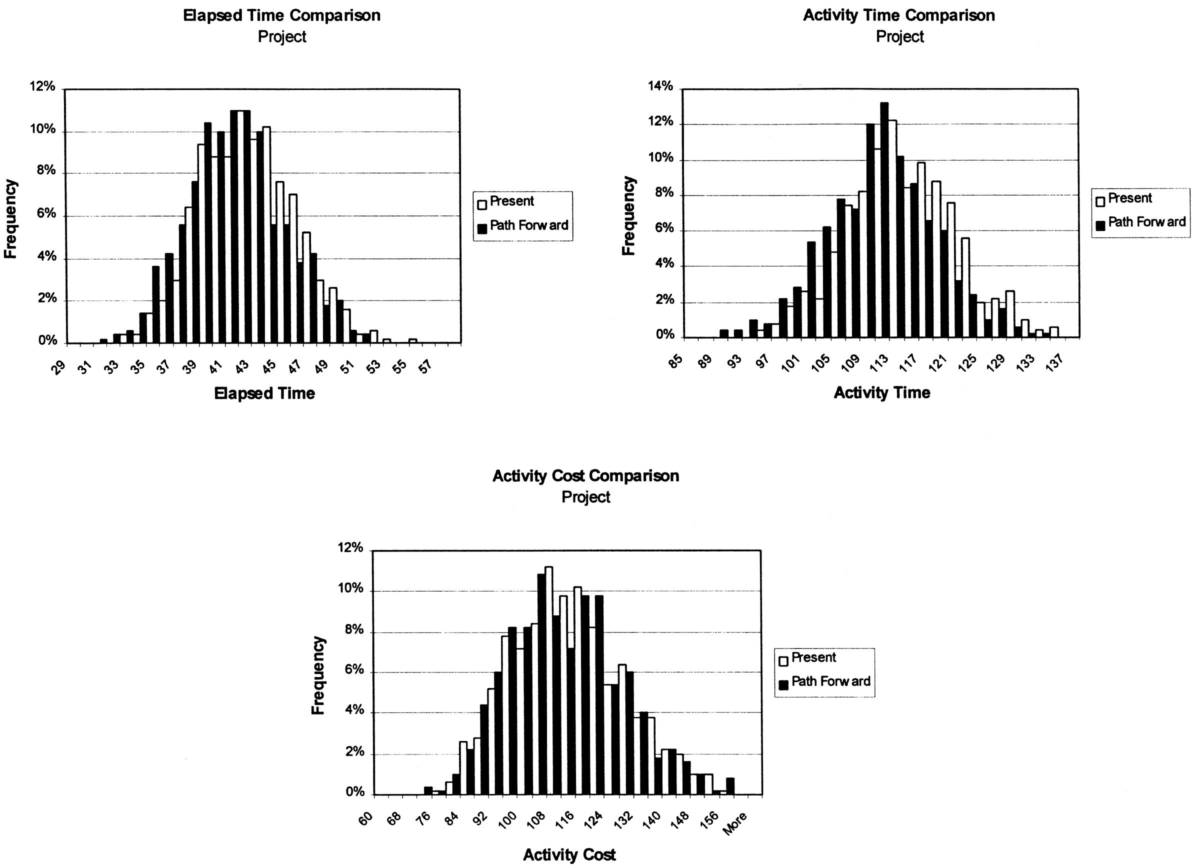


Fig. 8. Project time and cost comparisons of present and path forward simulation output at project level.

Table 6
Statistics comparison of present and path forward project simulation output

	Elapsed time		Activity time		Activity cost	
	Present	Path forward	Present	Path forward	Present	Path forward
Mean	43	41	114	110	111	110
Standard error	0.2	0.2	0.3	0.3	0.7	0.7
Median	43	41	113	110	110	108
Mode	43	42	111	111	107	116
Standard deviation	4	4	7	7	16	16
Sample variance	13	13	55	55	244	246
Range	22	20	40	44	79	83
Minimum	34	31	95	88	74	71
Maximum	56	51	135	132	153	154

was new data for each activity, which represented path forward values of time and cost for activity execution. Like the original data sets, new triangular distributions were developed using a least squares minimization technique.

New path forward output was obtained by incorporating these new time and cost distributions, for the selected design activities, into the ABC-SIM simulation model for the baseline condition. A comparison of EPC project baseline and path forward results are shown in Fig. 8 and Table 6.

10. Results and conclusions

As the histogram and related statistics indicate (see Fig. 8 and Table 6, respectively), the improvement from present to path forward for the project is substantially less than the improvement of any one of the individual activities from present to path forward. The calculated reductions are shown in Table 7.

Many of the individual tasks that were modified were estimated to improve by over 90%. Yet, at the individual activity level, the average improvement was only 25, 29, and 14% for the mean elapsed time, activity time, and activity cost, respectively. At the broader project level, the improvements were again substantially lower than those observed at an activity level, with no performance measure indicating a reduction greater than 5%. This strongly demonstrates the value of quantifying changes at the project level rather than performing an analysis strictly at the subprocess level.

Table 7
Reduction in project mean values from present to path forward

	Reduction in mean
Elapsed time	5%
Activity time	3%
Activity cost	1%

Although Fig. 3 indicates that the design activities consume a greater percentage of project cost than project time, Table 7 indicates that the impacts of design changes were more significant in terms of project time than cost. This is in spite of the fact that similar changes were made to the time and cost data values for each task that was modified.

These results may at first appear to be counter-intuitive. However, when one recalls that the values in Table 7 were influenced not only by time and cost data but also by activity dependencies, the results are entirely logical. This further emphasizes the need to quantify the impact of change in a project level model that incorporates the inter-relationships at the activity level. Evaluating work process improvements at the functional or discipline level of the EPC process may yield misleading conclusions.

These results demonstrate the ability to predict and quantify the impact of design process changes on total project cost and time. This study also helps to explain the reason why many companies claim they are not realizing project level benefits when improvements to a given subprocess are so readily apparent and easily identified. As this case study has illustrated, analyzing the design portion of the project, without considering its interaction with and dependencies on other phases, may lead to inaccurate and overly optimistic expectations for project savings. Expectations can be improved, and managed, by investigating the project execution process holistically, even if changes are only contemplated for a few key activities.

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