DISSERTATION

A DECISION SUPPORT SYSTEM FRAMEWORK TO IMPROVE DESIGN-CONSTRUCTION INTEGRATION AND PROJECT PERFORMANCE ON PUBLIC SECTOR UNDERGROUND UTILITY PROJECTS

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY G. BRUCE GEHRIG ENTITLED A DECISION SUPPORT SYSTEM FRAMEWORK TO IMPROVE DESIGN-CONSTRUCTION INTEGRATION AND PROJECT PERFORMANCE ON PUBLIC SECTOR UNDERGROUND UTILITY PROJECTS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

A DECISION SUPPORT SYSTEM FRAMEWORK TO IMPROVE DESIGN-CONSTRUCTION INTEGRATION AND PROJECT PERFORMANCE ON PUBLIC SECTOR UNDERGROUND UTILITY PROJECTS

One of the noted difficulties with the traditional public works project development process is the lack of integration and sharing of information between engineering and construction entities that results in a decrease in project performance. To improve project performance on public sector underground utility projects, the research develops a decision support system framework that enhances the exchange and integration of relevant information and knowledge between entities on such projects by incorporating a lessons-learned database to document, organize and disseminate lessons-learned on a project.

To identify the critical activities within the project development process that could be linked to the decision support system, the Integration Definition for Functioning Modeling (IDEF0) technique was used to create a representative model of the public works project development process. The resultant model demonstrated the repeatable nature of the process both across project phases and from project-to-project and identified the decision-making activities of generating and evaluating alternatives as key opportunities for construction-related input that could be linked to a decision support system.

An inspection of current industry practices was conducted through interviews with knowledgeable industry sources to determine the scope of the decision support system framework. Results revealed the type of critical decisions on underground utility projects that could benefit from construction-related input and identified the documentation of lessons-learned as a major industry weakness.

A prototype decision support system incorporating a lessons-learned database was developed and the framework integrated into common project management reporting mechanisms found in the industry. The actual decision-maker can retrieve lessons-learned according to predetermined categories of critical decisions, compare and evaluated retrieved alternatives, and document the rationale behind the ultimate decision made.

The framework for the decision support system was evaluated by knowledgeable industry sources and through the use of a hypothetical case study. Evaluations determined the proposed system would improve design and construction integration and project performance on public sector underground utility projects. However, additional research is required into determining both the most suitable lessons-learned database structure and ways to increase the incentive for project participants to fully participate in the methodology.

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I would also like to thank the individuals and organizations whose willingness to participate in the interviews and evaluations that made this dissertation possible. Participating individuals included John Bambei, John Cevaal, Mel Spangler, Mike Leister, Tom Meyers, Roger Wood, Link Mueller, and Opal Dick. Appreciation is given to the Denver Water Department, The City of Fort Collins Stormwater Division, Grimm Construction Company, and Camp, Dresser, and McKee for allowing their employees to take time out of their busy days to participate in my research.

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And finally, but clearly not last, my love and appreciation go to my wife, Karen, for her undying support over the last three years. I know it was extraordinarily difficult for her at times to have to work part time jobs, to live in someone else's house, and to endure the stress that I often carried home from school. Without her support neither this research nor my academic accomplishments would have been possible. Nor would have any of it been worth the effort. All I can say is thanks and I love you a lot.

On a closing note, it is hoped that the engineering and construction industry can find something of value to take from this report. I have always considered it a privilege to be a part of the civil engineering profession and to play a small part in its efforts to improve the quality of life of others by providing the necessary infrastructure upon which society depends. It is my wish that this research will prove to be a contribution to that continual effort.

Sincerely,

Bruce Gehrig, P.E.
B.S., Brigham Young University, 1984
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This dissertation is dedicated to my beloved wife and companion, Karen

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CHAPTER 1: INTRODUCTION

Section A: Need for Improvement in the Delivery of Public Works Projects

The world's civil infrastructure systems, increasingly complex and interconnected, are under stress and eroding due to age, neglect, misuse, and excessive demand [Bordogna]. As a result, public work agencies are faced with the task of building new facilities and/or upgrading existing systems in order to provide adequate levels of service that will enable continued economic prosperity. However, constrained by both limited financial resources and inefficient procurement methods for engineering design and construction services, such agencies often find it difficult to construct the required improvements in a timely manner or within the available budget.

Despite these difficulties, the traditional method of delivering public works projects has changed little over the last several decades. The process of planning, engineering, constructing, and operating a facility is often referred to as the project development process. It is a cyclical, repetitive process that encompasses all of the major phases involved in the life cycle of a project from conception through decommissioning as illustrated in Figure 1-1. Traditionally, the process is a segmented, sequential process where one entity performs and completes a task before passing the results on to another, often different entity for further processing, and so on until the project is completed. One party might carry out the planning or needs assessment for a project. Then, using the resulting planning document, a different engineering firm performs the detailed engineering analysis and prepares a set of contract documents that are passed on to a contractor and the project constructed.

Such a segmented, sequential process restricts feedback between the phases and entities, thereby limiting access to information that could be used to improve the project. A potential

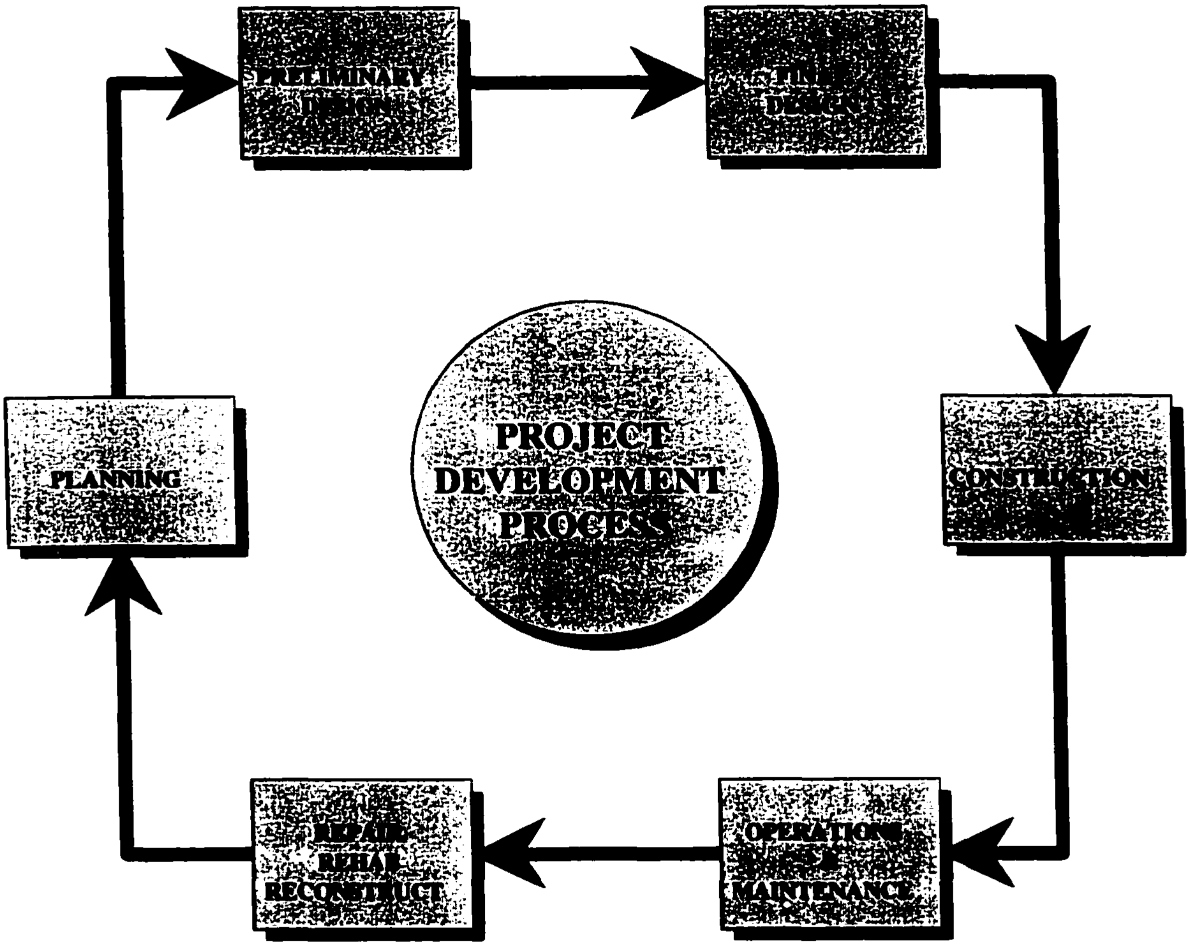


Figure 1-1: Project Development Process

contractor may have an idea or construction technique that could potentially reduce the cost or time to construct a project. However, by the time the contractor enters the process the planning and design has already been completed making it difficult to formally incorporate the suggestion into the project, particularly if it involves major changes. In addition, any lessons-learned during the project development process are not transferred to other project participants with each entity maintaining exclusive control and ownership of any new experience gained over the course of a project. The result is a lost opportunity for project innovation that could improve performance, reduce costs, or shorten construction schedules.

In addition, the segmented nature of the process tends to produce opaque results where much of the information and rationale used during the decision-making is hidden from subsequent participants. This impedes communication and obstructs understanding between entities, which often leads to contractual disputes when errors or changed conditions are encountered on a project [Reinschmidt]. Much time and effort is involved in resolving such disputes as attempts are made to reconstruct the process to determine the basis for decisions made and to appropriately allocate liability for actions taken. Such disputes often drive up project costs and delay project completion and are considered a major contributing factor in the lack of productivity improvement within the construction industry [Business Roundtable (1983)].

The traditional method of planning, designing, and constructing public works projects reflects the pre-digital era of communication in which it evolved. During that era the process was necessarily segmented as the only way to transfer information in a permanent fashion was through delivery of a hard copy paper document. Therefore, when one task was finished the results were transmitted to others via written reports and hand-drafted drawings. Information in such paper documents is by nature opaque as it is difficult to incorporate all of the underlying information behind the documents' creation directly within the documents themselves.

With the advent of the digital age, particularly the personal computer, the engineering design process has become more integrated as software was developed that allowed many different design functions to be combined in one package. Before the computer, a surveyor would deliver his field notes to the engineer, the engineer would perform his design calculations and give his sketches to a draftsman, and the draftsman would prepare the final plans. Now, the surveyor's data is directly downloaded into the computer, the engineer accesses the electronic surveying data, performs the design modeling and produces the sketches all in the same program, and the draftsman uses compatible software to produce the final drawings. All parties have access to all of the same information and tools, thus making the transfer of data more transparent. And the same information can be delivered to other third parties, with all of the underlying data, as a digital electronic package.

Construction contractors can utilize the same digital information to prepare cost estimates, produce construction schedules, and to manage their projects. However, due to the traditional design-bid-build project delivery method contractors still are not given access to the project data, digital or otherwise, until the bid solicitation period. This has allowed the traditional information-sharing gulf between the engineering and construction sectors to remain little changed from the pre-digital era.

Therefore, due to the apparent shortcomings of the traditional design-bid-build project delivery method, new approaches are being tried to lower costs and increase productivity in delivering public works projects. Formal contracting methods such as design-build and construction management-at-risk, and non-contracting management philosophies such as partnering, constructability, and concurrent engineering are all being utilized and evaluated in an effort to improve the exchange of information and knowledge between the owner, engineer and contractor, particularly on larger, long-term projects.

However, the applicability and effectiveness of these alternative methods for use on the more typical and smaller public works project has yet to be fully demonstrated. But it seems reasonable that, if identified, the same underlying principles that make these alternative methods effective on larger projects could be applied on smaller, more straightforward projects such as underground utilities. As a result, it should be possible to develop a methodology that improves the traditional design-bid-build project delivery process by expanding the opportunity for construction-related input into the engineering design process. A systems approach that improves the transfer and sharing of data and expertise between the engineering and construction entities on a project, increases the potential for innovation, and improves project performance, reduces costs, and shortens construction schedules.

Section B: Problem Statement and Research Objectives

Based on the preceding discussion, the problem statement for the research dissertation is:

To improve the performance of traditional design-bid-build public sector underground utility projects through the development of a decision support system framework that enhances the exchange and integration of relevant information and knowledge between engineering and construction entities during the engineering design phase of capital improvement projects.

The problem statement was decomposed into several key objectives by which the research was evaluated. First, the primary objective of the research was to improve the performance of underground utility projects within the context of the public sector's traditional design-bid-build project delivery system. Indicators of performance on civil construction projects commonly include reduced capital and life cycle costs, reduced engineering and construction duration, improved project or system functionality, and reduced contract administration difficulties and disputes.

A review of the research literature indicates that improvement in project performance is generally correlated with both the extent and timing of the exchange of information between the engineer and contractor on a project [ASCE (1990), Gibson]. However, the critical decision-making links within the traditional design-bid-build project delivery process that could benefit from the additional construction related information have not been rigorously identified [Russell (1992), Vanegas]. Therefore, in order to properly structure a methodology that will enhance the exchange and flow of information, the next objective of the research was to identify and describe the nature of the critical decision-making activities required for improved project performance.

Once the critical decision-making activities had been described, the last objective of the research was to develop a decision support system framework that enhances the exchange and integration of information between the engineering and construction sectors during the engineering design phase. For this research, enhancement of informational exchange was defined to include not only improvement in direct communication among project entities but also to include improved access to relevant construction related knowledge or information.

The exact nature and structure of the decision support system was dictated by the results obtained during the research effort. The resultant decision support system was a web-based application hosted by public works agencies (i.e. owners) that allows project participants to electronically submit and access project information, to share and document decision-making rationale on project alternatives, and to develop a lessons-learned database of experienced gained for use on future, subsequent projects.

Section C: Dissertation and Research Outline

The structure and outline of the dissertation parallels closely the research methodology used to undertake the research project. Following the introduction provided in Chapter 1, Chapter 2 presents a summary of the extensive literature review that was performed to develop the foundation for the research. The literature review provides background information on design and construction integration research, project delivery methods and management philosophies, project development process modeling studies and techniques, and electronic data information exchange technologies. The chapter concludes with a summary of relevant future research needs as identified from the literature.

Chapter 3 discusses project development process modeling in detail and presents the aggregated model developed by the author. The author's model was synthesized from models taken from the literature that addressed design and construction integration in general and the project planning, design-bid-build, design-build, and constructability processes in particular. The model then is used as a basis for identifying and discussing the critical information exchange activities required for improved project performance and to identify possible links between the project development process and a decision support system.

Chapter 4 provides a summary of the information obtained from interviews conducted with representatives from the owner, engineering, and construction sectors of the public works sector. The purpose of the interviews was to establish a baseline for the state of the industry as it pertained to current project delivery strategies and design and construction integration practices. Also, an effort was made to discover the key informational or integration opportunities on underground utility projects.

Based on the information gathered concerning both the project development process and industry needs, a framework for a lessons-learned based decision support system was developed and presented in Chapter 5. The decision support system framework was structured to overlay the project development process model presented in Chapter 3 and the typical project management control mechanism(s) used in industry.

Chapter 6 provides an evaluation of the effectiveness of the proposed framework. A second series of interviews was conducted with the original industry respondents where they were asked to evaluate the developed project development process model, the major conclusions obtained from the first interviews, and the usefulness or effectiveness of the proposed decision support system methodology. An effort was made to focus the evaluation on the probable effect on overall project performance and potential barriers to implementation.

To further demonstrate the proposed concept and to highlight potential incentives for adopting and participating in the concept, Chapter 7 presents a hypothetical case study comparison. Finally, Chapter 8 summarizes the conclusions obtained from the research, significant research contributions, and identified future research needs.

CHAPTER 2: LITERATURE REVIEW

Section A: Design and Construction Integration

A.1: Introduction

As stated previously, the basic premise of the dissertation research project is that the performance of public works projects can be improved through improved coordination or communication between the design and construction sectors during the project development process. This coordination or communication process is what has been referred to in the research literature as "*design and construction integration*." Therefore, before undertaking research into improving the process of design and construction integration, a review of the research literature was performed in order to clearly define the term so that the actual scope of the research problem could be identified.

The word "integration" is defined as "the bringing or fitting together of parts into a whole" [Funk & Wagnalls]. As an extension, therefore, design and construction integration can be viewed as "the continuous interdisciplinary sharing of data and knowledge between design and construction" [Fischer]. As this describes a rather ambiguous process, researchers have attempted to further refine the concept

Vanegas described the concept of design and construction integration in the framework of a two dimensional model. In the horizontal direction, he indicated integration could occur between project disciplines such as architectural, structural, mechanical, etc. In the vertical direction, he proposed integration occurring over time or across project phases such as planning, design, construction, etc. Therefore, horizontal integration primarily focused on the coordination of parties during a common or single phase of a project while vertical integration focused on the interaction or exchange between project phases.

Vanegas noted that design and construction integration would not happen on its own. Too many opposing and conflicting interests and objectives prevent the natural blending of design and construction. To work, integration needs an appropriate plan and treatment as another project objective, just like cost-effectiveness or timely delivery. This requires an adequate administrative climate and a contractual approach that supports integration.

Along the same lines, Nam identified three possible methods of integration on construction projects. The first was organizational integration where the design and construction functions were concentrated in and performed by a single entity. The second method was contractual integration where the design and construction entities are separate but tied together by third party contractual arrangements. The last method was informational integration where the design and construction entities share common databases.

In general, the first method would fall in the domain of horizontal integration as described by Vanegas, the second would fall in the domain of vertical integration, and the last method could address issues in either direction of integration. Besides these formal methods of integration, Nam indicated that there were also informal methods that could be used to promote integration on a project. Specific methods mentioned include the owner's leadership, development of long-term business relationships, professionalism of individuals and organizations, and the designation of "integration champions" to promote the cause of integration.

Building on this research, Fergusson developed a framework for integration that added a third direction or vector of integration. Maintaining the horizontal and vertical directions of integration as proposed by Vanegas, she added a third, longitudinal vector that included integration across time between successive projects. This third direction would encompass organizational development or lessons learned through repetition with similar projects. A schematic of the concept is shown in Figure 2-1.

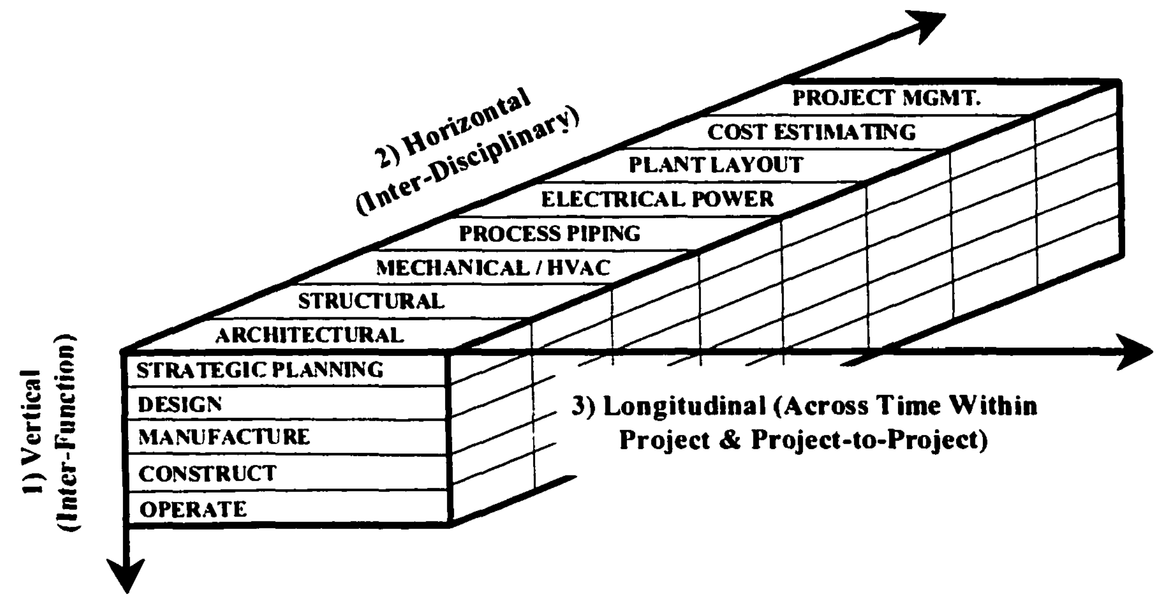


Figure 2-1: Fergusson's Three Dimensional Model of Integration

Considerable effort in improving design and construction integration has been focused on the horizontal or inter-disciplinary integration. These efforts have included methodologies to improve the efficiency of sharing and exchanging data between parties during a single or common phase of the project development process. However, using a statistical regression analysis, Fergusson demonstrated that the vertical and longitudinal components of integration had a more significant impact on overall project quality then did the horizontal component.

Design and construction integration, therefore, spans the entire project development process and across successive projects. The concept relates to other project objectives, contracting strategies, cost estimating, scheduling, procurement, communication mechanisms, decision-making, problem solving, and technologies that support integration [Vanegas]. It is this overall project development system that is the focus of this research dissertation.

Unfortunately, despite these efforts to explicitly define design and construction integration, confusion continues to surround the concept, as other terms found in research and industry are often erroneously considered synonymous. For example, the concepts of value engineering, construction management, and constructability all incorporate portions of design and construction integration but do not represent the full scope [Vanegas]. The term "constructability" or "design constructability" is probably the most frequently encountered terminology that is often used synonymously to mean design and construction integration. In its purest form and definition, there is probably little error in considering the terms synonymous. However, as constructability itself is often ill defined and poorly understood [Vanegas], care must be taken when encountering the term in the literature. More specifics on constructability and other similar concepts can be found later in the literature review.

A.2: Quantifying and Evaluating Integration and Associated Benefits

It has been shown that the ability to influence a project's performance decreases over the life of the project [ASCE (1990), Gibson]. In other words, decisions made early in the initial phases of a project while expenditures are still low have greater impact then later decisions as qualitatively illustrated in Figure 2-2. As some have estimated that 75% of the problems encountered during construction are generated in the design phase, construction expertise must be brought into the review process at the earliest conceptual stages of the project [Mendelsohn].

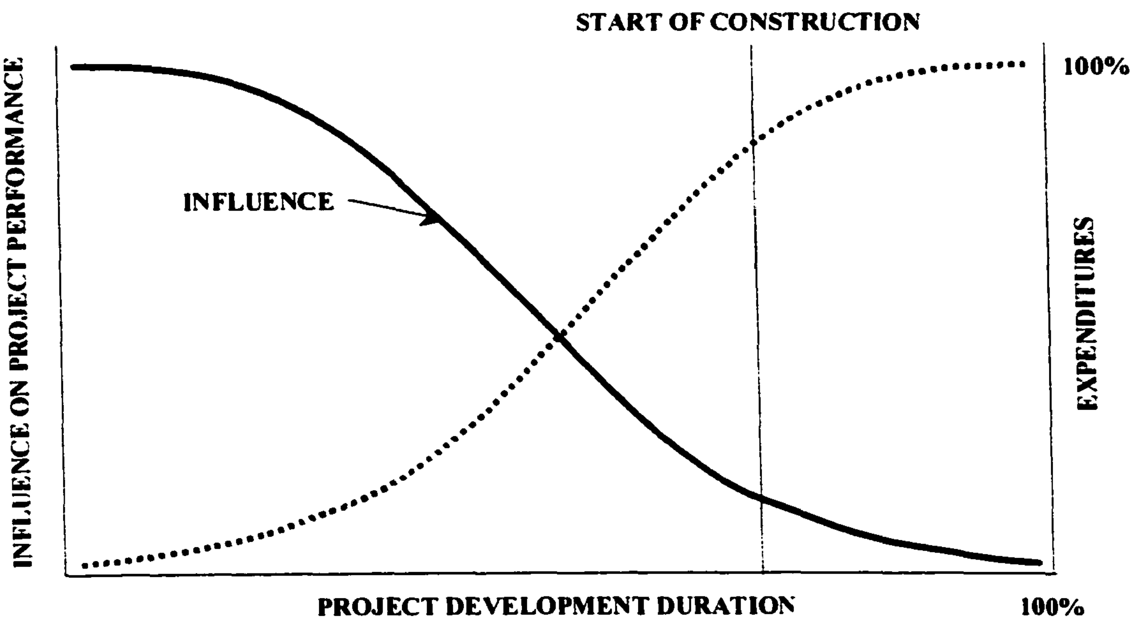


Figure 2-2: Influence and Expenditures Curve for the Project Development Process

One of the goals of this research, and with design and construction integration research in general, is to address this problem by developing methodologies that incorporate construction expertise earlier into the project development process where it can have a greater impact on the performance of the project. In order to evaluate the effectiveness of any such methodology, it becomes necessary to establish how project performance or quality is defined. Surprising, defining quality is not as straightforward as it would appear, as it is dependent on the reviewer's perspective and relationship to the project [Fergusson].

ASCE has defined quality as "the totality of features, attributes, and characteristics of a facility, product, process, component, service, or workmanship that bear on its ability to satisfy a given need: fitness for purpose" [ASCE (1990)]. In other words, quality is meeting the project requirements. In most instances, the four primary areas of concern when evaluating project performance for most public works projects are cost, schedule, functionality, and ease of management (i.e. lack of disputes). Unfortunately, these parameters are often weighted and evaluated differently by different project participants. Despite this difficulty, these four basic parameters of project performance were selected as the benchmarks for evaluating the effectiveness of the research results.

Vanegas notes that design and construction integration is often cited as a means to improve project performance, but there is no clear understanding of why or how to formally incorporate construction as a part of the process of design. In addition, there are no performance indicators to measure the actual degree of integration or to measure the cost, schedule, or quality improvements. Without these measurement and evaluation indicators to quantify both the extent and benefits of integration, questions of "why do it" will persist.

To address this issue of "why do it", Pocock developed a formula for measuring the degree of interaction or integration between project participants on projects. Based on his formula, he was able to demonstrate quantitatively that the earlier and larger degree of interaction resulted in improved project performance, as defined previously, thus confirming the qualitative chart shown in Figure 2-2. Unfortunately, most design and construction integration studies lack hard, quantitative data on the benefits resulting from improvements in integration.

Section B: Project Delivery Methodologies

B.1: Public vs. Private Sector Distinctions

Before a discussion of the various project delivery methodologies can be undertaken, a brief outline on the distinctions between public and private sector projects is required. The obvious distinction between public and private sector projects is the financing mechanism. Public projects are designed and constructed using public or taxpayer funds while private sector projects obtain their financing from private sources such as banks or individual investors. Because of this distinction in funding sources, regulations have been developed to strictly control expenditures on public projects in order to protect the public funds from mismanagement or abuse.

As a result, public sector agencies have organizational boundaries that are rigid and impermeable and employees have well-defined jurisdictions, responsibilities, and a hierarchy of authority [Crowley]. This bureaucratic organizational system with its accompanying procurement regulations limits the flexibility of how public agencies contract for engineering and construction services. In contrast, private-sector organizations have fewer limitations or controls and, therefore, can be much more creative and innovative in how they contract for services. As a consequence, the low-bid, competitive contracting generally required on public works projects inhibits the development of the long-term business relationships evident in the private sector [Larson].

In addition, the budgeting process for the two sectors differs. Public works projects often must be subjected to a series of protracted reviews and approvals by public agencies, political bodies, and even the vote of taxpayers before monies can be budgeted for a particular project. Also, the budgeting process often requires separate budget approvals for each project development phase, which results in a lack of continuity between project phases. On the other hand, the budgeting process for private sector projects is limited only by the willingness of financial institutions to provide funding for the project.

B.2: Contracting Methods

B.2.1: Introduction

A project delivery system is a way of organizing the building of a project. This is usually accomplished through a series of contracts between the owner of the project and the design engineer and construction contractor. The contracts are merely a legal mechanism to assign responsibility for various tasks and to distribute or apportion the risks associated with bringing a particular project from conception through completion [Rubin]. One of the primary mechanisms for achieving vertical integration across project development phases is through contracts [Fergusson, Nam, Sanvido, Vanegas].

Therefore, numerous efforts have been made to devise contracting strategies that maximum the potential for vertical design and construction integration. In fact, it has been said that many really great project deliveries owe at least a portion of their success to the design of the process itself, and many of these deliveries have used components from several distinct project delivery styles [Young]. Although many hybrid project delivery systems have been developed, most contracting methods for civil infrastructure projects fall into one of three basic categories: design-bid-build, design-build, and construction management-at-risk.

B.2.2: Design-Bid-Build

The design-bid-build project delivery system is the traditional methodology used for public works projects. The system is a sequential process where the owner contracts with an engineering firm to complete the design of a project and to prepare a package of detailed plans and specifications referred to as contract documents. Once the contract documents have been finalized, the owner then solicits competitive bids from construction contractors and awards the construction contract to the lowest, responsible bidder. The selected contractor then proceeds to

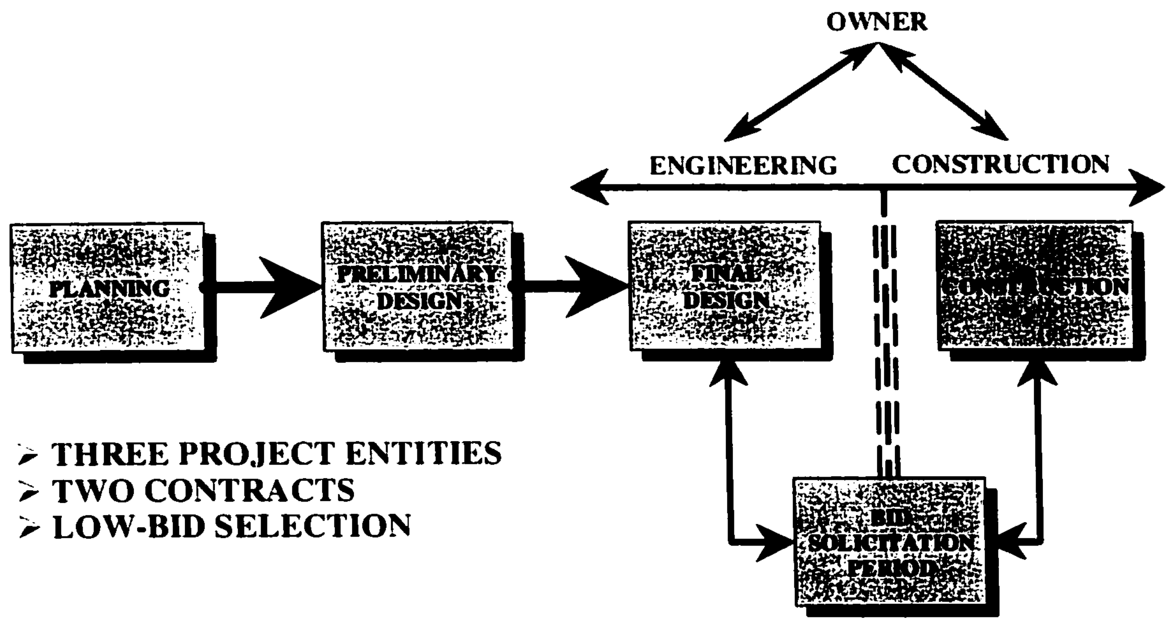


Figure 2-3: Design-Bid-Build Project Delivery Schematic

construct the project in accordance with the contract documents. A schematic of the process is shown in Figure 2-3.

As can be seen from the diagram. the contractor does not become involved in the project until relatively late in the overall project development process and. therefore. has very little opportunity to provide construction related input or innovation to the design process. Also. the engineer's and contractor's only real opportunity to collaborate before committing to a final cost is during the short bid solicitation period. As a result. one of the major identified weaknesses of the design-bid-build process is the lack of integration between design and construction entities [Iyer. Lynch]. This lack of integration is due. in part. to three problems [Iyer]:

1. Basic information and knowledge about construction technologies is not being shared between designers and contractors.
2. Interactive procedures to apply construction knowledge at early design stage have not yet been developed.

3. No systematic evaluation and feedback of relevant data and information is occurring during construction.

One consequence from this lack of integration is an increase in the cost of a project. Because designers lack sufficient knowledge in construction technology to provide the necessary construction expertise during design, it has been estimated that costs are typically 10 to 20% higher than necessary [Heery]. As the best source of construction knowledge lies within the construction industry and not with engineers or architects [Heery], improved design and construction integration could help provide the required construction expertise and lower project costs. Some have attempted to provide this input by conducting a symposium of interested contractors to evaluate the preliminary design of a project but feedback indicated that the process should have been held even earlier in the design phase [Wood].

Another major weakness is the adversarial nature of the contracting arrangement [Lynch]. As there is no direct contractual relationship between the engineer and the contractor. there is no implied obligation of the parties to work together for the overall good of the project. Instead. each party's primary concern lies in protecting their own self-interests or profit margin under the terms of their respective contracts with the owner. Therefore, as it is impossible to produce an error free set of contract documents, disputes and litigation often arise between the parties because of the discrepancies [Heery]. Unfortunately. due to the nature of the contracting relationships, the owner usually finds himself caught in the middle of the disputes.

Despite these disadvantages, the design-bid-build contracting method remains the predominant method for delivering public works projects. The primary reason is its close association with the competitive, low bid system for awarding public construction contracts that is legislatively mandated by many jurisdictions. Although it is impossible to pinpoint the exact origin of the concept, competitive, low price bidding has been practiced in New York State since 1847 and has been mandated for highway and bridge contracting in the State by legislation dating to 1898 [Herbsman]. Most Federal, State and local agencies have adopted similar procurement regulations for public works projects.

In describing the concept, Herbsman indicated the basic premise behind the low bid system was that it would protect the public from extravagance, corruption, and other improper practices by public officials. Also, the public would receive the full benefit of the free enterprise system by providing public construction at the lowest price offered by competitive bidding. The one major advantage of low price bidding is that it is completely objective and independent from any sort of political pressure. The major disadvantage is that it excludes other criteria such as schedule and quality.

Ironically, it should be noted that public procurement regulations for professional services, such as engineering, take a completely opposite approach then that used for construction services. The Federal government's Brooks Act and other similar State and local legislation specifically forbids the procurement of professional services on a low bid or lowest cost basis [McManamy]. Instead, a qualification based selection process must be used where cost is not a consideration in the decision making.

One consequence of the competitive, low bid system is that it can encourage some contractors to submit prices that are below reasonable costs in order to get the work. This practice often results in disputes during construction as the contractor tries to find ways to increase his monetary compensation through claims of changes or errors in the design. In an effort to overcome this drawback, some other countries have methods where the bid closest to the average of all bids is accepted as the lowest reasonable bid while others consider only those bids that fall within a predetermined bracket [Herbsman].

Because the design-bid-build method requires the design to be fully completed before commencing construction, it is completely compatible with the competitive, low bid system as it allows contractors to bid on a complete, finalized design. This complete, finalized design is one of the major advantages of design-bid-build as the owner can specify and know all of the exact details of the project before it is bid and constructed by a contractor. The major risks to the owner is that a project built according to the plans and specifications may not perform as expected and is liable for any delays associated with providing information to both the engineer and contractor [Rubin].

B.2.3: Design-Build

The design-build project delivery system is not new and was once considered the traditional method and is also sometimes referred to as "turnkey", "build-to-suit", or "engineering-procurement-construction" [McManamy]. The system is a process where the owner establishes the basic objectives of the project and prepares a detailed request for proposals (RFP). Qualified teams or joint ventures of engineers and contractors then respond to the RFP with individualized design and construction concepts indicating how they propose to satisfy the project objectives and complete the work. After reviewing the proposals, the owner then selects the concept that best satisfies his needs and awards a contract to the selected project team. The design-build team then proceeds to complete the final design and to construct the project. A schematic of the process is shown in Figure 2-4.

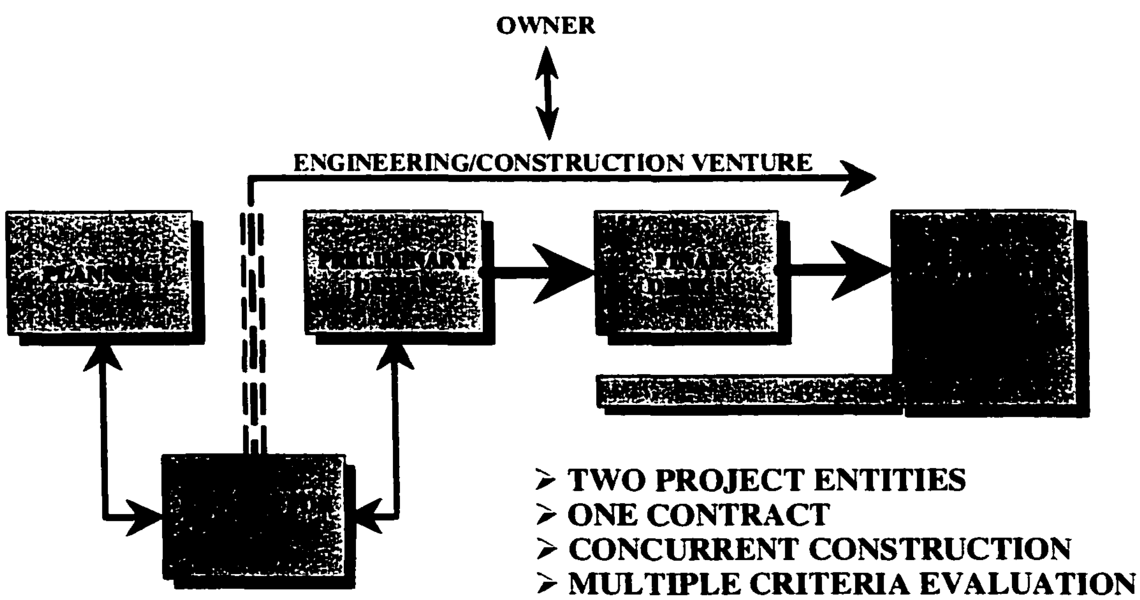


Figure 2-4: Design-Build Project Delivery Schematic

As can be seen from the diagram, the design-build process differs from the design-bid-build process in that the design and construction functions are performed concurrently rather than sequentially. Therefore, this allows the contractor to get involved earlier in the project development process and allows for more construction-related input or innovation into the design process. Obviously, this increased design and construction integration is seen as one of the major advantages of the design-build project delivery system and is one reason more public agencies are becoming interested in the concept.

In addition to the improved design and construction integration, another major reason for the increased interest by the public sector in design-build is the desire to decrease the overall time it takes to deliver a completed project [FCC]. Under design-build it is possible to complete the design and commence construction on portions of the project while the design of the remainder of the project is still being completed. This process of schedule compression by commencing construction before the entire design is complete is referred to as "fast-tracking." Although fast-tracking is often erroneously considered synonymous to design-build, the concept is not limited to nor is it a necessary component of the design-build project delivery system.

Although the private sector has used design-build contracting for a considerable time for residential and building type projects, there has been a recent upsurge of interest in the concept. For example, the estimated volume of non-residential design-build construction has increased from 10% to 50% of the market from 1980 to 2001 [Gray]. Despite this trend, the public sector has been slow in adopting design-build project delivery systems. The first documented public-sector use of design-build was in 1968 at school districts in the Midwest and it wasn't until The Federal Acquisition Reform Act of 1996 that federal agencies were given the legal authority to engage in design-build projects [Molenaar (1999)].

The primary obstacle in adopting design-build in the public sector has been the public procurement requirements mandated by many jurisdictions. Some of these requirements, which vary by jurisdiction, include [Terrill]:

1. Construction contracts must be awarded by competitive, low bid.
2. Design services must be acquired through qualification based negotiations.
3. Design and construction services must be performed separately.

Because the design has not been completed at the time of the RFP, the owner must evaluate design-build proposals on other factors, such as quality or functionality, besides just lowest cost. This often conflicts with regulations that require construction contracts to be awarded based solely on lowest cost. Conversely, since design-build proposals include engineering as well as construction services and the owner's evaluation of the design-build proposals usually includes cost as one of the criteria, this violates the regulations on procurement for professional services which allow only qualification based negotiations. Also, there are some jurisdictions that specifically mandate the separation of design and construction services. Clearly, the process is often ahead of the laws [McManamy].

Another reason for the slow adoption of design-build by the public sector is the lack of hard data supporting its value in improving project performance. However, several research studies have indicated an improvement in cost, schedule, functionality, and contract administration for design-build projects over traditional design-bid-build projects [FCC,Konchar, Molenaar (1999)]. Another advantage is that it removes the owner from the middle of conflicts between the designer and contractor and reduces claims because of the direct contractual relationship between the design and construction entities [Stortstrom]. Accountability is clear, undivided and centralized in one entity, therefore, there can be no "passing of the buck" [Brott].

Numerous researchers such as Heery, Rubin, Songer (1992), and Stortstrom have noted both the advantages and disadvantages associated with the design-build project delivery system. A summary encompassing these and other researcher's views on advantages and disadvantages of design-build was compiled by Songer (Ph.D.) and reproduced in Table 2-1.

Table 2-1: Primary Advantages and Disadvantages of Design-Build

Advantages for Owners Include:

- Owner only has to communicate with one entity for the entire project and only one entity is approached concerning job performance.
- Total project duration can be reduced because phased construction is easier to implement.
- Integration of construction planning into planning and design phases.
- Continuity of project management throughout entire project.
- Claims reduction
- Innovation in design and construction can be encouraged.

Advantages to a Design-Build Organization Include:

- Receipt of both design fee and construction profits.
- Reduction of negligence claims between engineer and the construction contractor since they are under an umbrella firm.
- A specialized organization can be developed that has a specific expertise which will be attractive to specific market areas.
- Ability to react rapidly to changes in scope.
- Improved constructability through design and construction integration.

Disadvantages for Owners Include:

- Fewer checks and balances so owner must rely on integrity of the design-build firm.
- Reduced owner involvement in the design process may result in less than expected results.
- Increased difficulty in properly portraying objectives and developing specifications.

Disadvantages for the Design-Build Organization Include:

- Heavy overhead due to large multi-disciplined staff requirements.
- Acceptance of additional project risk.
- Possible premature release of bid packages, if project is fast tracked, which can lead to increased errors in the plans and specifications resulting in delays and extras.

In addition, Terrill summarized some additional legal issues surrounding design-build contracts, which include:

1. Courts understanding of design-build. Do the courts have a clear enough understanding of the contractual relationships in design-build to make informed decisions?

2. Liability. Do the various entities understand how risk is allocated under design-build? For example, designers may become liable for construction errors and contractors liable for design errors.
3. Insurance coverage. Typical insurance coverage includes professional liability and builder's risk-all and possible gaps in coverage may exist when a single entity performs both functions.
4. Bonding. What does a performance bond on design-build encompass? Normal bond covers just construction.
5. Licensing. Who is required to hold what licenses? This varies by jurisdiction.
6. Conflicts of interest. What duty does the designer have towards the owner? Under design-build, the designer has a legal contractual relationship with the contractor but a professional ethic duty to the owner and public.
7. Mechanic's Lien. Does the principle party have lien rights for the other parties work (i.e. contractor for the designer's work)?

One of the primary difficulties for owners utilizing design-build is the preparation of the request for proposals. As the RFP is the primary communication tool for conveying the owner's goals and objectives to the design-build team, how does one best convey this information? Research has shown that to receive the maximum benefit from the design-build process, performance based rather than prescriptive based specifications should be used to define the project [Brott, Molenaar (1999), Lynch, Songer (Ph.D.)]. This gives the design-bid team more flexibility and increases the opportunity for innovation. However, if criteria are shown graphically, the owner cannot assume proposals will improve upon the design [Songer (Ph.D.)] and, therefore, the RFP must be based on a "good" initial design. Research has also shown that the optimum amount of engineering that should be completed before the RFP is issued is between 15 to 35% [FCC, Heery, McManamy, Molenaar (1999)].

Unfortunately, the biggest risk to an owner under design-build is a poorly written or defined RFP [Rubin]. Statistical regression analysis by Molenaar (1998) indicated that a significant project variable in the outcome of a design-build project was the RFP includingscope definition, schedule definition, and budget definition. A well defined RFP can lessen the odds of excessive change orders. however, an oversight requiring correction can be far reaching and very costly as construction often has progressed farther along then under traditional design-bid-build delivery methods [Brott]. Because of the increased difficulty in preparing the RFP, design-build has a slightly higher administrative burden, particularly in the early stages of a project, then other project delivery methods [Molenaar (1990)].

One other key concern with the design-bid project delivery method is the evaluation of proposals. Since the evaluation is based on other criteria in addition to cost, how does one minimize the subjectivity and keep the process as fair and open as possible? First, research has shown that evaluation criteria and the relative weights between criteria must be clearly stated in the RFP and should not be changed after the fact [Molenaar (1999), Songer (Ph.D.)]. Also, it is generally recommended that potential bidders be shortlisted in order to reduce the cost of preparing and evaluating proposals [Gray]. Songer (Ph.D.) recommends the use of anonymous proposals during the technical evaluation phase in order to eliminate any personal biases that may exist towards individual contractors.

The preferred method for shortlisting of contractors is the two-step process adopted by the Federal government in 1996 [Gray, Molenaar (1999), Napier]. In step one, professional qualifications are screened and three to five firms are selected to compete based solely on technical qualifications. In step two, the selected contractors refine their proposals and submit formal bids on the project. In a single, or one-step process, proposals are submitted and evaluated for both cost and technical items without pre-screening of bidder proposals [Napier]. Molenaar (1999) found the two-step method better in terms of the final cost and schedule of a project while the one-step method was better for project expectations and functionality. Finally, some have recommended reimbursements or stipends for non-selected bidders as it would allow small firms to compete, encourage originality and innovation, and increase the desire of firms to submit proposals [Gray, Songer (Ph.D.)].

Success of design-build has not been as easy as expected as the industry is fragmented with many legal and cultural barriers [Luiten]. The important thing to remember is that the intent of the design-build movement within public works is to move away from standard procedures and to inject private sector methodologies and products into the project [Songer (Ph.D.)]. For individuals who might be considering the use of design-build. a summary of many of the issues that need to be considered before making a decision has been provided in Table 2-2.

B.2.4: Construction Management-at-Risk

Construction management-at-risk is a project delivery system that is used less frequently then either design-bid-build or design-build within the public works sector. The system is one where the owner hires a construction management firm to manage the various contracts that may be associated with a project. The construction manager then procures the necessary contracts for design and construction services and provides the contract administration until the project has been completed. The important difference between construction management-at-risk and design-bid-build is that the contractual relationship with the design and construction entities is between the construction manager and not the owner. A schematic of the process is shown in Figure 2-5.

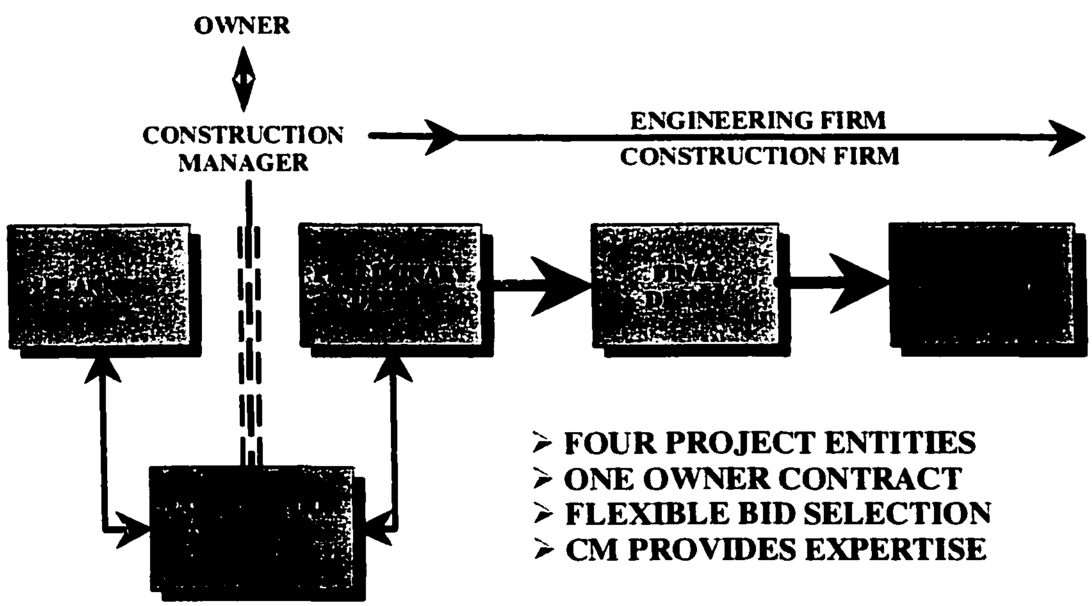


Figure 2-5: Construction Management-at-Risk Project Delivery Schematic

Table 2-2: Issues Surrounding the Design-Build Delivery System for Construction Contracts (Adapted from Lynch, 1995)

PRE-AWARD ISSUES:

1. Single point of responsibility (Removes checks and balances).
2. Use of third party consultants.
3. The lack of non-standardized construction contracts (no legal precedents).
4. How much preliminary design work to perform before RFP.
5. Compensation for unsuccessful bidders.
6. Prequalification of bidders.
7. Performance vs. prescriptive specifications (can stifle innovation).
8. Owner education of design/build process.

POST-AWARD ISSUES:

1. Owners (in)ability to make changes once award is made.
2. Value engineering throughout entire process (increase profit at project's expense).
3. Flexibility of information transfer between parties.
4. Potential for compromised integrity by design professional.
5. Lack of direct Owner to Designer interface.
6. Design professionals become responsible for job site safety.
7. Increased pressure on Owners to complete reviews in a timely manner.
8. Simplified level of detail in final construction documents (use shop drawings instead).
9. Measurement of completion for progress payments.
10. Risk acceptance by the design/build team.
11. Contractor controls overall process.
12. Fewer change orders.
13. Streamlined contract administration.

PUBLIC SECTOR ISSUES:

1. Brooks Architects-Engineers Act.
2. Fair and equitable proposal evaluation process.
3. Design and construction funds authorized in different fiscal years.
4. Lack of standardized contract format.
5. Liability of third party consultants reviewing project.
6. Lack of a centralized listing for lessons learned.

OTHER ISSUES:

1. Insurance and bonding difficulties and restrictive clauses.
2. Varying State to State regulations.
3. Obtaining financing without a firm price.
4. Improved warranty coverage.
5. Limited case law.

Because of the nature of the contractual relationships, the timing of when a designer or contractor enters the project development process is left to the discretion of the construction manager. The project delivery could be structured to mirror the design-bid-build process where the engineering design is completed first and then a contractor selected. On the other hand, the project delivery could be structured to mirror the design-build process and both the engineer and contractor selected at the beginning of the project development process. Or, the construction manager may select a system that falls somewhere between the two extremes. Therefore, the degree of design and construction integration is highly flexible under construction management-at-risk.

The project delivery system is typically considered "at-risk" because the construction manager often provides the owner with a guaranteed maximum price for the project. If the project is delivered for the agreed price, the construction manager earns his entire fee for managing the project. However, if the final price exceeds the guaranteed maximum then the construction manager's fee is reduced according to the provisions of his contract with the owner. But the project delivery system does not have to be performed "at-risk" in which case the system is just referred to as construction management.

One of the advantages of construction management-at-risk for public works projects is that it provides the owner more flexibility in selecting the design and construction firms. The owner's contract is with the construction manager and, therefore, that contract most often is procured using the standard competitive, low bid procedures. However, since the construction manager is a private entity, he is not bound by the same procurement regulations as the owner when procuring the design and construction services. Therefore, the contracts do not need to be awarded on just a low bid basis or just a qualification based basis but can be procured through negotiation, bidding, or any other manner chosen by the construction manager. This gives the owner a chance to have some input when the construction manager is making his selections.

Another advantage of construction management-at-risk is that the construction manager often has considerable construction experience and expertise. Therefore, he is able to provide construction related input into the design process even if the contractor has not yet been selected. However, in actuality, the construction manager's role often ends up being more administrative than technically oriented and, therefore, the direct impact of his construction expertise on the design process is not as significant as it could be [Vanegas].

Compared to design-bid-build and design-build, construction management-at-risk out performed design-bid-build when evaluating overall project performance but was less successful than the design-build project delivery system [Konchar]. The owner's primary risk associated with construction management-at-risk is having the construction manager accept marginal work in order to protect its fee [Rubin].

B.3: Management Philosophies

B.3.1: Introduction

In order to address some of the shortcomings and disadvantages associated with the various project delivery systems, other non-contractual methods have been devised to supplement the project delivery systems. These include the concepts of partnering, constructability, and concurrent engineering. As many of these methods are concerned with improving communication among project participants, project organizational structure, project controls, and other management related issues, the author has classified these non-contractual methodologies as "*management philosophies.*" Typically, none of the project participants are legally or contractual obligated to engage or participate in any of these management philosophies. However, they have been developed, primarily in the context of the traditional design-bid-build project delivery system, in an effort to improve design and construction integration on construction projects.

B.3.2: Partnering

Partnering has been defined as:

"A long term commitment between two or more organizations for the purpose of achieving specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is based upon trust, dedication to common goals, and an understanding of each other's individual expectations and values, Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services." [CII (1991)]

In the context of public works contracting, partnering has been defined as "the creation of an Owner-Contractor relationship that promotes the achievements of mutually beneficial goals... Partnering seeks to create a new cooperative attitude in completing government contracts" [Hightower]. Partnering wraps the major project participants into an alliance, creating a cohesive atmosphere for open interaction and cooperative project performance. The focus is on creative cooperation, efforts to avoid adversarial confrontation, development of an attitude of rapid problem resolution, and frequent joint evaluation of partnering effectiveness [Crowley].

Over the years, relationships between owners, designers, and contractors on construction projects have become more adversarial to the detriment of the primary goal, a successful project [Schroer]. Therefore, the goal of construction partnering is to improve teamwork, avoid litigation, and minimize disputes [Allred]. However, it requires a major cultural change from the traditional methods of doing business [Schroer].

Partnering is a formal process that commences immediately after the award of the construction contract [Schroer]. It usually involves a series of very structured group meetings with management level representatives from the owner, engineer, contractor, and major subcontractors. Often a third party consultant familiar with the process moderates the meetings. The goal of the process is to open the channels of communication and to increase the level of trust and teamwork among the parties. The initial process is culminated with a formal partnering agreement that emphasizes the following [Choquette]:

1. A commitment to partnering by top management from all parties.
2. A commitment to engage in open communication between all parties.
3. A partnering charter identifying mutual goals and objectives for the project.
4. A commitment to timely resolve disputes at the lowest possible level.

To be successful, partnering must be continuous throughout the course of the project and must have support from upper management on down through every level of the organization [Hills, Sincoff]. It has been shown that partnering can provide the same benefits regardless of project delivery method, however, the less adversarial the contracting parties, the better the project performance [Larson]. Also, it was emphasized that partnering is a preventative measure not a remedy for an already contentious project [Hills].

Hills compared ten Army Corp of Engineer projects that utilized partnering with 13 similar non-partnered Army Corp of Engineer projects. He found that the partnered projects had 39% less cost growth, 56% less schedule growth, and 39% fewer modifications than the non-partnered projects. Also, partnering proved effective on the overall project performance of a $226 million rocket test facility [Demoret]. However, because there are no regulatory, professional, or legal reasons which prevent open communication between any group involved on a project [Ball], many in the industry consider partnering to be nothing more than a new buzzword for good business practices.

Although typically used during just the construction phase of a project, partnering has also been found to be effective during the design phase in an effort to improve the teamwork among various design professionals [Allred, Ball, Sincoff]. However, it should be noted that as a tool for improving design and construction integration, partnering could be effective only in the horizontal direction within a single project phase. The partnering concept is not designed to improve integration in the vertical direction across phases of the project, as it does not provide any mechanism for bringing construction expertise earlier into the design process.

B.3.3: Constructability

The Construction Industry Institute Task Force has been defined constructability as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. Maximum benefits occur when people with construction knowledge and experience become involved at the very beginning of a project." In addition, the task force indicated that constructability is not just determining more efficient methods of construction after mobilization, allowing construction to review engineering documents periodically during design, assigning construction personnel to the engineering office during design, or a modularization or preassembly program. Rather, constructability is a continuous project-improvement process that attempts to optimize the entire project not just separate functions. As such, the scope of constructability includes, but is not limited to, the items indicated in Table 2-3.

According to Young, "the fact that constructability is an issue apart from design is an indicator of the present degree to which design has moved away, in many cases, from its roots. And, the fact that constructability is an issue that can be thought of as apart from construction is

Table 2-3: Summary of Tasks Included in the Scope of Constructability
(Adapted from ASCE (1991) and Young)

• Optimization of overall project plan • Planning and design • Construction scheduling • Cost estimates • Construction methods • Project delivery system • Contracting strategy • Risk management • Construction bid packaging • Labor plan • Access to site • Layout of site • Access for O&M operations • Sequence of construction • Availability of equipment and materials

an indicator of the truncation of the design and build processes. Regardless of these trends, and regardless of the historical precedents that bring us to this point, constructability is the potential "bridge" issue between the design and construct disciplines."

Therefore, if implemented properly, constructability could be a critical component of design and construction integration, particularly along the vertical and longitudinal directions. Of course, the major challenge of implementing constructability is how to effectively integrate construction knowledge and experience into each phase of the project development process [Anderson (2000), Tatum]. In fact, questions remain as to how a formal constructability program relates to the project development process and future research is needed to identify the variables and their impact in linking constructability procedures to the project development process [Russell (1992)].

The Business Roundtable (1982) indicated that opportunities to reduce project costs and schedules are being lost because construction is relegated to operate as a production function separated from financial planning, schedule and engineering or architectural design. They went on to say that constructability programs could cut costs by 10 to 20 times the added cost of extra personnel. One way to achieve these savings is to have experienced construction personnel involved with the project from the earliest stages to ensure that the construction focus and experience can properly influence the owners, planners, and designers [ASCE (1991)].

Collecting constructability improvement ideas is not an easy task and requires perseverance and alternative thought processes as designers are asked to think like contractors and contractors are asked to think like designers [O'Connor (1986)]. Some general concepts to facilitate constructability during the project development process are summarized in Table 2-4.

Table 2-4: Concepts to Facilitate Constructability During the Project Development Process (Adapted from CII(1987))

1. Constructability programs are made an integral part of project execution plans.
2. Project planning actively involves construction knowledge and experience.
3. Early construction involvement is considered during development of contracting strategy.
4. Overall project schedules are construction sensitive.
5. Basic design approaches consider major construction methods.
6. Site layouts promote efficient construction.
7. Design and procurement schedules are construction sensitive.
8. Designs are configured to enable efficient construction.
9. Design elements are standardized.
10. Construction efficiency is considered in specification development.
11. Module designs are prepared to facilitate fabrication, transport, and installation.
12. Designs promote construction accessibility of personnel, material, and equipment.
13. Designs facilitate construction under adverse weather conditions.

It has been shown that constructability concepts and procedures are not being applied consistently throughout the U.S. construction industry, if at all [Gugel]. Constructability activities, efforts, and results need to be continuously evaluated, updated, and improved [O'Connor (1994b)]. One of the best ways to accomplish this is through the use of comprehensive tracking that utilizes a database of lessons learned and where benefit/costs data are routinely collected [Gugel, Russell (1994)]. Other tools that could be incorporated include CAD, hypermedia or multimedia, and electronic data exchange [Anderson (1997)].

One barrier for implementing constructability, among others, is the lack of direct incentives for contractors to expand integration [Business Roundtable (1982)]. Other significant common barriers to constructability are included in Table 2-5.

B.3.4: Concurrent Engineering

Concurrent Engineering has been defined as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause developers from the outset, to consider all elements of the

Table 2-5: Significant Common Barriers to Constructability
(Adpated from O'Connor, 1994a)

1. Complacency with the status quo.
2. Reluctance to invest additional money and effort in early project stages.
3. Limitations of lump-sum, design-bid-build contracting.
4. Lack of construction experience in design organization.
5. Designer's perception that "we do it"
6. Lack of mutual respect between designer and constructor.
7. Construction input too late to be of value.
8. Lack of hard, quantifiable proven benefits.
9. Owner's lack of awareness of the concept of constructability.
10. Misdirected design objectives and performance measures.
11. Owner's perception that "we do it"
12. Lack of commitment to constructability.
13. Designer's lack of awareness of the concept of constructability.
14. Poor communication skills of constructors.
15. Lack of documentation and "lessons-learned".
16. Lack of team-building.
17. Poor timeliness of constructor input.
18. The right people were/are not available.

product life-cycle from conception through disposal including quality, cost, schedule, and user requirements" [Love]. The process has also been described as "a planning process that requires customer input in every phase of the capital project planning: front-end engineering; detailed design, procurement, contracting, construction, check-out, start-up, operation, maintenance, and business management, and communication among all project participants" [Geile].

Conceptually, concurrent engineering is an effort to integrate all aspects of product development, by performing simultaneously a variety of activities that used to be done sequentially [Love]. In other words, concurrent engineering is an expanded form of constructability. Whereas constructability is concerned with improving the integration across the project development phases of planning through construction, concurrent engineering encompasses the entire project development cycle including operations and maintenance. Therefore, concurrent engineering can be considered the Holy Grail of project integration research.

Love has indicated that concurrent engineering is a holistic approach to the design, development and procurement of a product that requires a multi-disciplinary project team, whereby participants are brought together during design to determine how downstream issues may be affected by design decisions. It requires that all organization-wide information be used to augment design information to arrive at the finalized product design for manufacture or construction. In addition, he noted that traditional price-driven selection procedures would not be used as they may limit the flexibility of the designers and contractors to explore innovative avenues that result in optimal performance.

No specific examples of concurrent engineering being used in public works projects could be found in the literature. As the construction industry is still trying to address the simpler concept of constructability, no further efforts have been made to address the topic within this research dissertation. However, in the manufacturing industry, Monsanto Co. realized a 10 to 15% in cost reductions when the concept was applied to their operations [Geile].

B.4: Trends in Public Sector Bid Evaluation and Award Practices

B.4.1: Low Bid – Cost Only

As discussed previously, construction contracts for public works projects are typically awarded by competitive, low bid procedures, particularly under the design-bid-build project delivery system. Such bidding procedures usually require that the bids be publicly opened and read. Therefore, the normal process of receiving and opening the bids requires the contractors to have hard copies of their bids submitted to the owner by a pre-established deadline. Then, interested parties meet in a designated location and the bids are opened and read aloud one at a time. After all bids received have been read and tabulated, the lowest bidder is announced and the proceedings come to an end.

In order to insure that their bid is received on time, the process usually requires a representative of the contractor to appear in person at the location specified by the owner. In addition, as part of their bid package, the contractor is required to submit their bid, a signed and notarized bid form indicating their commitment to entering into a contract, and original copies of required performance, payment, and bid bonds. Due to their legal nature, these documents must usually be submitted in a hard copy format.

In an effort to streamline this process, some agencies have begun to explore the use of electronic bidding systems. The objective of electronic bidding is to transmit all the project information in an electronic format. This information consists of bid announcements, project plans and specifications, bid proposals, bid submittals, and reports of bid results. According to Hancher, receipt of electronic bids is currently limited to a submittal of a diskette accompanied with a hard copy. However, other project information, such as bid announcements, is being posted on the Internet and plans and specifications are being distributed using CD-ROMs.

In his survey of the industry, Hancher found the following issues of concern with electronic bidding:

1. Reliability of hardware, software, and communication systems
2. Validation of bid responsiveness
3. Confidentiality and security issues
4. Contractor access to bid prior to bid opening
5. Owner access to bid files prior to deadline
6. Public opening of bids
7. Legislative restrictions

Security and reliability were the primary concern for the respondents. Other difficulties included the fact that many jurisdictions do not allow for digital signatures and a need to address the handling of bonding and deposits. In general, guidelines for the whole electronic bid process need to be developed from input from industry before electronic bidding would be generally accepted.

To deal with security and confidentiality issues, Hancher indicated that software has been developed for the following:

1. Encryption & decryption (transforms data into unreadable format).

2. Authentication (identifies an entity processing or accessing information).
3. Digital signatures (bind the document to an entity using public and private keys to encode).
4. Digital time stamp (binds a document to its time of creation and prevents modification).

B.4.2: Design-Build Proposals and Multiple Criteria Evaluation

As noted previously, design-build proposals must be evaluated on multiple criteria in addition to just cost. Therefore, the process of proposal evaluation becomes a multiple criteria decision analysis (MCDA) problem. The successful process for selecting a design-build proposal requires that evaluation mechanisms for multiple criteria and selection processes be efficient. proper. and capable of withstanding any protest. audit. or review [Paek]. As is common in most MCDA problems, the objectives or criteria are often in conflict and may be of varying degree of importance. For example, the objectives of maximizing the degree of technical factors and minimizing the project cost are in conflict.

Because of these difficulties. researchers have proposed the use of various MCDA procedures in proposal evaluation. Several have proposed the use of the analytic hierarchy process (AHP) for establishing the weights or relative importance of the criteria as the process is well suited for eliciting preferences and detecting inconsistencies of judgement when comparing one criterion to another [Banai-Kashani, Paek]. Paek also proposed the use of fuzzy sets to represent the range a particular technical criterion is likely to fall within, as there is uncertainty in the degree of attainment for technical criteria.

In contrast, Herbman proposed a multi-parameter bidding system using a weighted average type methodology. However, quantification of the various criteria has proven to be the major problem in implementation. For example, time can be converted to a dollar amount by applying a daily cost of the time furnished by the owner, similar to the manner in which provisions for liquidated damages are currently calculated. Quality, however, proves to be much more problematic. Herbman indicated that there were two possible approaches: a subjective evaluation of a bidder's past performance or a cost of deviation per unit from some established quality benchmark. In any instance, some sort of structured method for measuring and quantifying quality and past contractor performance is required before the procedure could be implemented.

Section C: Project Delivery Process Modeling

C.1: Design and Construction Process Modeling Methodologies

As part of a computer integrated construction research project, Chung examined several modeling methodologies and determined that, for modeling design and construction processes, the appropriate methodology should be hierarchical, modular, standardized in structure, and capable of representing the complex processes involved in the project development process. As a result, he selected the Integration Definition for Function Modeling (IDEF0) modeling technique for his research project. The IDEF0 modeling technique is an activity-only subset of the more generalized Structured Analysis and Design Technique (SADT) developed in the late 1960's by Douglas T. Ross from the Massachusetts Institute of Technology [Marca, NTIS]. Based on Chung's report, most subsequent research efforts concerned with modeling the design and construction processes have utilized the IDEF0 modeling technique.

The IDEF0 modeling technique can be viewed as a rigorously structured flowchart methodology where boxes represent activities and arrows represent interfaces or interconnections between the boxes [Marca]. Input and output arrows enter a box from the left and right respectively and refer to the data required by or produced by the particular activity [Gibson (1993)]. Control arrows enter the top of the box and represent constraints on the activity while mechanism arrows enter from the bottom and represent tools for accomplishing the activity [Gibson (1993)]. Descriptive syntax is attached to the boxes and arrows in order to produce a

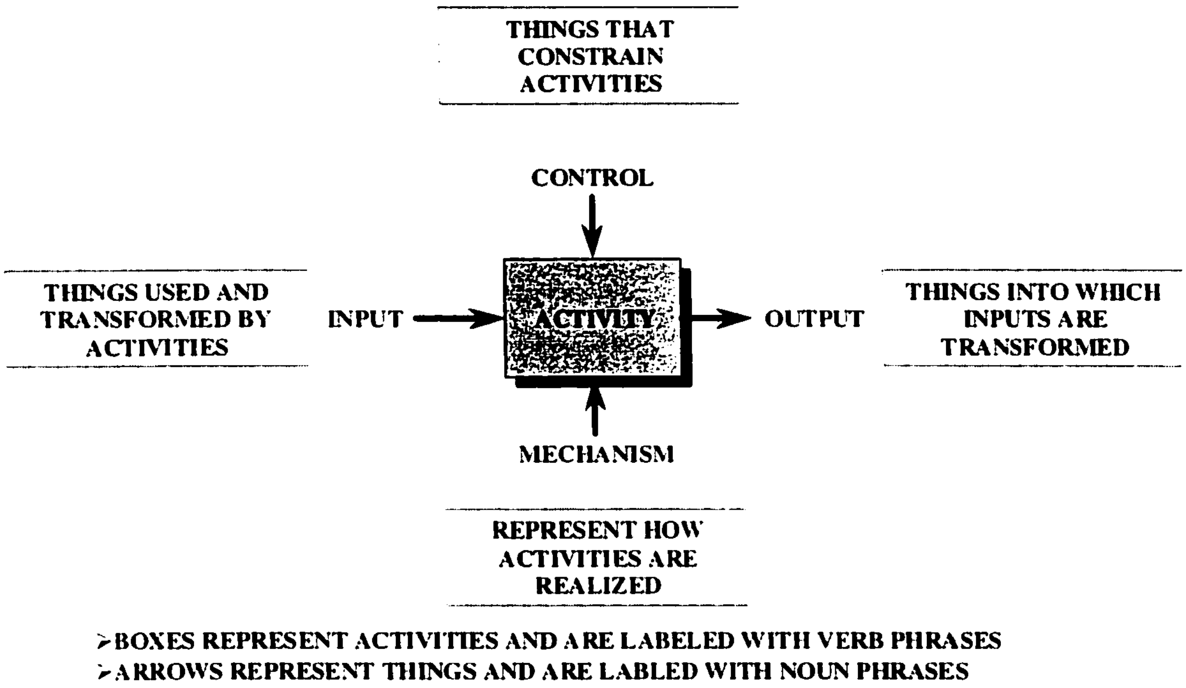


Figure 2-6: IDEF0 Methodology Syntax

descriptive model of the overall system process being studied. A schematic of the basic activity and logic diagram is illustrated in Figure 2-6.

The methodology is hierarchical where activities can be decomposed in to smaller, sub-activities so that a process can be viewed in as much detail as desired or necessary. In addition, research has shown that it is possible to develop models where over 90% of the necessary activities are included to define a process [Austin]. Although projects vary considerably, it has been demonstrated that the design and construction processes are largely repeatable and, therefore, properly constructed generic models are valid for representing the project development process [Austin].

A brief summary of project development process modeling efforts found in the research literature is provided in the following sections. However, as project development process modeling is a key component of the research dissertation project, no attempt has been made to provide specific details concerning any of the models at this point in the report. Rather, the pertinent models and methodologies are discussed in detail in CHAPTER 3: IDENTIFICATION OF CRITICAL INTEGRATION LINKS.

C.2: Design-Bid-Build Process Models

Most design and construction integration research has been focused on the building or the residential and commercial structure sector of the industry. As such, several attempts have been made to model the process of delivering such projects [Karhu, Sanvido (1994)]. These models were primarily in the context of the private sector and did not specifically address issues related to processes within the public sector. As such, the compatibility of such models with project delivery processes other than design-bid-build was stated as an area requiring additional research [Karhu]. However, one useful aspect of such models is that they allow the tracking of information through the processes and allows for specific bottlenecks in the flow of the information to be identified [Sanvido (1994)].

In a study of implementing constructability on highway projects, Anderson (1997) produced an IDEF0 model illustrating the project development process typically found encountered within the public sector. The model focused primarily on the preliminary design, final design, and construction phases of a project.

C.3: Design-Build Process Models

As part of his dissertation research into design and construction integration during the initial phases of building construction projects, Vanegas developed a model of the project development process that split the process into two parallel processes, one for design and the other for construction. He then illustrated, using a non-IDEF0 modeling process, the links and feedback between the design and construction functions required in achieving full design and construction integration on a project. He also incorporated decision-making and conflict resolution processes into his model.

Songer, as part of his dissertation research, developed a process model for public sector design-build planning using a knowledge modeling methodology. The intent of his research was to develop a knowledge-based expert advisory system that could be used by the U.S. Army Corp of Engineers to aid in the selection of projects suitable for the use of design-build. As such, Songer created a logic flowchart of the planning and decision-making process that was then used as a schematic for the expert system and the "what-if" type rules used to manage the expert knowledge.

It should be noted that an example of an IDEF0 model for the design-build project delivery process, particularly within the context of public sector contracting, could not be found in the literature. This is probably due to the relative newness of design-build contracting for public works.

C.4: Other Related Integration Models

Anderson (1997, 2000) developed an IDEF0 process model for the constructability process on highway projects. The model was developed to parallel the project development process for highway projects discussed previously. The two process models were tied together with a three-dimensional interface in an effort to illustrate the opportunities for providing constructability advice during the development phase of a project

Gibson (1993, 1995) developed an IDEF0 model for the pre-project planning phase of a project. Pre-project planning is often synonymous with feasibility analysis, conceptual planning, programming, etc. and is a process of developing sufficient strategic information to determine whether to commit resources to maximize the chance for a successful project [Gibson (1995)]. As part of an effort to optimize the sequence of design tasks, Austin developed a generic IDEF0 model of the design process. The model was then incorporated as part of a new planning methodology called the Analytical Design Planning Technique.

Other, less formal conceptual models include a pre-bid and pre-construction planning model [Laufer], a partnering process model [Crowley], and a constructability implementation process model [Radtke]. Radtke demonstrated that there were three primary steps in implementing constructability: obtaining constructability capabilities, planning the constructability program, and implementing the program. To implement the program, the owner must mandate it and be fully committed to the process.

Section D: Construction Integration through Information Technology

D.1: Introduction

According to Bernstein, the public would save in the long run if, for example, the designers, contractors, specialty subcontractors, and product manufacturers could share information by working off the same documents electronically. In fact, it has been estimated that the effective use of information technologies could improve the productivity of construction by 30% if it were coupled with other best practices from the industry [Love]. Along these same lines, some have indicated that the integration of software is the answer for improving the quality and efficiency of the construction industry [Iyer].

Some have proposed the use of computer aided drafting (CAD) technology as the mechanism for migrating from paper-based document exchange to computer-aided information and knowledge sharing [Luiten]. Others have proposed the use of Geographical Information Systems (GIS) [Berstler] while still others have proposed Internet based applications [Ramakrishna]. Despite the integration mechanism, the goal of such integration strategies is to improve communication between project participants. The main difficulty, however, is that the construction engineering process is not clearly understood and the tasks that need to be pursued and the information required to carry out these tasks are not well defined [Iyer].

D.2: Electronic Data Interchange (EDI)

Electronic Data Interchange (EDI) is the electronic exchange of information between two computers in a specific predetermined format. According to Hancher, EDI is more rigid than just sending or exchanging computer files across a network, which requires both the senders' and receivers' computer applications to be the same. Instead, industry sectors each have created generic formats for information exchange applicable to their industry and the information can be processed in one of two ways: through the use of VANs (Value Added Network) or through the use of Internet technology.

Along the same lines, Berstler states that there are two types of integration possible between software applications: loosely coupled and tightly coupled systems. Loosely coupled systems involve either the transfer of files using common file formats, such as AISC text format, or through the use of a Windows^{C} type multi-tasking function. Tightly coupled systems involve either being able to directly view other files types within only one program or using a commonly shared database to generate the files in only one program.

D.3: Computer Aided Drafting and Design (CADD)

Computer aided drafting (CAD) refers to software packages that allow the user to create the graphical manufacturing or construction drawings or plans for a project. As the CAD software creates a mathematical model of the project, CAD programs have been expanded to allow designers the ability to perform analytical design tasks within the same program. One of the advantages CAD offers over other graphical programs is its precise design and dimensioning capabilities that are necessary when constructing and installing specific, often repetitive, project components [Berstler]. By using CAD, most facets of the project development process can be accessed by different disciplines through the common CAD database [Love]. For this reason, CAD has been purposed as the integration mechanism, particularly in the horizontal direction across disciplines [Luiten].

D.4: Geographical Information Systems (GIS)

Geographical Information Systems (GIS) are graphical software programs that allow users to display and analyze maps and other data that can be categorized as a function of its spatial location or geographical location. In contrast to CAD, the advantages of GIS include its mapping capabilities that are suitable for larger geographic scale areas and the ability to associate database attributes to particular drawing entities and, therefore, perform database type queries [Berstler]. While CAD can be viewed as a design tool, GIS is a conceptual modeling and analysis tool.

Because of its large-scale mapping and analysis capabilities, many researchers have explored the use of GIS in performing corridor or site suitability analyses for project facilities such as highways and underground utilities [Banai, Jankowski (1994)]. The map overlay and analysis capabilities of GIS are robust in translating physical constraints into feasible alternatives for route locations, however, are often weak in incorporating the decision maker's preferences, and, hence, are of limited use for decision support. Therefore, methodologies have been developed that couple GIS with multiple criteria decision analysis techniques and use such criteria as total cost, right-of-way costs, environmental concerns, reliability, length, slope, etc [Jankowski (1995), Malczewski]. A sensitivity analysis can then be performed on the results by varying user preferences or weights for each criterion [Jankowski (1994)].

Lee proposed a prototype GIS-based highway design review system to improve constructability of design. The prototype uses common milepost markers to access information about a particular stretch of highway and includes databases for accident rates, traffic counts, construction details, etc. The system also had a database of change order reviews indicating the cause or basis for each change.

Surface and subsurface conditions influence construction methods and choice of equipment, which, in turn, affect the cost and scheduling of projects. As such physical site data has a spatial correlation, O'loufa suggested that exchanging such information through a GIS database could improve design and construction integration on projects.

D.5: Web-Based Information Transfer Applications

In the past, information technology managers used information technology for providing numerous, but separate, decision support systems for the professionals involved in the industry, which created "islands of automation" and, therefore, failed to achieve an acceptable level of integration across disciplines and project development phases [Ramakrishna]. As a result, Ramakrishna proposed a web-based Enterprise Information Portal (EIP) system that would provide the following functions:

1. A file server that acts as the repository for all project related documents.
2. A means for controlling access to these documents on the basis of document type, project, and individual.
3. Work flow software that routes documents to appropriate individuals.
4. Software that enables users to access data, creates reports, and communicates with other project personnel.
5. Scheduling software for setting up meetings.
6. Software for archiving completed projects.

In another application, Carver developed and posted a web site that demonstrates an Internet based GIS decision support system for the site suitability analysis and site alternative selection for hazardous waste facility projects in the United Kingdom. Through a graphical user interface, users are able to assign weights or preferences to selected site criteria and visually see a map indicating the results of their decisions.

Section E: Summary of Key Points and Future Research Needs

Research has shown that the ability to influence a project's performance decreases over the life of a project [ASCE (1990), Gibson]. As the earlier decisions within the project development process have a larger impact on overall project performance, construction expertise must be brought into the project development process as early as possible. This concept of creating or allowing for greater construction input during the planning and design of a project is referred to as design and construction integration within the research literature.

Design and construction integration has been described within the context of a three dimensional framework [Fergusson]. In the horizontal direction integration could occur between disciplines within a single project phase while vertical integration could occur between entities across project phases. The last direction of integration could occur in the longitudinal direction across time between successive projects.

Although design and construction integration is often cited as a means to improving project performance, there is no clear understanding of how to formally incorporate construction expertise as a part of the design process [Vanegas]. Therefore, a better understanding of current practices for design and construction integration in each of the major segments of the industry is needed to identify opportunities for experience transfer [Tatum]. In addition, better methods for defining and measuring project integration, improving integration through technological and non-technological means, and methodologies to overcome barriers to implementation are required [Pocock].

One barrier to implementing design and construction integration methodologies is the lack of direct incentive for contractors and others to expand integration [Business Roundtable (1982)]. Because of this lack of direct incentive design and construction integration will not happen naturally on its own and, therefore, must be treated as another project objective requiring an adequate administrative climate and contractual approach [Vanegas]. In other words, to successfully implement any program the owner must mandate it and be fully committed to the process [Radtke]. This issue of incentive is an important consideration that must be addressed by the current research effort when developing a decision support system framework for improving design and construction integration within the industry.

One of the primary mechanisms for achieving vertical integration across project development phases is through contracts or project delivery systems [Fergusson, Nam, Sanvido, Vanegas]. Three project delivery systems are commonly used with the industry: design-bid-build, design-build, and construction management-at-risk. Design-bid-build in combination with competitive, low bid selection of contractors is the predominant project delivery system within the public works sector, however, one of the major weaknesses of the system is the lack of integration between design and construction entities [Iyer, Lynch].

In an effort to improve project performance through enhanced design and construction integration, many public work agencies are beginning to explore the use of design-build contracting. However, there remain many legal and institutional barriers to its adoption within the industry [Luiten, McManamy, Terrill]. Construction management-at-risk is a less frequently used project delivery system. Comparisons between the three delivery systems have shown that projects built using design-build typically out perform the others when it comes to project performance [Konchar].

In addition to the three project delivery systems there are three management philosophies used within the industry or noted in the literature. Partnering is a concept to improve communication and teamwork between designers and contractors after construction has commenced and, therefore, has only a minor impact on design and construction integration. Constructability is a concept often considered synonymous with integration and, although misunderstood, is a continuous project-improvement process that attempts to optimize the entire project development not just separate functions [CII (1986)]. Studies have shown that constructability programs could cut costs by 10 to 20 times the added cost of implementation [Business Roundtable (1982)].

One of the major challenges of implementing constructability is how to effectively integrate construction knowledge and experience into the project development process [Anderson (2000), Tatum]. Also, questions remain as to how a formal constructability program relates to the project development process and future research is needed to identify the variables and their impact in linking constructability procedures to the project development process [Russell (1992)]. In addition, Gugel, Russell, and O'Connor all discussed the potential of utilizing a lessons-learned database as a constructabililty tool to improve the project development process. The last management philosophy is concurrent engineering, a more advanced form of constructability, but the concept was found to have only theoretical relevancy as no examples of its actual use within the public works industry could be found in the literature.

In an effort to better understand the flow of information and activities within the project development process, several researchers have developed process models of the system [Anderson, Gibson, Karhu, Sanvido, Songer, Vanegas]. Many of the models utilized the Integration Definition for Functioning Modeling (IDEF0) technique. Although projects vary considerably, it has been demonstrated that the design and construction processes are largely repeatable and, therefore, properly constructed generic models are valid for representing the project development process [Austin].

The reviewed process models were primarily focused on the private sector building industry. None of the models specifically addressed the design-build project delivery system. As such, the compatibility of design-build with the current process models requires further study [Karhu]. In addition, it has been noted that the information point of view should be emphasized more in the process models in order to integrate involved parties better [Karhu].

Information technology has been explored as a tool for improving integration, particularly in the vertical direction between disciplines. It has been estimated that the effective use of information technologies could improve the productivity of construction by as much as 30% [Love]. This requires the development of methods, procedures, and tools for coordination of project planning and design among the various internal and external parties, working with multiple data and information formats, and using advanced information technology to facilitate the integration of parties and plans [Laufer]. Other tools that should be incorporated into constructability or integration programs include CAD, databases, hypermedia/multimedia, and Electronic data exchange/Bar coding [Anderson (1997)]. However, the full potential of the tools cannot by realized without first understanding how the ways that information flows in a project affect the quality of the product [Church].

CHAPTER 3: IDENTIFICATION OF CRITICAL INTEGRATION LINKS

Section A: Relevant Project Development Process Models and Research

The first major step of the research methodology was to identify the critical activities within the typical project development process that could benefit from construction related input or expertise. In order to improve the design and construction integration at identified critical integration links, it is necessary to have an understanding of both the content of the information required by the activities and the timing or location of the activities within the project development process. To accomplish this, relevant project development process models found in the research literature were reviewed and analyzed.

To illustrate how design and construction integration could occur on structural building projects Vanegas developed a comprehensive model of the initial development phases of a project. A key contribution of his model was the splitting of the overall process into two parallel processes, one for design and the other for construction. This result follows from the logical assumption that complete integration on a project can only occur if the design and construction entities are working side by side for the duration of the project. In order to achieve the integration, Vanegas included in his model a complex series of communication and feedback links between the two parallel processes as shown in Figures 3-1 and 3-2.

According to Vanegas, some characteristics of an ideal integration process would include a system where the planning and preliminary design phases would offer the best opportunity for integration and contain identifiable leverage points for construction input. The process would also recognize different types and levels of integration and avoid the "review fallacy" by providing meaningful opportunity for serious consideration of alternatives. Finally, the process would

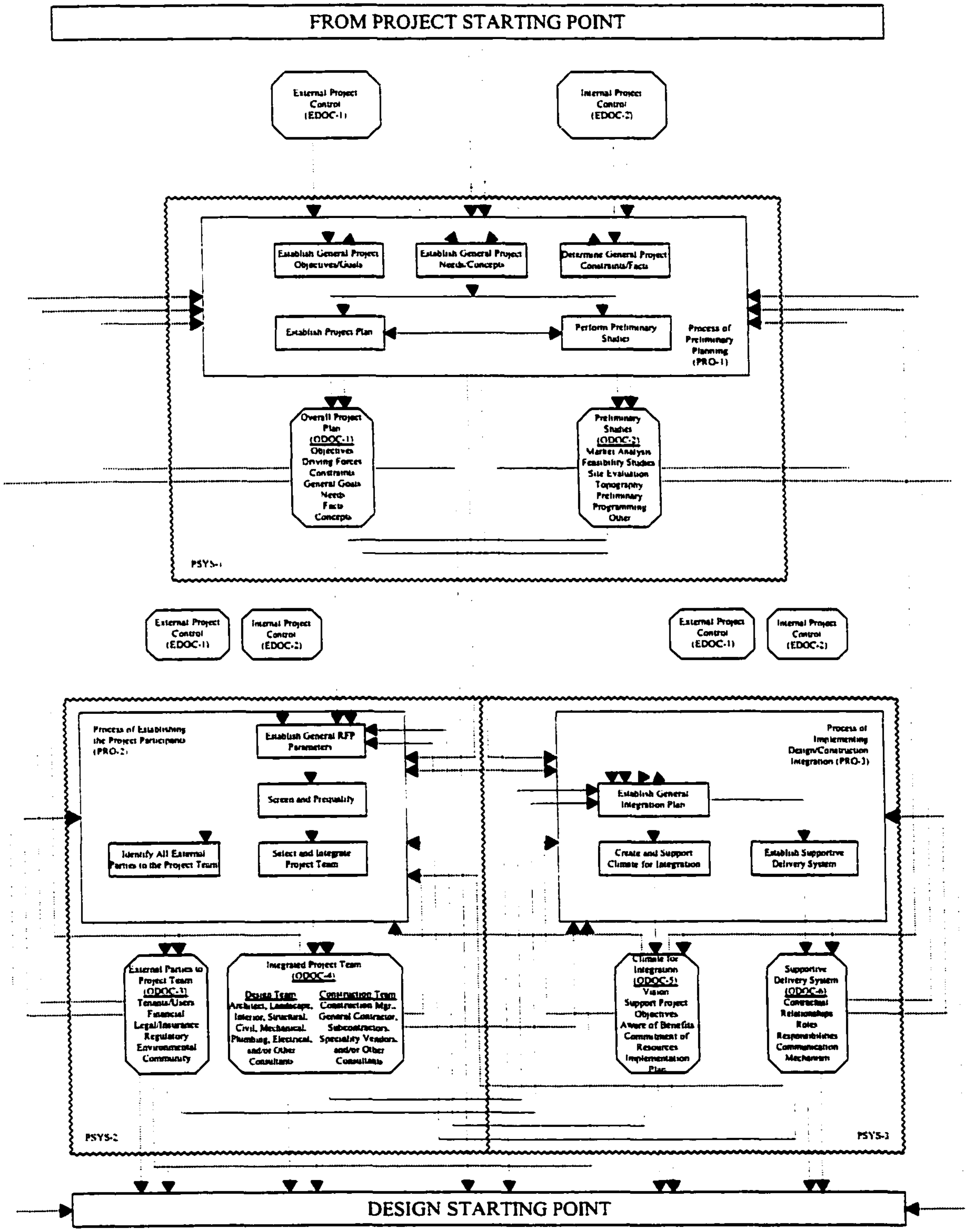


Figure 3-1: Adaptation of Vanegas' Integration Model – Planning Phase

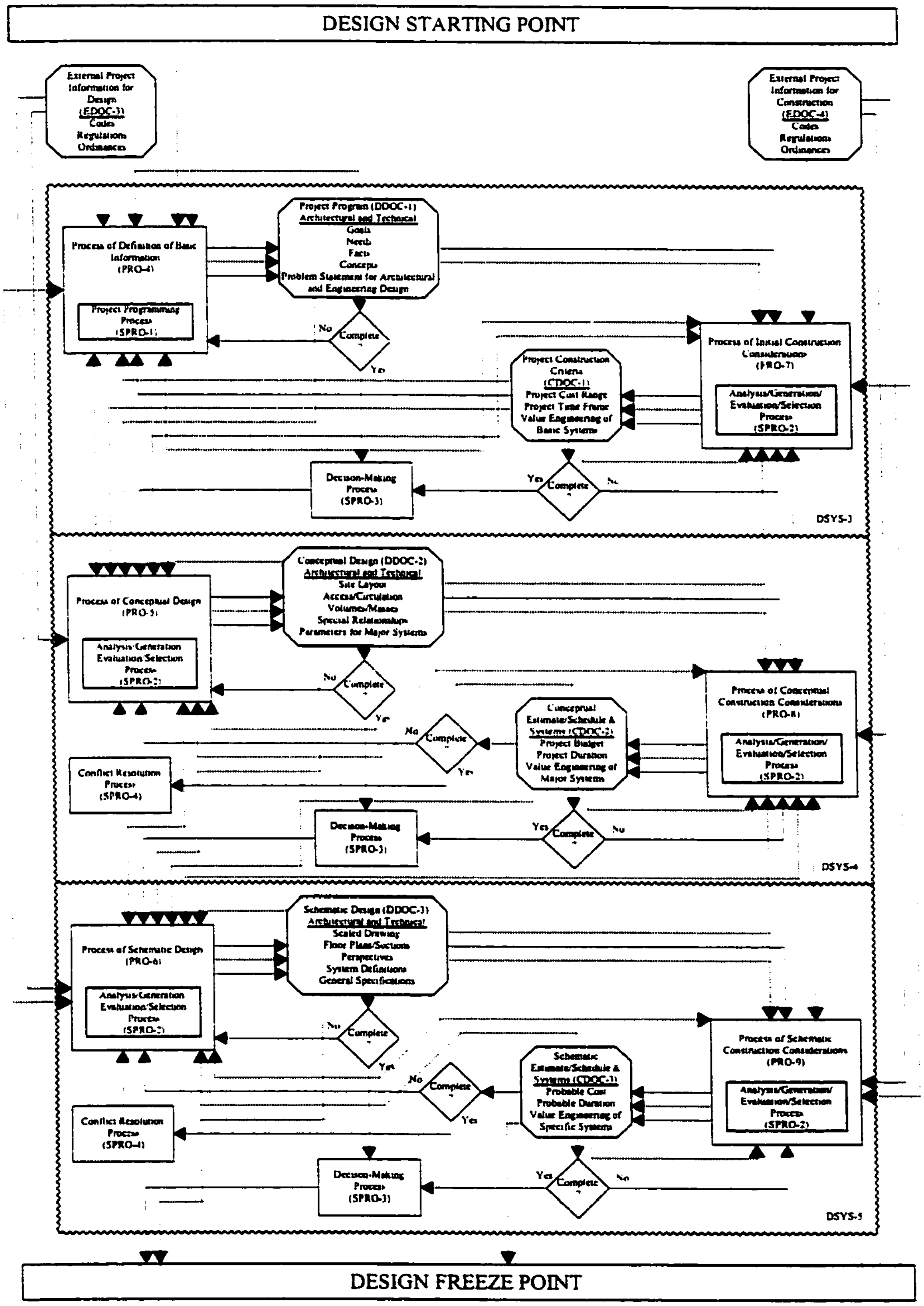


Figure 3-2: Adaptation of Vanegas's Integration Model – Design Phase

require milestones for consensus decisions and a formal conflict resolution process for mediating disputes between the design and construction sectors.

Vanegas also indicated that to be successful, design and construction integration must be a project objective that has the commitment of all project participants. Also, that the owner must create and support a climate for integration and establish a supportive project delivery system. To accomplish this requires planning, proper project staffing, an integrated team approach, and supportive communication mechanisms.

In an effort to help designers better integrate the activities required to accomplish the design, Sanvido [1994] developed an IDEF0 model of the private sector building design process. The model represents the major functions and activities necessary for a successful design and identifies the flow of information and knowledge that supports the development of the design. The model divided the design of a facility into five major activities: acquire design projects/work, plan and control design, acquire resources and services, perform design, and communicate design to others as shown in Figure 3-3. Using the hierarchical decomposition features of the IDEF0 modeling technique, his study decomposed each of the five major activities into additional subactivities indicating further relational connectivity.

In a similar type study by Karhu the scope of the IDEF0 modeling effort was expanded to include the entire project development process for private sector buildings. His model incorporated five distinct project phases: draw up brief, draw up programme, prepare for design, supervise design, prepare for construction, and supervise construction and manage facility. He noted that the compatibility of his model with project delivery systems other than design-bid-build had not yet been demonstrated and was an area requiring additional research.

In a study of implementing constructability on public sector highway projects Anderson developed two IDEF0 process models, one for the project development process and one for the constructability review process. The project development process model encompassed the planning, design, and construction phases of a project. The planning phase included the major

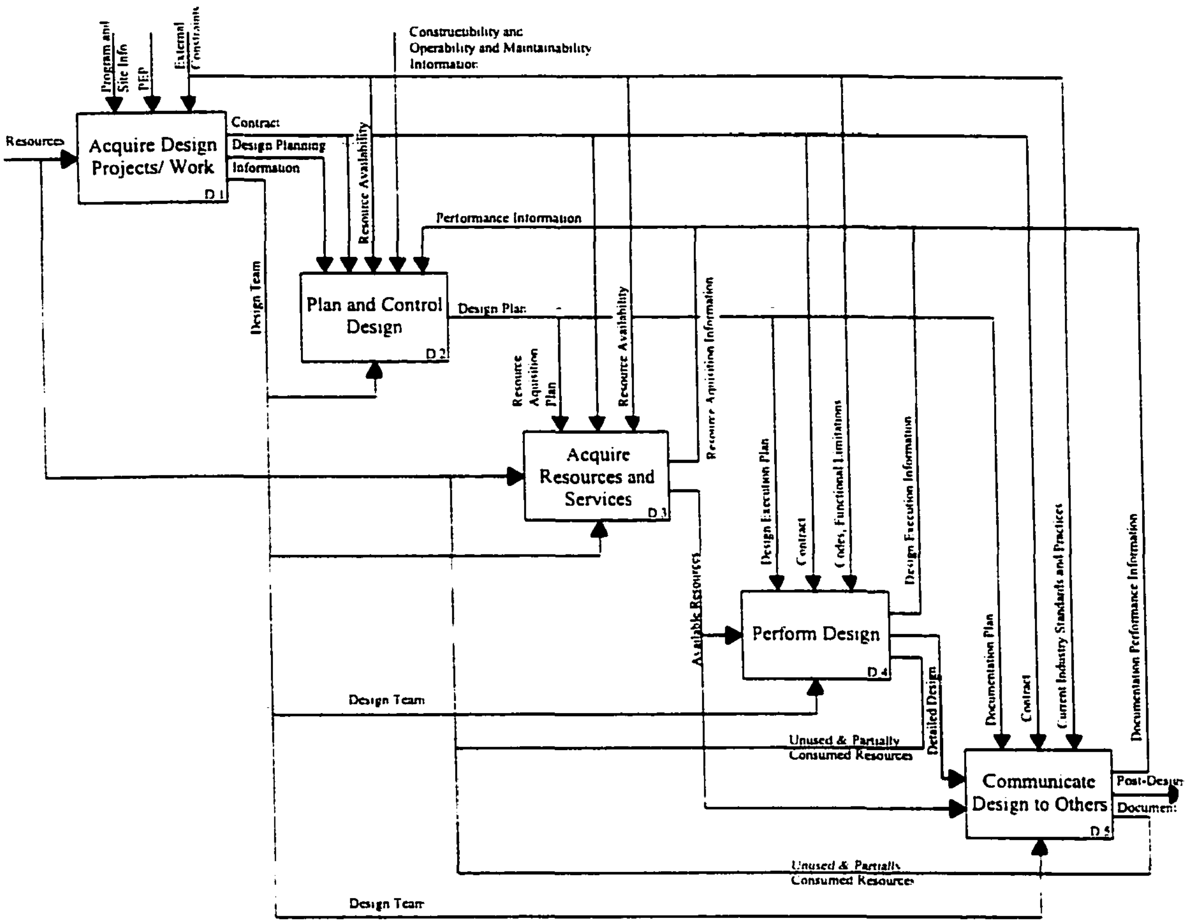


Figure 3-3: Sanvido's Integrated Design Process Model

activities of project definition and concept plan development while the design phase included preliminary design, plans, specifications, and estimate development, and final design. The construction phase included pre-construction, construction, and post-construction activities. The hierarchical tree of the process model is shown in Figure 3-4.

The constructability review process model entailed applying constructability during the phases and activities illustrated for the aforementioned project development process model as shown in Figure 3-5. This demonstrates the parallel nature, as described by Vanegas, of the design and construction integration process with the project development process. Anderson proposed tying the two parallel processes together with a three-dimensional interface in an effort to illustrate the opportunities for providing constructability advice during a project. One of the

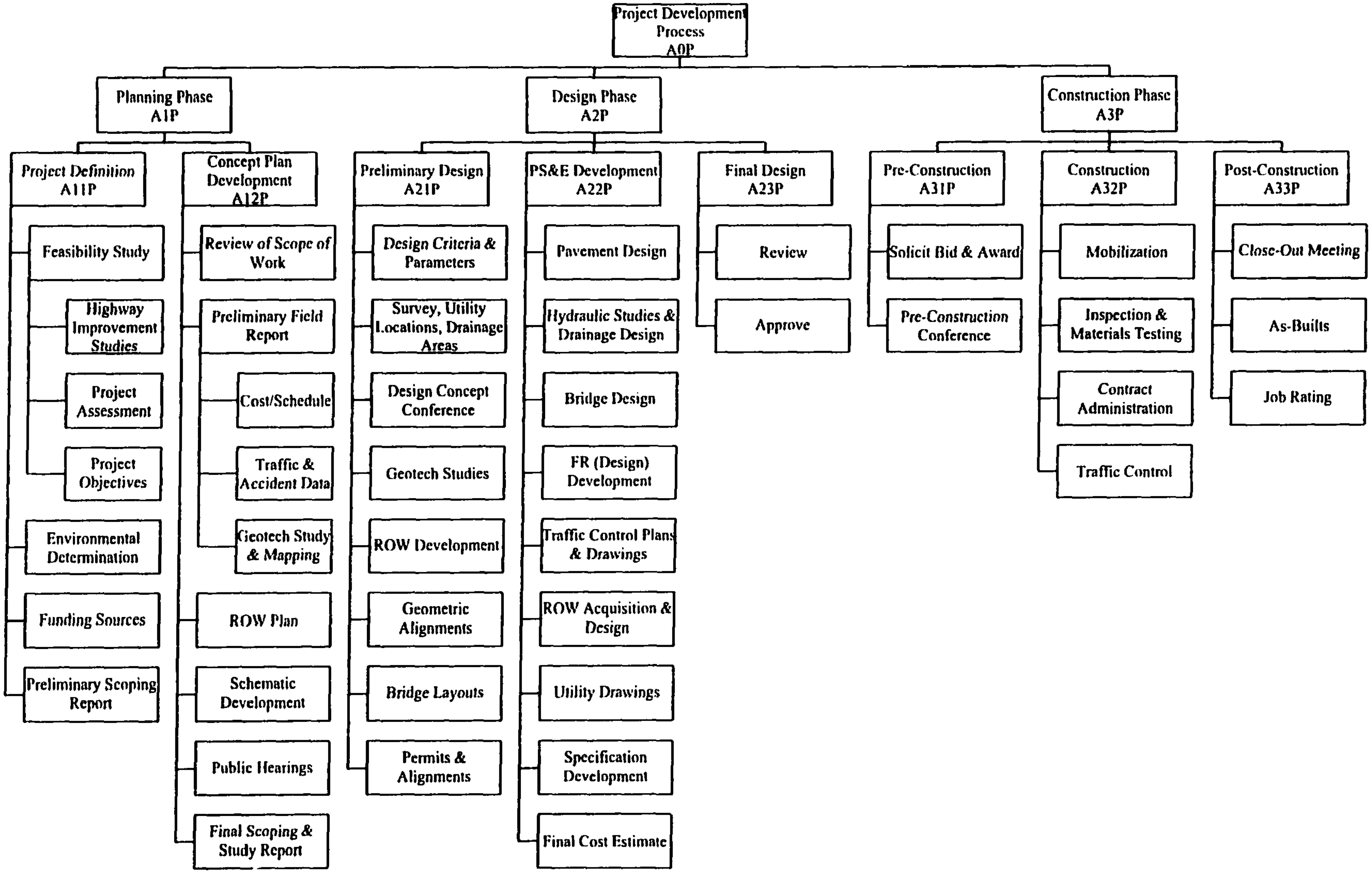


Figure 3-4: Anderson's Project Development Process Framework

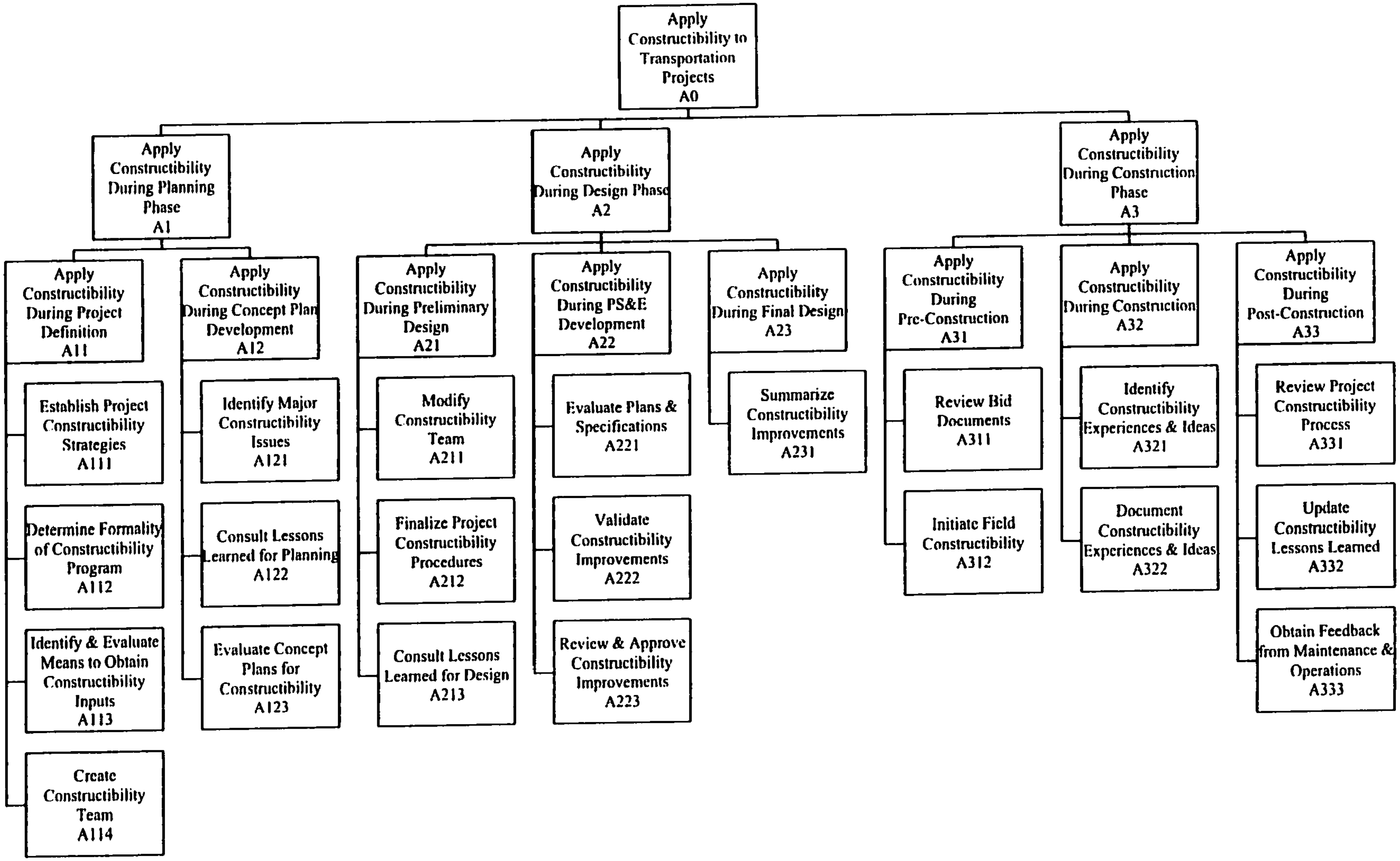


Figure 3-5: Anderson's Constructibility Review Process Model Framework

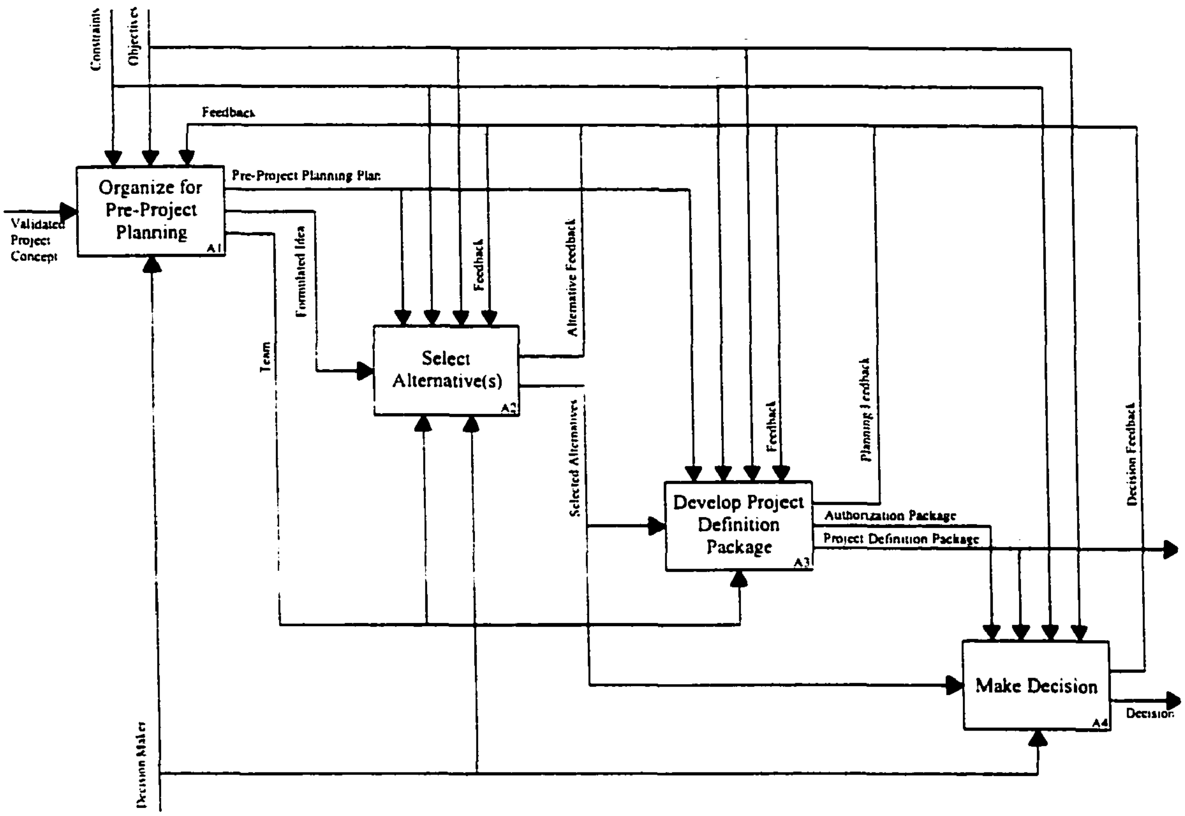


Figure 3-6: Gibson's Pre-Project Planning Process Model

key components of the model is the recognition that constructability or integration has formal management activities that need to be planned for and incorporated into the project development process.

As many efforts to model the project development process have not focused on the planning phase in any detail, Gibson developed an IDEF0 model for the pre-project planning phase of a private sector project. The model's major planning activities included organize for pre-project planning, select alternative(s), develop project definition package, and make decision as shown in Figure 3-6. The project definition package developed during planning includes important project parameters such as project objectives and constraints, conceptual designs, project delivery strategy, project control mechanisms, and project budgeting and financing that provide the decision-making framework for everything else that occurs later during the project.

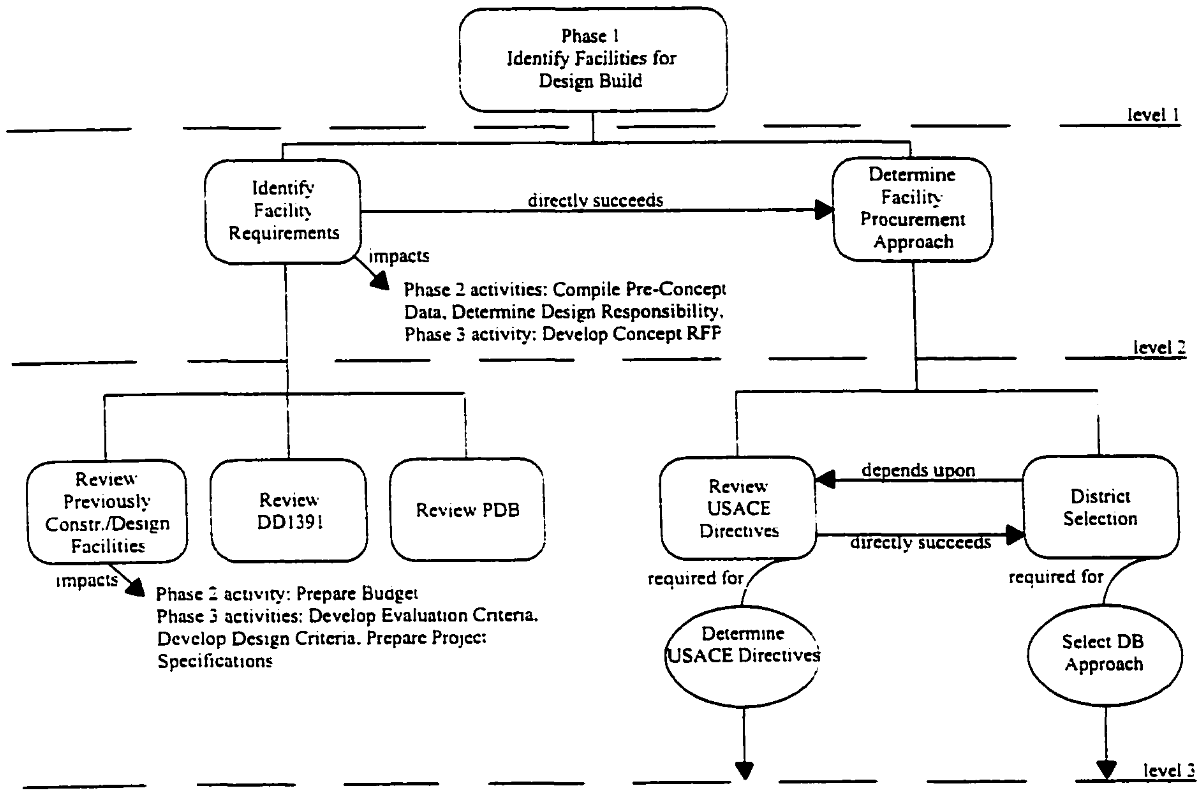


Figure 3-7: Portion of Songer's Schematic for Knowledge Based Decision Support System for Design-Build Project Selection

Also, the model incorporates the important concept critical, milestone decisions, as someone has to make a decision on whether to proceed with a project or send the project back for additional revisions.

Approaching the problem of design and construction integration from a different angle Songer (Ph.D.) developed a knowledge base decision support system to aid the U.S. Army Corps of Engineers (USCOE) in selecting projects appropriate for design-build contracting. As part of his research, Songer developed a flowchart schematic of the decision-making process the USCOE uses when determining project delivery strategies, a portion of which is illustrated in Figure 3-7. The schematic identified 70 or more critical decisions considered when determining if and how to implement design-build on a project. The research also incorporated the important concept of documenting the intent behind decisions. Intent is the rationale or "why" behind a decision outcome and is valuable information that should be captured and made available to project personnel as it traverses the project [Songer (Ph.D.)].

Section B: Model Aggregation and Development of Proposed Public Works Process Model

Based on the project development process models reviewed in the literature, the next step of the research methodology was to develop a proposed model that accurately represented the project development process used in the public works sector. As the focus of the research is on design and construction integration an effort was made to incorporate some of the key integration concepts taken from the literature into the model. The hope was to produce a synthesized model that illustrated the opportunities for integration on public works projects and identified both the informational content and timing of critical activities within the project development process that could benefit from construction related input or expertise.

The constructability review process model developed by Anderson was selected to provide the overall framework and starting point for the modeling effort. The rationale for this decision was based on two primary factors. First, the model was one of the few found in the literature that focused on the delivery of projects within the public works sector. Second, the model was constructed with the intent to illustrate constructability or integration concepts. As this research dissertation is likewise concerned with integration on public sector projects, it was felt that Anderson's model provided the best foundation for the current modeling effort.

As has been noted previously, Anderson's model was developed within the context of highway construction projects. In contrast, the current research effort was focused on underground utility projects. However, this was not deemed to be a major issue in adapting the model, as the overall public works project development process is generally independent of the type of project. In addition, as the processes are largely repeatable, properly constructed generic models have been demonstrated to be valid for representing the system [Austin]. Therefore, the outline of the model should be readily transferable to another model with a similar context.

One goal of the modeling effort was to develop a model that spanned the entire project development process. Anderson model's first activity phase is labeled "apply constructability during planning phase", which would appear to indicate that the model commences from the planning phase within the project development process. However, a closer inspection of the model indicates that the inputs into this initial phase include project concept plans, project characteristics, and project design basis. These are all items that are typically associated with the project definition that typically characterizes the planning phase. Thus, it was concluded that the Anderson model really commences at the preliminary design phase and that a planning phase would have to be added to the model in order to complete the full project development cycle.

Therefore, the IDEF0 model developed by Gibson for the pre-project planning phase was further investigated in an attempt to develop an appropriate model of the planning phase that could be grafted on to the beginning of the Anderson model. Gibson's model illustrates the process used in the development of the project definition package, a package that includes the primary inputs into Anderson's model of conceptual plans, project characteristics, and the project design basis. The project definition also included project financing, project execution, and risk assessment. As the pre-project planning phase commenced with only one input, a defined problem or need, it was clear the model was commencing at the earliest stage of the project development process. Therefore, it was concluded that the Gibson model could be used as a basis for creating the desired planning phase model.

Before adapting and adding the Gibson model, the overall structure of typical project development process models was studied in order to ensure the newly developed model was compatible with the standard framework for the process. The review indicated that any phase of the project development process is composed of three general activities: plan and organize to perform the function, generate and evaluate alternatives, and make a decision. All of the reviewed models demonstrated to some degree this reoccurring pattern including the non-IDEF0 models generated by Songer and Vanegas. Fortunately, Gibson's model also demonstrated this pattern and the model was adapted and added to the beginning of Anderson's model. As Anderson's model indicated key locations for opportunities for constructability input, similar locations where noted in planning phase activities in order to maintain context compatibility between the phases of the model.

At this point the modeling effort deviated somewhat from the strict IDEF0 syntax and methodology. Since Vanegas indicated that the integration process requires milestones or key decision points, an effort was made to clearly illustrate these decision points through the use of diamonds that demonstrated the iteration and branching of the process that occurs depending on a decision's outcome. In public works contracting, these decision points are often associated with budgeting or procurement procedures. For example, after the project has been defined during the planning phase, before the next phase can begin funds have to be appropriated and a decision made on whether or not to proceed. The same type of decision milestone occurs when soliciting bids for construction.

Once the decision points were added with appropriate feedback loops, based on the author's own experience in public works engineering and contracting, the overall aggregated model was reviewed and modified to produce a logical and coherent model of the public works project development process. The order of some activities was rearranged and some connectivity arrows combined or eliminated as deemed necessary to create an accurate model. Finally, some of the terminology was modified to improve clarity and to maintain the context of the model. The resultant model in its entirety has been included in Appendix A.

Section C: Results and Conclusions

The hierarchical tree for the developed process model is shown in Figure 3-8 and an intermediate decomposition of the model is shown in Figure 3-9. As can be seen, the model spans four project development phases, planning, preliminary design, final design, and construction. It should be noted that the construction phase within the model also includes activities that would

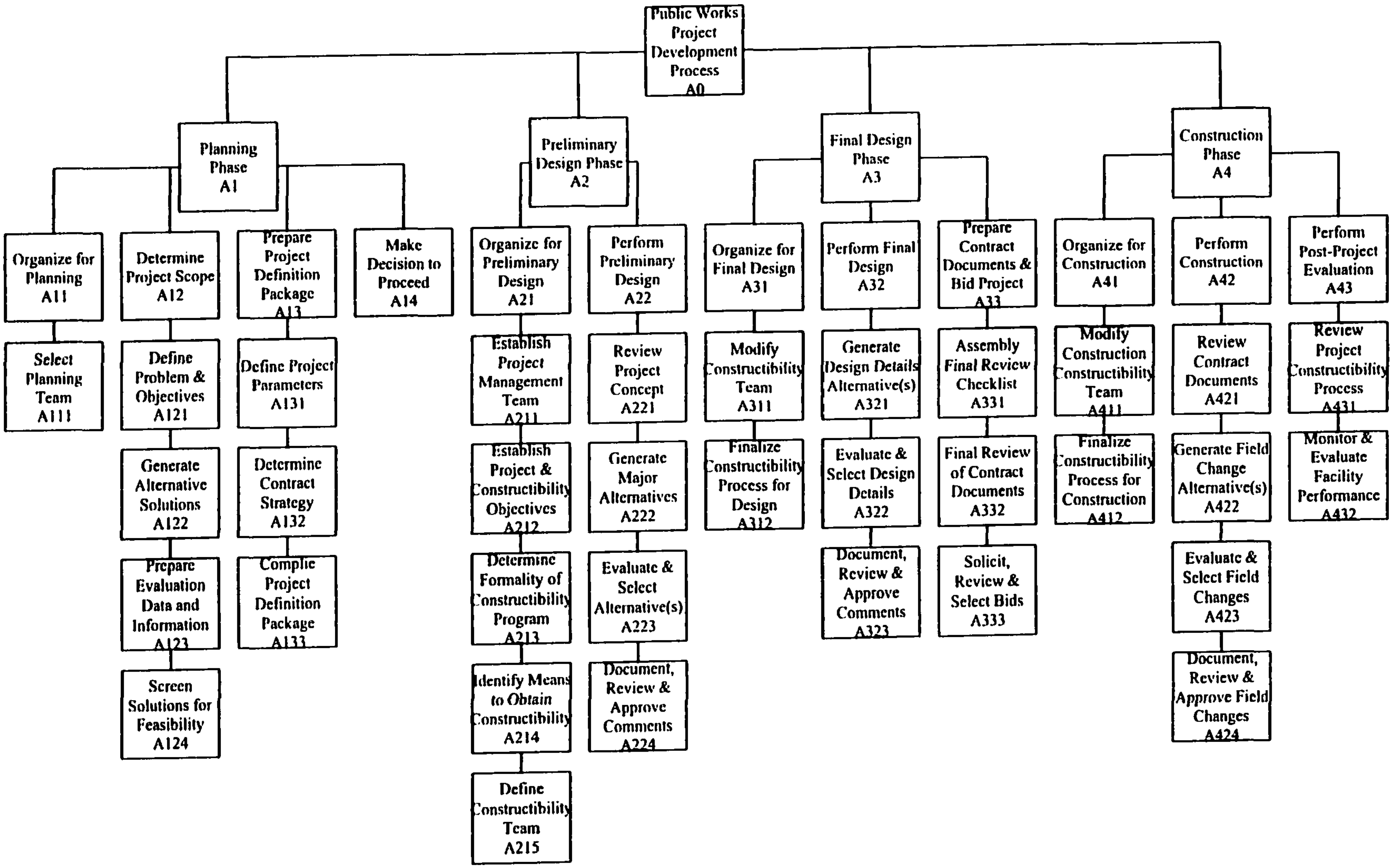


Figure 3-8: Hierachical Tree of Proposed Public Works Project Development Process Model

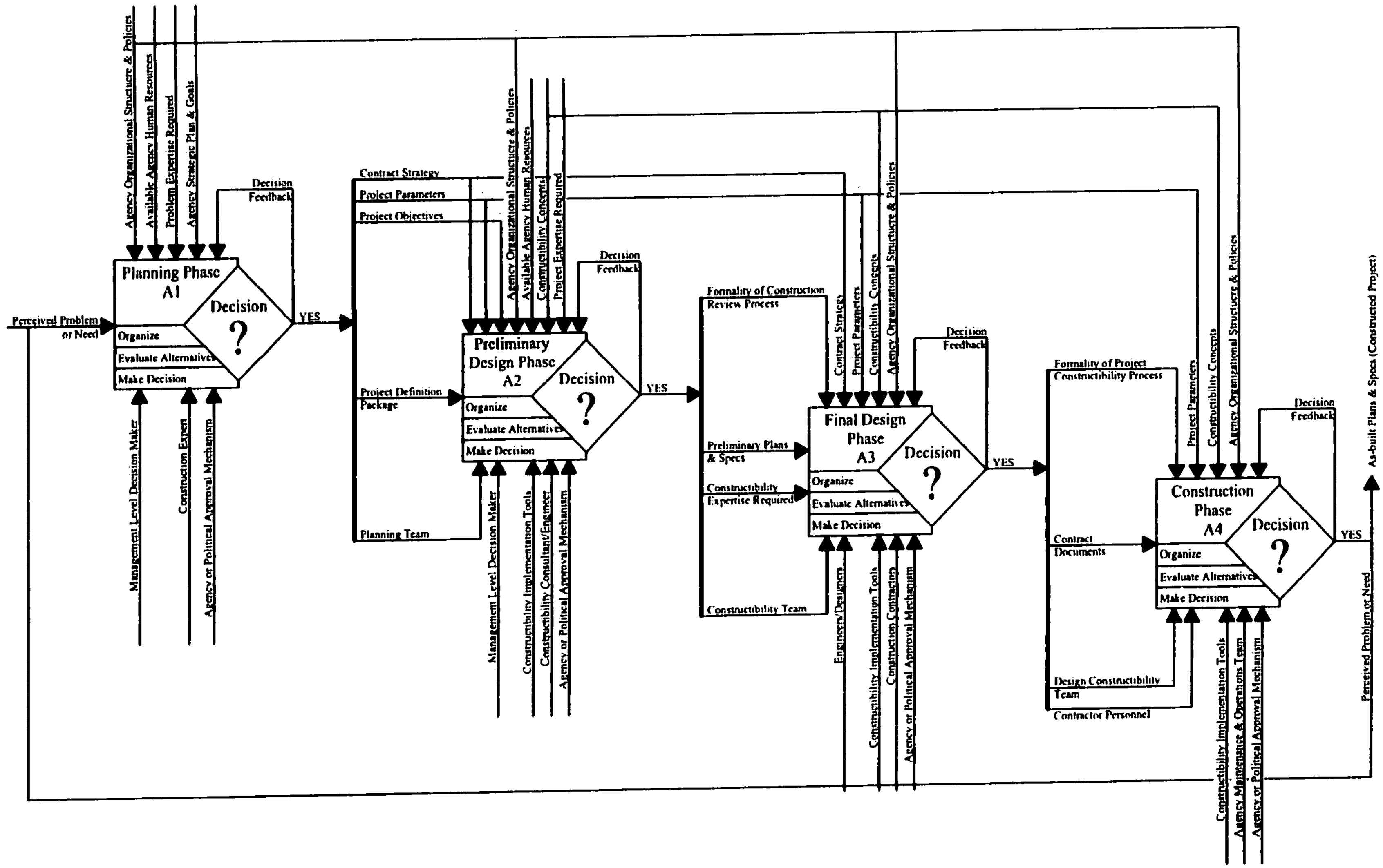


Figure 3-9: Intermediate Decomposition of Proposed Public Works Development Process Model

fall within the domain of the operation and maintenance phase. Therefore, the scope of the model encompasses a significant portion of the complete project development process.

It has been said that a model is not useful unless it describes a process, develops interesting implications, and looks for generality [Vanegas]. The developed model easily satisfies two of these criteria as it describes a process, the project development process, and looks for generality as it does not describe a specific project's or organization's procedures but rather is generic to the industry as a whole. Concerning the remaining criterion, several interesting implications can be derived from the model, thereby making it a useful model.

The first implication is the repeatable nature of the project development process across each project phase and from project-to-project. The repeatable nature of the project development process from project-to-project demonstrated by the model confirms the research results of others [Austin]. However, the author's aggregated model also reveals a repeatable structure across each project phase that was not explicitly described or illustrated in the process models taken from the research literature.

Each phase of the process has the same three primary activities. A phase commences with activities focused on planning and organizing to perform the particular task associated with the phase such as preliminary design. These organizational tasks involve defining or refining the project objectives and goals, selecting personnel and organizing the team who will perform the task, and establishing the project management and control structure to be used to monitor the performance of the task. In other words, establishing the structure or environment from which the task will be performed.

Once the organizational structure has been established, the next primary activity of a project phase is to generate and evaluate alternatives. The nature and specificity of alternatives is dependent on the location of the activity within the project development process. Alternatives generated during the planning phase would be less detailed and specific, as the primary goal would be to define the scope and parameters of the project. However, alternatives generated during the final design phase would be narrowly focused on project design details such as the specific components of a larger assembly. To evaluate the alternatives, information concerning the alternatives, such as cost estimates, scheduling, etc., needs to be developed. The alternatives are then evaluated in comparison with the initial objectives, goals, and constraints established for the project.

The final primary activity within a project phase is decision-making. A decision needs to be made on which alternative(s) to use and on how to proceed with the project. On public works projects the decision-making authority is often delegated to a governing or regulatory body and is often closely tied to the budgeting and financing process for the project. If at the end of a phase a decision is made to proceed with the project, an accompanying decision to appropriate funds for the next phase of the project is also commonly required. As appropriated funds are typically earmarked for a specific fiscal year or sometimes even have to be approved by voters, a significant time lag between project phases can occur on public work projects. This is often one of the significant differences between public works projects and those in the private sector.

This identified repeatable nature of the project development process is significant when attempting to develop a decision support system that is to be linked to the project development process. The repeatable structure within each phase of a project allows the same decision support system framework to be used during any of the phases while the repeatability of the process from project-to-project allows the same decision support system to be used across multiple projects. Without such repeatability, it would be difficult to develop and implement a decision support system, as it would have to be modified for each project phase and for each individual project.

The model also identifies the alternative generation and evaluation activities as the key repeatable opportunities for inserting construction-related input or expertise into the project development process. This input could be beneficial in not only generating alternatives but in providing the data and information necessary to evaluate the alternatives. Other opportunities for construction-related input could include evaluating contract or project delivery strategies during the planning phase and providing input into project management control and constructability programs established at the outset of each phase of the project. The model demonstrates the opportunity for construction-related input beginning as early as the initial planning phase of the project. Each of these key construction input or decision points can become an opportunity to document the rationale behind decisions made that can be used as feedback to the overall process development process if incorporated into a readily accessible lessons-learned database.

Having recognized the basic repeatable nature of the project development process and identified the activities of generating and evaluating alternatives as key opportunities for construction-related expertise input, it becomes possible to construct a decision support framework that can be linked to the project development process. Such a framework is conceptually demonstrated in Figure 3-10 and illustrates the use of the decision-making activities found within the project development process as links to a decision support system. The ability to structure the project development process in a manner that allows it to be linked to a decision support system is considered a significant contribution of the current research effort.

Another implication the author's model demonstrates is that integration and constructability programs must be planned and formally incorporated into the project management and control structure of the project. This supports the same conclusion reached by others in the research literature [CII (1987), O'Connor (1994b), Radtke, Vanegas]. Such formal planning for integration is related to the issue of incentive raised previously in CHAPTER 2 as improved integration will not naturally occur on a project and must be mandated and actively promoted by the owner [Radtke, Vanegas]. Therefore, to be effective any decision support system framework will need to be integrated into the project management control structure established for a project, a key consideration that was included in the current research effort.

As discussed previously, decision-making activities are a major component of the public works process model. Several implications arise from this result. First, in order to have a true decision-making process there must be alternatives to compare. If the parameters or design of a

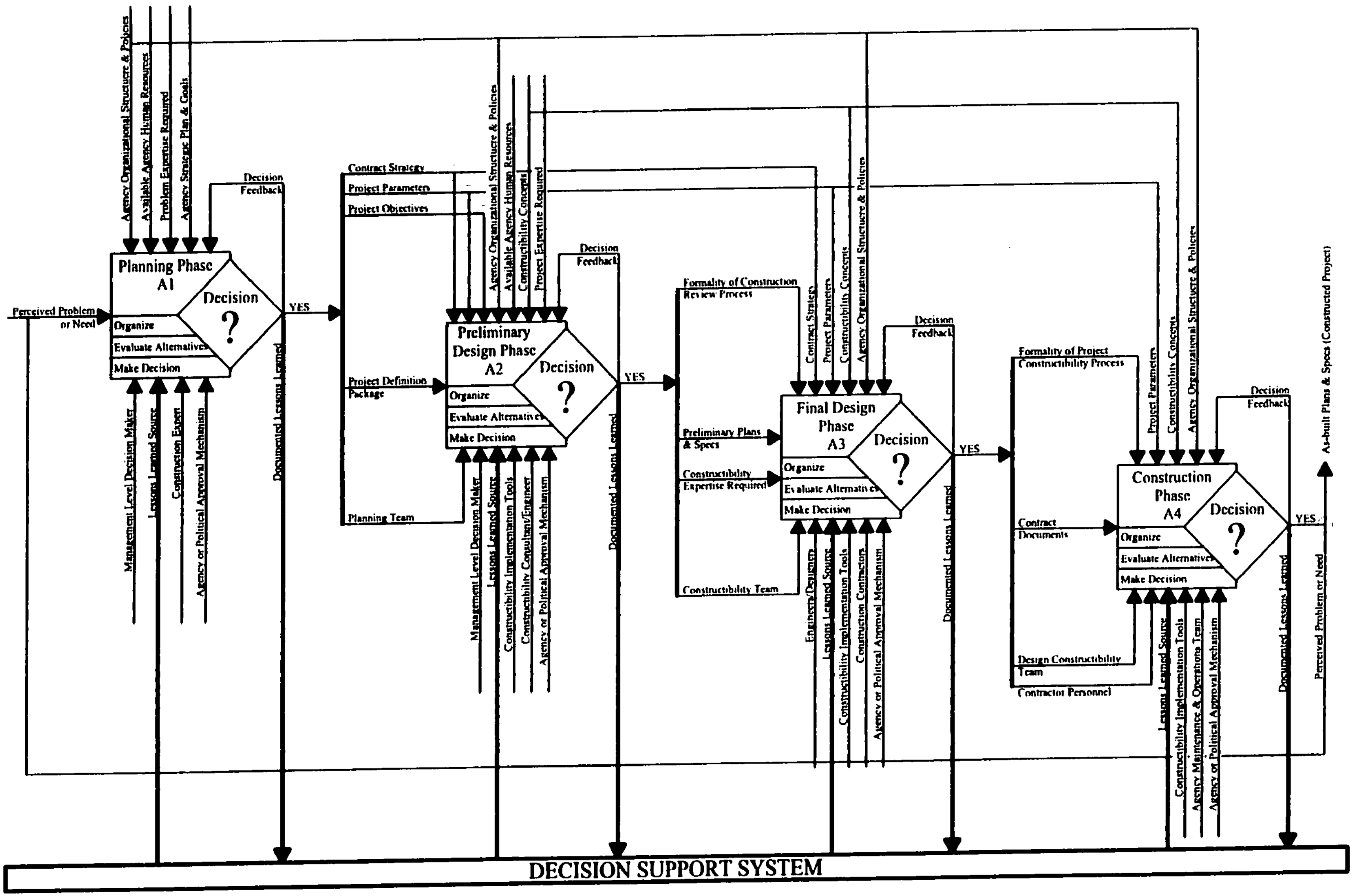


Figure 3-10: Intermediate Decomposition of Proposed Public Works Development Process Model with Decision Support System

project are so tightly proscribed as to preclude any reasonable alternatives, then there is no need to make a decision. In such a case, there would be no need for construction-related input or expertise to be included in the decision-making process. This confirms the research of others indicating the need to utilize performance-based parameters that allow a wider range of alternatives in order to improve project performance [Brott, Gray, Songer, Stortstrom].

An additional implication of the decision-making component of the model is the necessity of clearly transmitting the original goals and objectives for the project across all phases of the project. To be evaluated fairly and consistently alternatives need to be compared and evaluated against the same common goals and objectives regardless of the phase of the project. The author's model clearly shows the goals and objectives established early in the planning phase of a project traveling across the entire spectrum of the project development. This demonstrates the need for owners to clearly define and convey the project objectives to other subsequent downstream participants [Molenaar, Songer, Stortstrom]. Unfortunately, this is often not the case as evidenced by the poorly written requests for proposals seen within the industry and the resulting disputes arising therefrom [ASCE (1990), Mendelsohn].

One of the difficulties in conveying this information across and between subsequent phases is illustrated within the author's model. At the beginning of each phase the project must be staffed with appropriate personnel and the project team created. The project team's primary function is to perform the task associated with the particular project phase such as planning or preliminary design. However, in order to provide continuity between phases of the project the project team's involvement in the project must extend into the initial activities of the subsequent phase as illustrated in the model. The project team is then able to directly convey relevant project information such as the project objectives or rationale behind decisions to new project participants, thus creating a smooth transition. However, because of the time lag that often occurs between the phases on a public works project (or sometimes because of the sectionalized nature of public work agencies) this overlapping transition between project teams does not occur. Instead, the information is transmitted through written reports and other documents.

Finally, the public works process model demonstrates the compounding nature of the decision-making process. Downstream decisions are directly dependent on decisions made and data generated in previous activities and project phases. This provides some validity to the previously discussed concept that the ability to influence a project's performance decreases over the life of the project because earlier decisions directly impact all future decisions [ASCE (1990), Gibson]. Thus, the model supports the need for improving design and construction by providing avenues for construction-related input as early as possible into the project development process.

CHAPTER 4: AN INSPECTION OF CURRENT INDUSTRY PRACTICES

Section A: Formulation of Interview Methodology and Questions

To supplement the critical design and construction integration links identified from the project development process modeling performed in CHAPTER 3, the next step of the research methodology was to obtain actual background data on current project delivery and integration industry practices. The goals were to gage the current state of integration and to uncover opportunities for improved integration on the delivery of underground utility projects within the public sector, to determine characteristics of underground utility projects that would benefit most from improved construction input during the design phase, and to discover potential barriers to implementation of any integration improvement methodology. To accomplish this, a series of formal structured expert interviews were outlined, arranged and conducted with selected representatives from the industry.

The first step of the methodology was to determine the type of individuals to be interviewed. Considering the basis of the research objective, it was deemed important to interview individuals that were experts in the field of public works contracting, particularly in the underground utility project sector. In addition, as the research was concerned with improving integration among project participants, a pool of individuals forming a representative cross-section of the owner, design, and construction communities was necessary. Finally, it was decided that the interviewed individuals should have project management level experience as such individuals routinely view and interact with a larger spectrum of the project development process than lower level project engineers or superintendents.

The first set of questions was structured to document the professional background of the respondents so that the appropriateness of their participation in the research project could be validated. Besides the name of the respondents, elicited information included professional experience, relevant project experience, educational background, etc. Information concerning their current employer was also obtained in order to establish the organization's capability of providing relevant knowledge concerning the research topic.

Once the background information had been obtained, a series of questions were outlined to gage an individual's knowledge and experience with various project delivery systems and management philosophies. Respondents were asked to briefly describe each of the basic project delivery systems or management philosophies discussed in the literature review and to indicate the extent of their experience, if any, with the various methodologies. The intent was to develop an understanding of the breadth of the knowledge base that the industry was relying on when making decisions concerning project delivery strategies.

The next segment of the interview was structured to gage the current state of integration or interaction between project participants in an effort to uncover potential opportunities for improved integration. After briefly defining the formal constructability process, respondents were asked to describe the types of construction related knowledge or advice they currently sought on projects. An effort was also made to determine the sources used to obtain the information and the timing, in relation to the project development process, of when such advice was sought. If a respondent represented the construction sector, they were asked instead about current available opportunities to provide construction input during the design phase of a project. Finally, all respondents were asked to describe their current procedures for documenting and disseminating lessons-learned on a project.

Next, the interview was used to characterize underground utility projects to determine if there were any actual opportunity or need for construction related input during the design of such projects. Respondents were asked to classify various components of a facility's design according to its domain of primary responsibility; engineering, construction, or shared. Design components included facility sizing, facility location, selection of materials or equipment, project scheduling and sequencing, and installation methodologies. Respondents were also asked to provide the reasoning behind their classifications and to provide an opinion on what additional criteria, besides just lowest cost, should be used to evaluate project proposals.

To determine some of the issues or barriers that might have to be overcome when implementing any proposed integration methodology or alternative contracting system, respondents were then asked to discuss certain potential concerns. Items discussed included legal or regulatory obstacles, the sophistication or qualifications of the contractor community, project complexity, industry incentive to adopt changes, impact on bid competitiveness, evaluation of proposals, and cost of proposal preparation. Also, respondents were asked to discuss issues surrounding the pre-qualification and short listing of contractors within the industry.

The last portion of the interview was devoted to determining how information was currently being exchanged or shared on a project. Respondents were asked about their software, hardware, and Internet capabilities to ascertain what technological obstacles exist that might impede the efficiency of communication and data exchange between project participants. Also, the exact format (i.e. hard copy, floppy disk, CD-ROM, Internet, etc.) being used to transmit common project information and documents was explored.

An outline of the formal questions developed and used for the interviews is contained in APPENDIX B.

<u>Section B: Summary of Interviews and Responses</u>

B.1: Introduction

A total of five interviews were conducted over a period from November 1, 2001 to January 15, 2002. Interviewed experts included one representing an owner/engineer, one representing an owner, one representing a general contractor, one representing the construction side of a design-build firm, and one representing the engineering design sector. The interviews were performed at the respondents' place of employment and typically lasted between 60 and 90 minutes. All interviews were tape-recorded for later transcription. A complete transcription of a typical interview has been included in APPENDIX B.

Experts were selected from some of the author's professional contacts, referrals received from some of the respondents and others, and from personnel involved with construction projects within the local area. Research has indicated that an expert is typically considered someone who has at least 10-years of experience in the field of interest and has a more flexible approach to problem solving and decision-making [Songer (Ph.D.)]. Based on provided responses, all of the individuals selected for interviews satisfied this requirement.

A summary of the pertinent information obtained from the interviews is provided in the following section. The purpose of the interviews was to obtain information on current industry practices not to highlight or critique the project management style of any particular individual or entity. As such, an effort has been made to avoid attributing information to a specific respondent in order to maintain the focus on overall industry practices. However, because of the limited number of respondents, in some instances it may be possible to infer from the context the contributing source. Therefore, it is hoped that the reader will refrain from any undue criticism of respondents' remarks or practices and instead would be appreciative, as is the author, of the honest and forthright contribution made by the respondents to the research effort. In all cases, the author assumes full responsibility for the content of the summary, any errors or omissions that it may inadvertently contain, and for any conclusions or opinions drawn therefrom.

B.2: Respondents' Qualifications and Backgrounds

A brief overview of the professional credentials of the five experts interviewed is given below:

Expert No. 1:

- Denver Water Department, 27 years
- Private Consultant Firm, 2½ years
- B.S. Civil Engineering, Colorado State University
- Registered Professional Engineer, Colorado
- AWWA Steel Pipe Committee and AWWA Standards Council
- Design and Engineering Oversight for 6-inch to 72-inch Diameter Pipes

Expert No. 2:

- Construction Industry, 35 years
- Sinclair Oil Company
- Martin Ebby Company
- Lillard & Clark Construction
- Grimm Construction Company
- Pipelines, Pump Stations, Water Tanks, Water & Wastewater Treatment Plants

Expert No. 3:

- Camp, Dresser & McKee, 18 years
- Design Work for Pipelines and Water & Wastewater Treatment Plants
- Migrated to Environmental Remediation Projects
- CDM Design Build Section, 10 years
- Current Head of Design-Build Section for Geographical Area
- B.S. Civil Engineering, Colorado School of Mines
- Registered Professional Engineer, Colorado, Kansas & Others
- Water and Wastewater Treatment Plant Facilities

Expert No. 4:

- Navy Warfare Officer, 5 years
- Virginia Beach Public Utilities, 5 years
- Miller – Stevenson Consulting Engineer, 2 years
- City of Fort Collins Stormwater Division, 7 years
- B.S. Civil Engineering, Iowa State University
- Registered Professional Engineer, Colorado & Virginia
- Sewer Systems, Pump Stations, Channels, Detention Ponds, Stormwater Systems
- Planning, Design, and Construction Contract Administration

Expert No. 5:

- Camp, Dresser & McKee, 35 years
- Projects in United States, Far East and Middle East
- Design Engineering of Pipelines, Pump Stations, Treatment Plants
- Project Troubleshooter, 15 years
- Registered Professional Engineer, 10 States

As can be seen, the experts have between 17 and 35 years of professional engineering or construction experience with water, wastewater, and underground utility projects. A summary of their current employers is provided below. It should be noted that it was not intentional that two of the respondents were selected from Camp, Dresser & McKee. Both individuals were contacted through separate, independent referrals and the author was unaware that they worked for the same employer until the time of the interviews. However, both individuals represent different sectors of the industry within a large integrated design-build firm, work at different office locations and, therefore, are capable of providing independent and different perspectives of the project development process.

Denver Water Department:
- Owner/Engineer
- Large Water Utility
- Small to Large Diameter Pipelines, Water & Reuse Treatment Plants
- 100,000 L.F./year Small Diameter, 10 to 20,000 L.F./year Large Diameter
- Primarily Uses Traditional Design-Bid-Build Contracting Method

Grimm Construction Company:
- General Contractor
- 60% Design-Bid-Build
- 20% Design-Build
- 20% Construction Management-at-Risk
- No Internal Engineering Capability

Camp, Dresser & McKee:
- Engineer/Contractor
- Large National & International Environmental Engineering/Construction Firm
- Design-Build Section Annual Volume of $600 million
- Design-Bid-Build, Alternative Contracting & Constructability Consulting
- Can Take Role of Either Engineer or Contractor on Design-Bid-Build Projects

City of Fort Collins Stormwater Division:
- Owner/Construction Manager
- Stormwater Utility
- Small to Large Diameter Pipelines, Detentions Ponds, Channels
- Primarily Uses Alternative Contracting Methods

B.3: Knowledge of Project Delivery Methodologies

B.3.1: Project Delivery Systems

Not surprisingly, all of the respondents were familiar with the design-bid-build project delivery system and had participated on projects that utilized the methodology. The primary advantage noted by the respondents was that the owner was able to dictate and get exactly what they wanted on a project. Some of the disadvantages mentioned included little opportunity for contractor input or innovation, the process not being conducive to team building, and, the system resulted in errors that had to be addressed during construction because it was not possible for designers to produce a perfect set of plans and specifications.

All of the respondents were familiar with the design-bid project delivery system. However, neither of the owner organizations had been involved with utility projects that utilized design-build. In fact, one owner representative indicated that he could see no advantage of using design-build on utility projects and felt that the traditional design-bid-build system served their needs pretty well.

Some advantages of design-build that were mentioned included the ability to accelerate the project schedule, the ability to provide a greater level of constructability input into the design, and the creation of higher levels of trust or team building among project participants. In addition, some respondents noted an increase in project performance, both in cost and quality, compared to the traditional method when utilizing design-build. As an example, one contractor noted a situation where two similar treatment plants were constructed in the same general vicinity, one using design-bid-build and the other using design-build. Comparative results indicated that the one built using design-build had a lower treatment cost per gallon and a lower initial capital investment than the other one.

When it came to construction management-at-risk, only those respondents from the construction sector were familiar with the actual term or concept. However, one owner actually utilized a hybrid construction management methodology as their primary project delivery system without knowing that the process had a formal name. In their hybrid system, the owner acts as the construction manager and selects an engineering firm and a contractor from a pool of pre-qualified applicants at the start of a project's design. The engineering firm and contractor then work together as a team to complete the project.

One advantage that was noted with this system is the flexibility that the owner has in selecting both the engineer and contractor. As the selection is not strictly based on the lowest bid, the owner has the latitude, within prescribed limits, to select the contractor that he wants to work with on the project and is not forced to team with just any contractor that happens to submit the lowest bid. A similar advantage mentioned is an owner's ability to get around strict low-bid selection procedures by hiring a construction manager who then has the flexibility, in consultation with the owner, to select the engineer and contractor without being bound by competitive low bid restrictions.

Other advantages of the construction management-at-risk system mentioned include an increased level of constructability input into the design, reduced claims and contractor disputes, and an increase in project performance in terms of both cost and quality. Concerning reduced claims and disputes, the owner utilizing the construction management project delivery system indicated that they have not had even one contractor claim in the last seven years within their utility or public works section. One respondent disagreed with the claim of reduced costs as he felt that the owner would pay more because of the higher margin the construction manager would place on the project in order to cover his increased risk in providing the maximum guaranteed price.

B.3.2: Project Management Philosophies

All respondents were familiar with the concept of partnering and all, except for one contractor, had been involved with projects that had utilized partnering. The primary advantage mentioned was that partnering was a process that was conducive to team building and allowed all of the participants to come together to work towards a common goal. However, the general consensus of the expert industry group was that the success of partnering was dependent on the enthusiasm or commitment of the parties involved.

The overall feelings of the respondents towards partnering were mixed. Some felt that partnering helped reduce claims while others had not seen any real change in project performance. Several felt that partnering was just a recent "buzzword" attached to a way of doing business that good companies had been doing for years. Finally, one contractor felt that partnering was an outdated concept that has been supplanted by the recent rise in the use of alternative contracting methods.

When asked about the concept of constructability, all of the respondents appeared to be familiar with the general term, however, none were able to described it in the context of the formalized process as defined in the ASCE white paper. The general consensus of the expert industry group was that constructability referred to the review of the engineering design by someone with construction experience to insure that the project could be easily or actually constructed. The one contractor who was most familiar with the concept mentioned that it also included other considerations such as market conditions, product and/or labor availability, time of year, and project schedule.

One respondent felt that constructability practices were something that had been lost by the industry over the years. In his opinion, some of the reasons for the change included:

- Over reliance on computers and software for engineering analysis. He said that engineers just plug numbers into a computer program without consideration or connection to the real world and are unable to evaluate the reasonableness of their computer-generated answers.
- Over reliance on contractors to fix or solve problems that used to be addressed by engineers during design.
- Shortcomings in university engineering education systems where students are not getting enough exposure to the practical side of engineering and where there is an overemphasis on theoretical applications.

Finally, when it came to the concept of concurrent engineering, none of the respondents were familiar with the term. However, when it was explained to them, they were able to mention some projects where attempts had been made to get O&M personnel involved during the design process. One respondent did mention his experience that when O&M personnel are excluded from the project development process they typically do not end up "buying" into the project. This often results in many modifications being made after the facility is turned over to the owner for operation.

B.4: Constructability Utilization and Practices

Respondents from the owner or engineering sectors were asked to describe what items they typically sought construction-related advice on during the design of underground utility projects. In response, they listed such items as traffic control and related issues, installation methodologies including trenchless technologies such as boring, construction duration and schedules, and project cost estimates. They relied primarily on their own senior engineers or design personnel to provide the advice but also used contractors, independent cost estimators, and field inspection personnel in specific circumstances.

In comparison, when respondents from the contracting community were asked to describe what opportunities they typically had to provide input during the design of underground utility projects, they indicated that there was very little opportunity on traditional design-bid-build projects. One respondent felt that most owners thought that such projects were incredibly simple and, therefore, had very little interest in seeking input from a contractor. As a consequence, they noted that the opportunity to have a significant impact on cost or quality is lost by the time a contractor gets involved at the pre-bid stage of a project.

In general, when the information was sought was dependent on the type of project and what the major issues or problems were. In most instances, reviews were performed on a periodic basis with some respondents conducting reviews at major project milestones (e.g. 30% design completion, etc.) and the others holding more frequent or even weekly design meetings between the contractor and the engineer. The difference in timing and frequency was due primarily to the different project delivery strategies employed on a project with the use of major milestones predominate on design-bid-build projects.

As far as documenting lessons-learned for use on future projects, none of the respondents had a standard, formal process. Several prepared end-of-project reports that were routed to others within the office for review. Another conducted end-of-project review sessions on every third or fourth project with representatives from the owner, engineer, and contractor. One contractor's review was based primarily on determining whether or not a project made money and whether or not there were lots of claims or problems. When it came to tracking reoccurring changes or problems during construction, the response was split with the owners not having any mechanism to track the changes while the contractors all had some type of procedure in place for tracking reoccurring changes.

Most respondents did not have any formal procedures for documenting the rationale behind decisions made during design or construction. Decision-making rationale includes such things as describing the alternatives considered and the reasoning behind why a particular alternative was selected or discarded. The one owner utilizing alternative contracting methods incorporates design rationale into periodic design reports prepared over the course of a project.

The passing of knowledge or experience from senior engineers to younger engineers or from senior construction personnel to younger staff was generally done informally through questions asked during projects and through quality control reviews by senior staff. But there was a general consensus the expert industry group that engineers need to go out into the field and observe projects being built and listen to feedback from contractors in order to gain an understanding of constructability. One contractor indicated that the biggest need for experience on an underground utility project was in evaluating geotechnical conditions and that he often hired people who had worked out in the field in similar areas or conditions in order to obtain the relevant experiential knowledge. However, none of the respondents had methods for documenting the experiential knowledge base within their organizations.

One respondent, however, felt that most organizations would be reluctant to expend the cost or time associated with a formal lessons-learned documentation program. Also, he felt that the fear of litigation would keep organizations from adopting a documentation program, particularly when it came to documenting problems or shortcomings. Plus, he noted that the engineering profession doesn't openly discuss problems or failures just the successes and that you could look at any professional engineering journal or magazine to find evidence of this reluctance.

B.5: Underground Utility Project Characterization

Respondents were next asked to characterize the major design components of an underground utility project according to their primary decision-making domain. Design components considered included facility size, location, materials and equipment, project scheduling or sequencing, and installation methodologies. Each component was placed into one of three domains; engineering, construction, or shared.

When asked about the sizing of a facility, the expert industry group unanimously agreed that the responsibility fell within the engineering domain. The only potential area of input from the contractor would be to ensure that the selected size was compatible with common industry size standards. However, location of the facility in both the horizontal and vertical alignment was generally agreed to be a joint or shared decision between the engineer/owner and the contractor. However, some felt that the engineer should just specify a general corridor and let the contractor work out the rest of the details.

Selection of materials or equipment was generally considered to be a joint or shared decision between the engineer/owner and the contractor. The engineer should specify particular performance parameters and identify O&M compatibility requirements. The contractor, meanwhile, gets involved when evaluating the cost of alternatives that meet the specified parameters.

As far as project scheduling and sequencing, it was agreed that this was something that falls primarily within the contractor's domain. The only exception noted was when the owner had to specify planned outages in order to maintain overall system operations during construction. In fact, respondents from the contracting sector felt that owners should not dictate any firm completion dates or schedules for projects unless required by outside parties such as regulatory permitting agencies. Rather, just let the contractor complete the project at his convenience.

There was general disagreement on where the responsibility for determining installation methodologies should lie. Some from the engineering sector felt that is should fall within the engineer's domain because that was the way it has always been done. Others felt that is was more of a joint decision while others felt that is should be left up entirely to the prerogative of the contractor. However, the expert industry group realized that there were times, such as when crossing railroad rights-of-way, that installation methodologies might need to be mandated by the engineer or others.

When asked for the parameters that fell strictly within the engineering domain, the consensus was the sizing and performance specifications of the facility. On the other hand, when asked for the parameters that fell strictly within the contractor's domain, the responses were divided and included installation methodology and project scheduling. A comment was made by one of the contractors concerning how the engineer/owner needed to avoid being too proscriptive on a project or else they would lose a lot of the opportunities for savings through contractor innovations.

Respondents were also asked to specify what areas on an underground utility project would benefit most from contractor input during the design. Some mentioned constructability in general and said that there was no area that would not benefit from contractor input. Others mentioned project scheduling and project location or alignment. There was also a general consensus that the earlier in the design that contractor input was received the better.

Finally, respondents were asked to describe the criteria they would use to evaluate a proposal if the project were to be awarded on some other basis besides strict lowest cost. Project cost, contractor qualifications, and proposed project schedule were the three main criteria mentioned most. Some also noted constructability and proposed innovations as important criteria.

B.6: Design-Build Contracting Assessment

The respondents were then asked to discuss the viability of using alternative contracting methods, such as design-build, on underground utility projects. The enthusiasm for the method was varied with those from the contracting sector highly in favor of its use while those on the owner/engineering side less enthusiastic, particularly those using the traditional design-bid-build system. One respondent felt that eventually design-build might be beneficial on utility projects but admitted that it was going to be difficult to change the industry's philosophy from design-bid-build to design-build because of institutional inertia within public works agencies. Those in favor of the concept felt that it was an extremely viable option that a lot of owners were missing out on because of the apparent simplicity of pipeline projects and that even the simplest, most straightforward pipeline could benefit from design-build.

Respondents were also asked to discuss some of the barriers or obstacles that might exist when attempting to implement or adopt a design-build strategy. When it came to legal and regulatory barriers, it was dependent on the particular jurisdiction. Home ruled municipalities appeared to have the easiest time adopting design-build because they have more flexibility in modifying their procurement regulations. On the other hand, State and special local district regulations are less friendly towards design-build with many special districts in particular mandating the use of competitive, low cost bidding for awarding construction contracts. Respondents indicated that the Federal Government appears to be open to the use of design-build and expressly allow most of their agencies to use design-build. It was noted that in many instances it often depends on the advice of a particular legal counsel as some interpret the law more leniently than others.

There was a general consensus by the expert industry group that, in the industry as a whole, there are sufficient numbers of qualified or sophisticated contractors capable of participating in design-build projects and, therefore, it would not be a barrier to the implementation of design-build. There was general agreement, however, that competition (i.e. number of bidders) would likely decrease somewhat under design-build. But none indicated that such a reduction was necessarily bad, as design-build would eliminate the less-qualified contractors that many would like to eliminate from the industry anyway.

Concerning the level of project complexity that was suitable for design-build, there was general disagreement among the respondents. Those from the owner/engineer sectors felt a project would have to reach a certain level of complexity before it was suitable for design-build. On the other hand, the contractors felt that complexity was not a variable and that any project could be suitable for design-build. However, the expert industry group agreed that as the complexity of a project increases the more suitable it becomes for design-build.

As far as incentive for adopting design-build, whether or not this posed an obstacle was dependent on the industry sector. Because of the higher profit margins associated with design-build, some felt that contractors would generally be inclined to accept design-build. However, those contractors use to making money off of change orders and claims probably would not like design-build. The owners' incentive for adopting design-build is generally to get a lower cost and shorter schedule for their projects. But many owners are not interested in taking on the additional work required to setup and manage a design-build project. A disincentive to the engineers is that they usually end up losing the lead role on a project to the contractor. However, often their fees are higher because they are involved more during the construction of the project.

As long as it was fair and objective, the evaluation of proposals was not seen as an obstacle. However, the contractors expressed frustration with the current state of the industry indicating that owners don't know how to write a good proposal let alone evaluate one. They indicated it was often difficult to tell exactly what the owner wanted and doubted that owners knew exactly what they wanted.

The cost of preparing proposals was also not seen as a major obstacle to design-build. The respondents noted that if the engineers and contractors want the work, then it is the price that they are going to have to pay. Some, however, felt that owners should reimburse at least a part of the cost of proposals received from unsuccessful bidders but others felt that was something owners should avoid. One contractor admitted that the contracting industry was their own worst enemy and, since they have been willing to prepare proposals in the past without compensation, that owners would most likely be reluctant to move in that direction in the future.

As long as the process of evaluating contractor qualifications was fair and objective, contractor pre-qualification was not viewed as an obstacle. There was general agreement that the two-step process of pre-qualification used by the Federal Government on design-build projects was an appropriate methodology in providing a fair and objective evaluation.

Some miscellaneous issues raised by some concerning the successful implementation of design-build include the need for owners to establish a system of checks and balances when using alternative contracting methods, such as using an independent estimator to check the costs submitted by the contractor. Also, some sort of arbitration mechanism is needed to assess the distribution of cost savings on a project, particularly if value engineering or similar clauses are a part of the contract.

B.7: Information Exchange Capabilities and Techniques

When it came to assessing the informational exchange capabilities of the industry, all of the respondents indicated that they were fully "wired" with access to the full spectrum of computing hardware and office equipment. Also, all had full access to the software pertinent for their domain with CAD & GIS software belonging more in the engineering domain and cost estimating and scheduling type software in the contractors' domain. Responses indicated that all parties had sufficient computer skills to communicate effectively through email and Internet web pages.

Sufficient hardware was not viewed as an obstacle to communication or the exchange of data. However, direct sharing of electronic data across different software formats would be a barrier to communication in certain circumstances. In addition, most organizations had little, if any, capabilities in web-based programming or e-business type web applications.

Plans and specifications were almost exclusively exchanged as hard copies between organizations. Technical reports, such as geotechnical investigations, were also almost exclusively exchanged as hard copies. However, internally within organizations such documents were being transmitted via email and the Internet.

Bid advertisements are posted primarily in news print publications, however, they are also emailed to established lists of contractors. Addendum are often emailed to planholders and then followed up with a hard copy. On the other hand, bid submittal documents are almost exclusively hard copy and only occasionally submitted on disk.

Change orders and other field documentation is usually hard copy. At times, copies will be emailed between parties during negotiation but always consummated with a signed hard copy. Payment of contractors and vendors is typically done by written check with electronic transfer of funds not being used a great deal.

Most respondents could see no real advantage in moving to electronic bid submittals. The only apparent advantage appeared to be that contractors would not have to physically appear at a given location and time to submit a bid. The disadvantages included the reliability and security of email and Internet servers.

Section C: Summary and Conclusions

As only a limited number of interviews with experts from the public works industry were conducted, the results obtained therefrom do not represent a true, statistical survey of current practices within the public works industry. Therefore, caution must be used when attempting to make industry-wide inferences from the responses. However, the chosen experts were knowledgeable about not only the specific practices of their own organizations or businesses but also about general trends and practices found elsewhere within the industry. Consequently, it is the author's opinion that the responses received are likely representative of the typical attitudes and practices found in the industry as a whole.

It appears from the interviews that parties from all sectors of the industry are familiar with the design-bid-build and design-bid project delivery systems. However, construction management-at-risk appears to be a concept that the contracting community is more familiar with than are the other sectors. However, some of the difference may be due to semantics as one owner had adopted the project delivery system without realizing that it had the formal name of construction management. In any case, the contracting community had more actual experience with alternative contracting methods, probably as a result of the private sector work that they also performed.

According to the expert industry group, there are few, if any, real obstacles to implementing design-build or other alternative contracting methods on underground utility projects. The primary obstacle appears to be the institutional inertia within the owner sector of the industry that is accustomed to doing things "the way they have always been done." However, as the experience of one owner demonstrated, it is possible to develop innovative contracting practices within the context of current procurement regulations and industry practices. In their case, the results have demonstrated a marked decline in construction related disputes and claims.

Constructability is a concept that was misunderstood by most in the expert industry group. Most viewed it as the periodic review of the design plans by someone with construction experience in order to insure that a project can be easily constructed. Few recognized project planning issues such as financing, contract strategy or scope definition as candidates for construction related input. None discussed constructability in the context of an integration tool for optimizing the entire project development process and not just separate functions.

The expert industry interviews indicated that contractors are given very little opportunity to provide input during the design phase under the traditional design-bid-build project delivery system. In addition, limited efforts are made by the engineer and/or owner to gather construction advice during the design of underground utility projects and the entities tend to rely on their own personnel to provide the advice. Even within design-build firms, from the interviews it appears that advice from the construction side of the organization is limited to specific functions and construction personnel are not integrated into the full design team.

Probably because of this tendency not to seek outside construction advice, there was general consensus within the expert industry group that engineers need to become more familiar with construction technology. To achieve this engineers need to go out in the field more to observe their projects being built and to listen to feedback received from the contractor. According to some, the lack of integration has been compounded by both the specialization found within of the industry and the engineering university educational system.

Within the expert industry group, efforts to document lessons-learned on a project were extraordinarily weak. Most within the group are not tracking reoccurring changes or problems in a formal manner. Nor are they documenting critical decisions, particularly the rationale or "why" behind the decisions. Thus, owners are losing the opportunity to develop a knowledge base of past experience that could be applied to improving future projects. Instead, the experience gained remains with the engineering consultants or construction contractors who, because of the nature of public contracting, may or may not be involved with the owner's future projects. Because of this identified need or weakness within the interviewed industry group, the concept of a lessons-learned database was incorporated as part of the framework for the decision support system developed for this research.

However, some potential barriers to implementation of a lessons-learned based methodology were raised during the interviews. First, when asked in general about documenting lessons-learned information, several respondents expressed concern with the potential increased administrative burden. Next, some indicated that, in their opinion, many individuals would be reluctant to document lessons-learned because of a fear of increased liability, particularly in the case of documenting deficiencies or problems with a project. Again, these concerns relate to the issue of incentive noted in the literature review and highlighted further during the previous discussion concerning the author's model of the public works project development process.

Although not directly related to documenting lessons-learned, the expert industry responses concerning design-build contracting sheds some light on the issue of incentive within public works contracting and how it might relate to the proposed decision support framework. Responses from the interviews indicate that the owners' primary motivation for adopting alternative contracting methods is improved project performance or savings in terms of cost and schedule. Engineers and contractors, meanwhile, like design-build because, in their view, it allows them to provide a better project to the owner and to compete for projects on overall merit instead of just lowest bid or cost. This benefit accruing from improved project performance becomes a direct incentive to the owner and an indirect incentive to the other entities and could be applicable to the proposed decision support system framework as well.

However, the significant interview responses concerning incentive occurred during the discussion of the cost of preparing design-bid proposals. As unsuccessful bidders for design-build projects typically must absorb most if not all of the cost of preparing proposals (which can sometimes be substantial), one would assume this would be a major disincentive for wanting to participate in the process. However, according to the expert industry group this is not the case as the engineering and construction entities indicated that if they want the work that is the price they are going to have to pay. This does not mean they were enthusiastic about the prospect of absorbing the additional cost only that they would if required to do so.

This is directly related to the concerns raised about increased administrative burden and a reluctance to participate in the lessons-learned documentation process. Engineers and contractors are not going to participate in such a process voluntarily. Rather, the process will have to be contractually mandated and then they will participate, albeit reluctantly, if they want the work. Based on this reasoning, contractually mandating participation in the lessons-learned documentation process is the incentive structure that has been the adopted by the proposed decision support system framework. Such a strategy is in line with previous research that showed that to be successfully implemented, the owner must mandate constructability programs [Radtke].

There is a perception within the industry that underground utilities are straightforward and do not require significant construction related input. However, based on the interviews, it appears that underground utility projects could benefit most from construction advice on both horizontal and vertical location, selection of materials or equipment, installation methodologies, and project scheduling. In some circumstances, facility size and determination of contract strategy could also benefit from construction related expertise. The research used this characterization of the nature of the critical decisions on an underground utility project to structure the lessons-learned database developed for and used within the proposed decision support system framework.

CHAPTER 5: A DECISION SUPPORT SYSTEM FRAMEWORK TO IMPROVE PROJECT PERFORMANCE ON PUBLIC WORKS PROJECTS

Section A: Scope of Decision Support System

After completing the research effort to this point, it became readily apparent that the best way to improve design and construction integration on public underground utility projects is to have individuals with construction related expertise actively engaged with all phases of a project's development. Ideally, to maximize the benefits derived from the improved integration, the individuals providing the construction expertise should be the same individuals who would ultimately construct the project. However, on public sector design-bid-build projects it is difficult, if not legally impossible, to have the contractor that will build the project involved during the planning and design phases of a project.

Despite this difficulty, results from the expert industry group interviews indicate that there is no prohibition or legal barrier preventing owners from hiring other consultants or individuals with construction expertise to assist during the planning and design of a project. The reason such outside construction expertise is not actively sought appears to be twofold. First, the perception by owners and engineers that they already have sufficient construction related knowledge and experience within their organizations or on their staffs. Second, a lack of knowledge or quantified data concerning the benefits of such outside construction expertise on project performance resulting in an uncertainty of whether or not the effort is worth the additional expenditure.

The second reason is also probably why many public work agencies or owners are reluctant to try design-build or other alternative contracting methods on underground utility projects. Both research taken from the literature and responses from the expert industry interviews have indicated the possible benefits that could be derived through the use of alternative project delivery systems. In addition, the expert industry interviews demonstrated that it is possible for public works agencies to engage in design-build or to create other highly successful alternative project delivery strategies within the context of the current regulatory framework for public sector projects.

This having been said, the research effort could have stopped at this point and concluded with a statement that performance on public sector underground utility projects could be improved if owners and engineers actively pursued practices that sought out or encouraged construction related input during the development of a project. However, there is a component of design and construction integration not directly addressed by either alternative project delivery methods or by hiring construction experts or consultants during the design of a project. That component is the longitudinal direction of integration as described by Fergusson.

Integration in the longitudinal direction encompasses organizational development or lessons-learned through repetition with similar projects. Since Fergusson's research demonstrated that the longitudinal vector of integration had a significant impact on overall project performance, the decision was made to focus the remainder of the research effort within this domain. Therefore, maintaining the original intent of the problem statement for this report, a decision support system framework that could potentially improve the performance of public works projects by improving design and construction integration in the longitudinal direction was developed.

The concept selected for the decision support system was a system that aids the user in documenting, organizing, and retrieving lessons-learned or experienced gained on projects. Once documented, such information could be used as a surrogate source of construction related expertise to improve the decision-making process during project development. A system incorporating a lessons-learned database was an entirely different approach than was originally envisioned at the onset of the research effort. Initially, the author had hypothesized that difficulty in preparing, submitting, and evaluating design-based proposals might be a reason behind the slow adoption of design-bid concepts within the underground utility sector. Therefore, a decision support system that could act as an aid in this process was envisioned. However, nothing from the literature review or expert industry interviews supported the need for such a decision support system in improving design and construction integration.

Rather, many researchers have mentioned lessons-learned databases as being important tools in improving design and construction integration or constructability programs [Anderson (1997), Gugel, Lee, O'Conner (1986), Russell (1994)]. In fact, the Construction Industry Institute advocates a corporate lessons-learned database as a key element in any constructability program [CII (1987)]. Also, results from the interviews with the expert industry group indicated that the group as a whole is extraordinarily weak in taking efforts to document lessons-learned on a project. Therefore, it seemed appropriate to focus the research effort in the direction of developing an improved methodology for documenting and disseminating lessons-learned on a project.

Section B: Proposed Decision Support System Framework

B.1: General Overview and Introduction

The development of the proposed decision support system framework relied on the research results presented and discussed previously in this report. First, the framework takes advantage of the repeatable nature of the project development process revealed during the process modeling effort. As stated previously, without this repeatable structure it would have been difficult to link a decision support system to the project development process. The framework relies on the repeatable key decision-making activities of generating and evaluating alternatives by using those activities as links between the decision support system and the project development process.

Next, based on results from the expert industry group interviews, a lessons-learned database was incorporated into the decision support system framework. In addition, an attempt

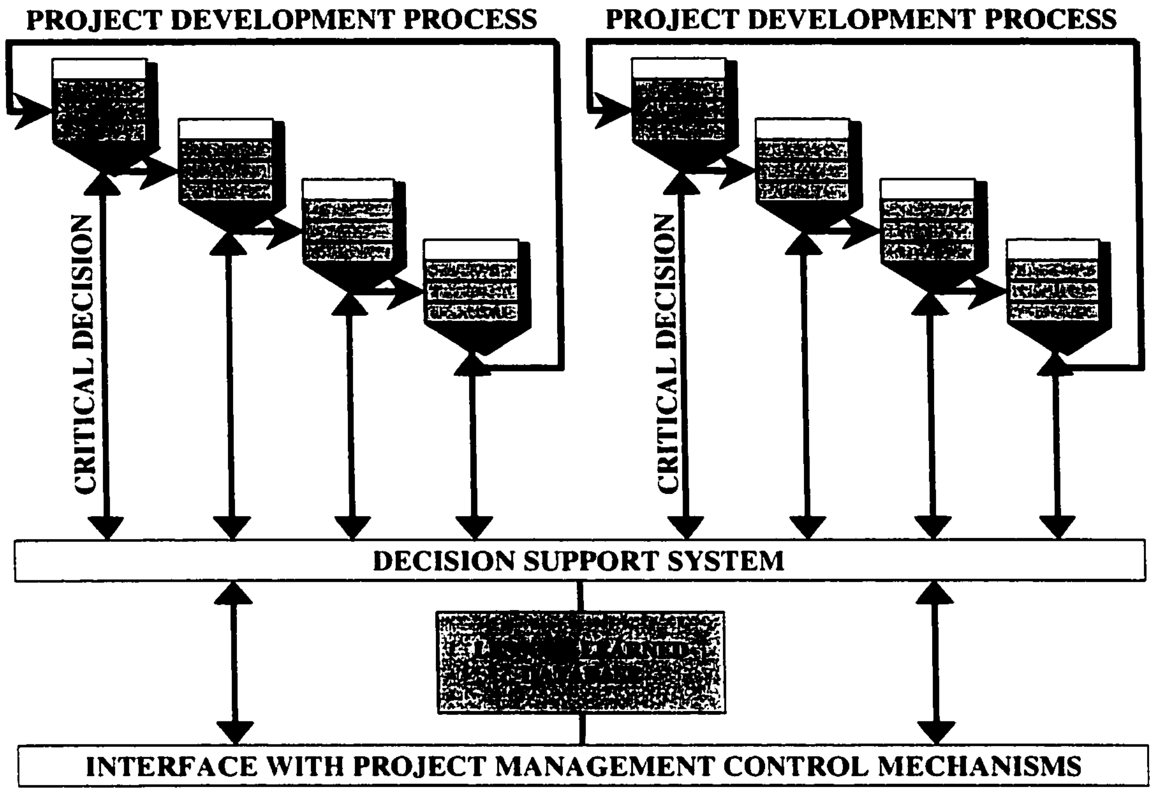


Figure 5-1 Diagram of Decision Support System Framework

was made to integrate the entire decision support system framework into typical project management control mechanisms in order to reduce the administrative burden of the system. thereby increasing the incentive for project entities to participate in the proposed process. A diagram of the proposed decision support system framework is shown in Figure 5-1.

Once the overall framework had been outlined. specific issues within the framework were explored and developed. The first major issue was the structure of the lessons-learned database to be used in the decision support system. This involves two key components. what lessons-learned to document and how to document the identified lessons-learned. To address the issue of what lessons-learned to document. the characterization of underground utility projects obtained from the expert industry group interviews was used to classify lessons-learned into predetermined categories of critical decisions. The categories used include vertical and horizontal alignment.

materials and equipment, installation methodologies, scheduling and sequencing, facility size, and contract strategy.

These critical decisions have been defined as those areas of a project's development that could benefit from construction related input or expertise and represent the outcome of the alternative evaluation processes found in the project development process. Therefore, these critical decisions provide the best opportunity for utilizing a decision support system to improve the decision-making activities within the project development process on underground utility projects. Thus, if the decision-making rationale behind these types of decision can be documented and saved as lessons-learned, it can be used as feedback to the project development process so that others can learn from the decisions-made and improve the overall process on future projects.

The concept of considering documented critical decisions as lessons-learned is different then those typically described in the research literature. Most lessons-learned reported on engineering and construction projects primarily focus on failures or incidents and are collected after a project has been completed through a "forensic" engineering type approach [Kartam]. Also, lessons-learned are commonly viewed from the perspective of post-project suggestions to improve future projects [Russell & Swiggum]. Neither approach involves a rational or systematic method for documenting and reviewing decisions made over the course of a project.

This situation leads into the development of the next key component of the lessons-learned database, how to document the lessons-learned. To avoid the post-project or forensic type approach to documenting lessons-learned, the decision support system framework requires that the actual project participants or decision-makers document the critical decision-making rationale during the course of a project. It is envisioned that one representative each from the owner, engineering, and construction sectors would have access to the decision support system for any given project and that each would be required to document their respective critical decisions made.

This approach where the actual decision-makers document their own decisions or lessons-learned is different than other approaches found in the literature. One purposed the use of personal interviews with relevant project individuals such as those commonly used when developing a knowledge-based or expert system [Kartam] while others have advocated the use of a "suggestion box" method for collecting lessons-learned from project participants [Russell & Swiggum]. The first method requires time consuming interviews that are not normal activities commonly found on engineering and construction projects. The second approach leaves the lessons-learned collection process up to the whim of the project participants in deciding both what and when lessons-learned are to be submitted.

The author's approach has the benefit of avoiding time consuming interviews and other activities not commonly found on public works projects, which reduces the administrative burden of documenting lessons-learned on a project. When combined with the proposed predetermined classification system for critical decisions, the approach provides more consistent and meaningful structure to the lessons-learned documentation process then that provided under the suggestion box technique. In addition, critical decision rationale is documented first-hand by the person who understands the decision best, the actual decision-maker and it is documented when the information is still fresh in the mind of the decision-maker.

Once it was decided what and how the lessons-learned would be collected, the actual mechanics of the documentation process could be developed. Since the selected approach was to have the actual decision-maker document the lessons-learned and to have the decisions documented as soon as they occurred during the course of a project, a mechanism was needed that would facilitate this happening on a project. The concept selected by the author was that of the periodic project status report commonly used on public works projects. If properly incorporated into the decision support system, the report could be used to compel project participants to interact with the decision support system on a regular basis, which would allow the decision support system to prompt or force the user to enter critical decisions or lessons-learned into the system.

Such a reporting mechanism would also allow users to document lessons-learned while generating information and reports that would otherwise be required anyway. It also allows the decision support system framework to be integrated into typical everyday activities and project management control systems, which has been noted as a requirement of any effective lessons-learned database system [Kartam]. Integration into normal project activities would increase the likelihood entities would to adopt the concept for as Bordogna stated "it is a waste to perform the research, garner the new knowledge, and develop the technology if people will not or cannot use it."

Although the frequency of periodic project status reports typically varies between organizations and project phases, a weekly status report interval for all phases of the project was selected for the decision support system framework. It was felt that a weekly interval would be a short enough timeframe that users could still accurately recollect details concerning decisions made and lessons-learned while still being infrequent enough not to create an undue administrative burden. But as discussed in previous chapters, despite any efforts to reduce the administrative burden users, particularly those from the engineering and construction sectors, will not voluntarily use the proposed decision support system. As a result, the author proposes contractually mandating both the engineer and the contractor to complete the weekly project status report and to participate in the documentation of lessons-learned on a project.

So far the discussion has been focused on the documentation of lessons-learned. However, the objective of the proposed decision support system framework goes beyond just documentation and is primarily concerned with utilizing the documented information to improve the decision-making and project development process on underground utility projects. Therefore, the framework incorporates a multicriteria decision analysis (MCDA) function that allows decision-makers to query the database for past lessons-learned or critical decisions made, to use that retrieved information to generate additional alternatives or supporting information, and then to compare and evaluate the alternatives based on multiple project performance criteria.

As stated previously, the proposed framework requires users to document critical decisions made as they occur. The one drawback to this methodology is that the outcome of a decision may not be known until the project is completed. In other words, a particular decision might be made during the planning phase of the project but its impact on the final project performance may not be known until construction is completed. To overcome this difficulty, a post project evaluation function was included in the decision support system framework. This function allows all of the critical decisions made during the course of a project to be evaluated at the conclusion of a project so that future users of the database can have access to the final outcome of the decisions.

In addition to weaknesses in documenting lessons-learned, the expert industry group interviews also identified the tracking of construction change orders as a potential weakness. As the tracking of construction change orders is important in identifying reoccurring problems within the project development process that need to be corrected, the decision support system framework added a function that allows user to document construction change orders according to industry standard classifications. This allows project participants to query the lessons-learned database and identify reoccurring trends or problems during construction.

The key to making the whole decision support system framework work effectively is the ability to efficiently query the lessons-learned database. As a result, a database query function was incorporated as a part of the overall concept. It is envisioned that a fully developed database function would incorporate Internet search technologies and knowledge or ruled-based systems to aid users in efficiently screening and retrieving lessons-learned and other documentation from the database. A schematic of the complete decision support system framework with all of its primary functions as discussed is shown in Figure 5-2.

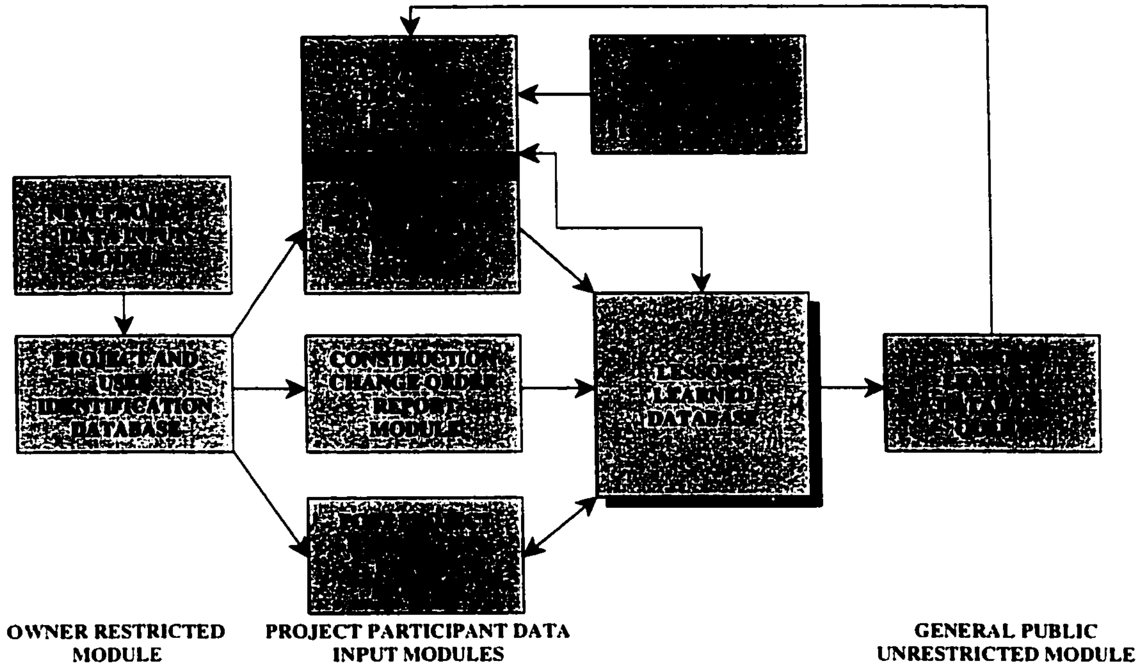


Figure 5-2: Schematic of Proposed Decision Support System

It is envisioned that a fully functional decision support system would be a web-based system hosted and maintained by the utility owner or public works agency. As engineers and contractors often change from project to project. the owner is the best repository for information collected concerning lessons-learned on a project. This will allow participants on subsequent projects to access the lessons-learned database and to learn from decisions made on past projects. thus allowing the project development process to be improved over time.

The database query function would be available to the general public not just to particular selected project participants. Since the decision support system would be hosted by a public entity, it is the author's opinion that any information collected belongs to the general public or taxpayers that are ultimately paying the cost of projects. Therefore, other entities and individuals without ties to the owner would be able to access the database to improve their own projects.

To illustrate how information may be collected and utilized within the decision support system framework a prototype of the system was developed. The purpose of the prototype was not to present a fully functional decision support system that could be used to rigorously test the concept's impact on project performance. Rather, it was developed solely as a platform to facilitate additional discussion concerning the informational collection and dissemination attributes of the proposed framework and how they may be developed further in the future. To demonstrate the potential benefits accruing to project performance from the proposed overall conceptual framework, a hypothetical case study is presented in CHAPTER 7. Microsoft Excel incorporating Visual Basic macros and applications was used as the platform for the prototype system. Obviously, any fully developed decision support system would require the use of more powerful database programs and software computer programming languages.

B.2: Starting a New Project

Upon accessing the decision support system, users would be presented with a home page similar to that shown in Figure 5-3 that allows users to access the various modules in the system. The first module of the prototype decision support system is a module that allows the user to setup and establish a new project in the database system. As the anticipated web-based decision support system would be hosted and maintained by the public works utility owner or agency, this

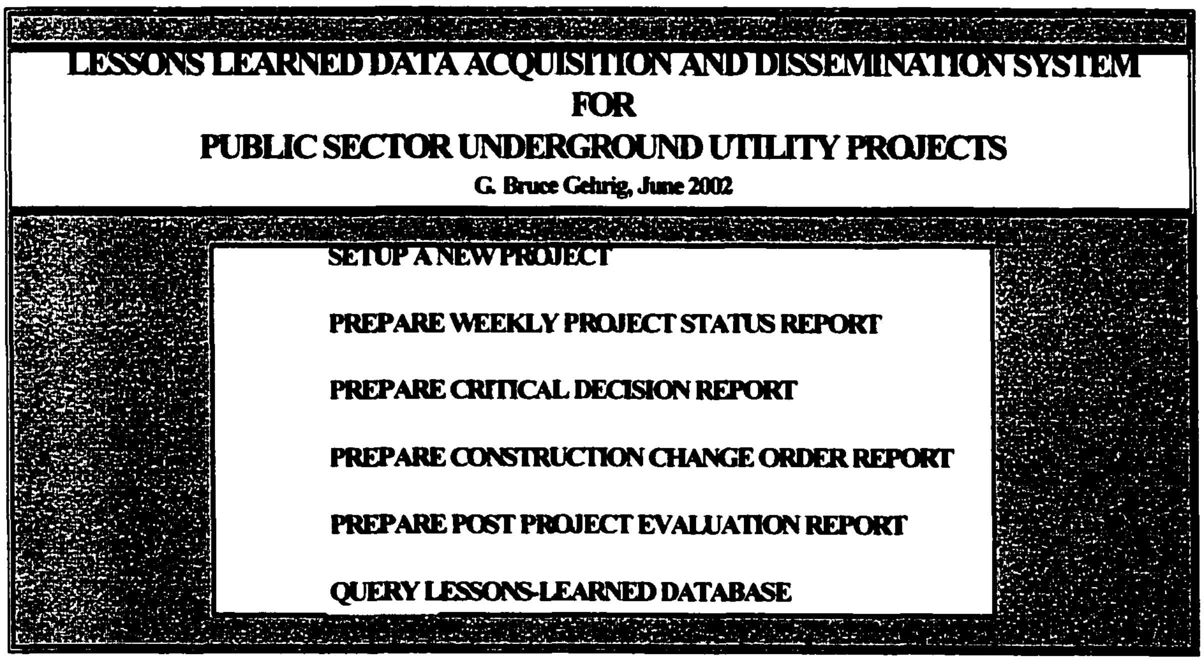


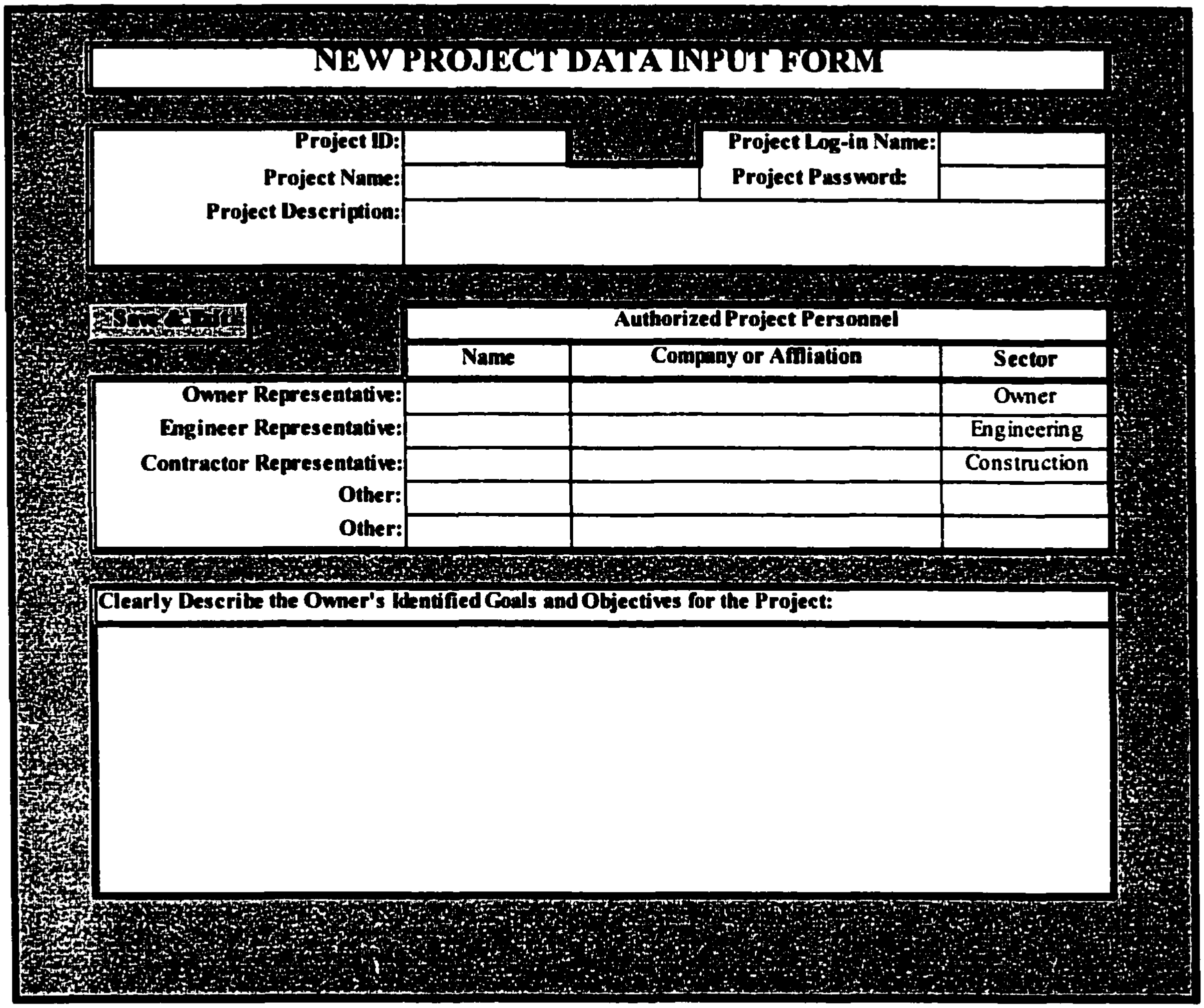
Figure 5-3: Prototype Decision Support System Initial Home Page

initial function would be performed by and restricted to designated individuals within the owner's organization. In order to maintain the restricted access, the user would be required to provide the program with an administrative level login name and password available only to the owner before being granted permission to enter the module.

Upon entering the module, the user would be presented with a New Project Setup form outlining the initial project information required by the decision support system. Using the graphical user interface the user would enter data such as the project's name, identification number, description, login name, password, and objectives and goals. In addition, the owner would enter the names and professional affiliations of those project individuals that would have authorization to access subsequent modules of the decision support system to file project reports and enter lessons-learned data into the database. A prototype of the form is shown in Figure 5-4.

As stated previously, it is envisioned that at least one individual or representative from the owner, engineering, and construction sectors of the particular project would be given access to the decision support system. As a new project would be setup in the decision support system as early in the project development process as possible, not all of the project participants may be initially known. In addition, participants may change over the course of a project. Therefore, the owner would have the ability to add or delete authorized project personnel from the decision support system as deemed necessary during the project.

Aside from establishing project access authorizations, one of the most key aspects of the setup module is the statement of the project goals and objectives. The literature review, the project development process modeling, and expert industry group interviews conducted as part of this research effort all highlighted the importance of clearly defined and communicated project goals and objectives in design and construction integration. Ideally, all subsequent project alternatives and decisions should be evaluated based on the original goals and objectives established at the onset of a project. Unfortunately, the goals and objectives are often either



NEW PROJECT DATA INPUT FORM

Project ID:
Project Name:
Project Description:
Project Log-in Name:
Project Password:

Authorized Project Personnel			
	Name	Company or Affiliation	Sector
Owner Representative:			Owner
Engineer Representative:			Engineering
Contractor Representative:			Construction
Other:			
Other:			

Clearly Describe the Owner's Identified Goals and Objectives for the Project:

Figure 5-4: New Project Data Input Form for Prototype Decision Support System

poorly defined by the owner or miscommunicated during the course of a project, thereby leading to disputes or disappointment when evaluating the final performance of the completed project.

In an attempt to address this issue, the decision support system has been structured in such a manner that project users of subsequent modules within the decision support system will be reminded of a project's initial goals and objectives established by the owner. Therefore, the owner should take the time and effort to clearly delineate the goals and objectives for the project before entering them into the setup module. Of course, if the goals and objectives are refined or changed during the course of a project, the owner would have the ability to update the decision support system accordingly.

B.3: Weekly Project Status Report Module

The second module of the decision support system is used to prepare the contractually mandated weekly project status reports. Access to this module would be restricted to authorized project personnel and users would have to provide the appropriate project login name and password. Once the user has successfully logged into the system, an introductory "greetings" screen would appear that would briefly describe the current project and provide the user with the goals and objectives established by the owner for the project as illustrated in Figure 5-5.

Continuing with the module, the user would then be presented a Weekly Project Status Report form as shown in Figure 5-6. The heading information such as project name, identification number, date, and document file number are automatically filled in based on the project login name provided. The user would then select the project stage and the user's name through the use of drop-down list boxes. The remainder of the heading information is then automatically

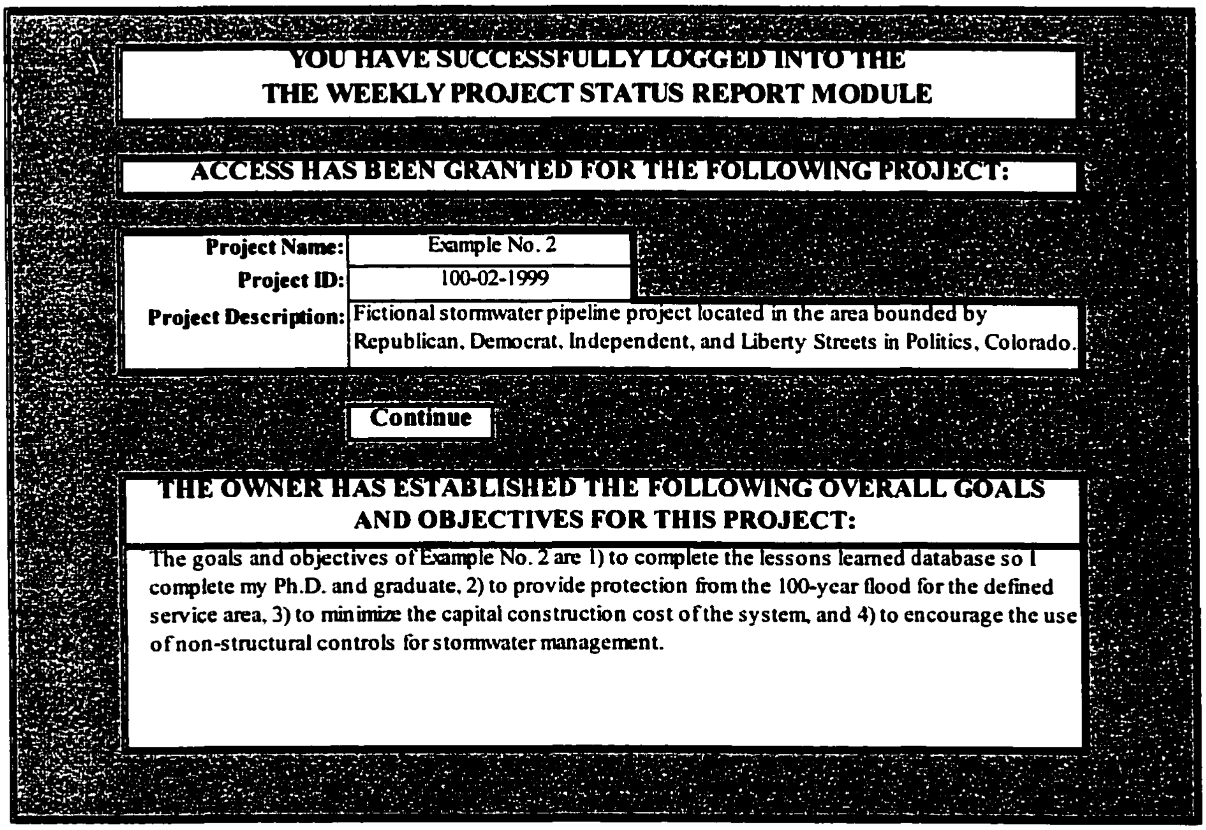
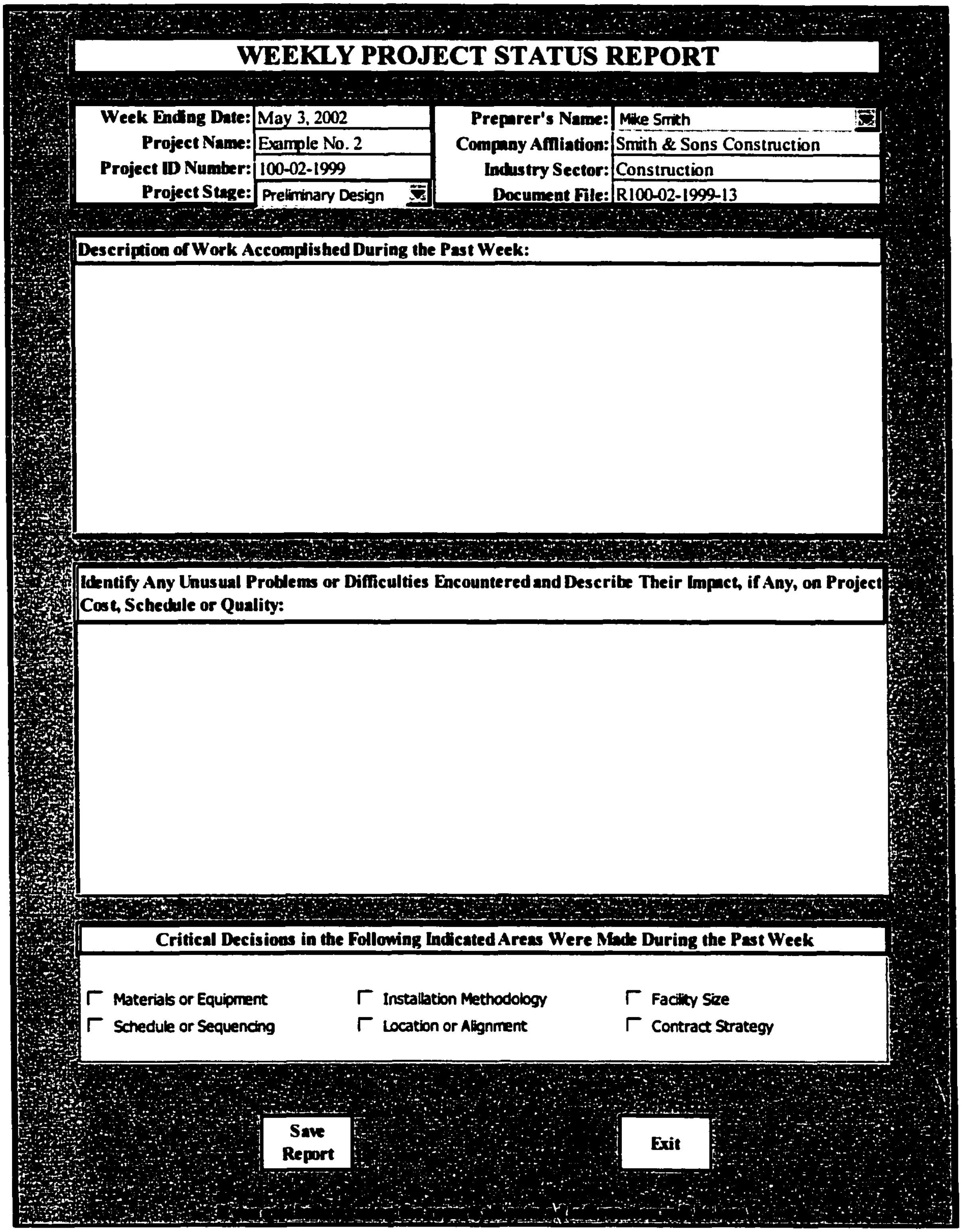


Figure 5-5: "Greetings" Screen Used in Prototype Decision Support System


WEEKLY PROJECT STATUS REPORT

Week Ending Date:	May 3, 2002	Preparer's Name:	Mike Smith
Project Name:	Example No. 2	Company Affliation:	Smith & Sons Construction
Project ID Number:	100-02-1999	Industry Sector:	Construction
Project Stage:	Preliminary Design	Document File:	R100-02-1999-13

Description of Work Accomplished During the Past Week:

Identify Any Unusual Problems or Difficulties Encountered and Describe Their Impact, if Any, on Project Cost, Schedule or Quality:

Critical Decisions in the Following Indicated Areas Were Made During the Past Week

- Materials or Equipment
- Installation Methodology
- Facility Size
- Schedule or Sequencing
- Location or Alignment
- Contract Strategy

Save Report

Exit

Figure 5-6 Weekly Project Status Report Form for Prototype Decision Support System after saving the status report the user would automatically be directed to the Critical Decision Report module. This automatic feature will help insure that critical decisions over the course of a project will be documented on a regular basis.

It should be noted that, other than the requirement to note whether or not a critical decision was made during the week, there is nothing original or unique about this particular form or module. In fact, this type of form could likely be generated by many of the existing project management software packages found within the industry. This is intentional and demonstrates the potential of integrating the decision support system framework into typical reporting activities found within the engineering and construction profession.

It is important to point out, however, that there is a distinct difference between the framework proposed by the author and the function of the existing project management software packages. Existing project management software is designed primarily for project control and monitoring while the proposed decision support system is concerned with documenting lessons-learned. The key contribution of the proposed framework, therefore, is not in its reporting of project information, a task already well addressed by existing software, but in its expansion of the typical reporting activities to include the ability to extract lessons-learned information and to organize it into a useable lessons-learned database. It is conceivable that software programmers could seamlessly incorporate the proposed decision support system framework into existing project management software packages, thereby eliminating the need for an entirely new and separate software system.

B.4: Critical Decision Report Module

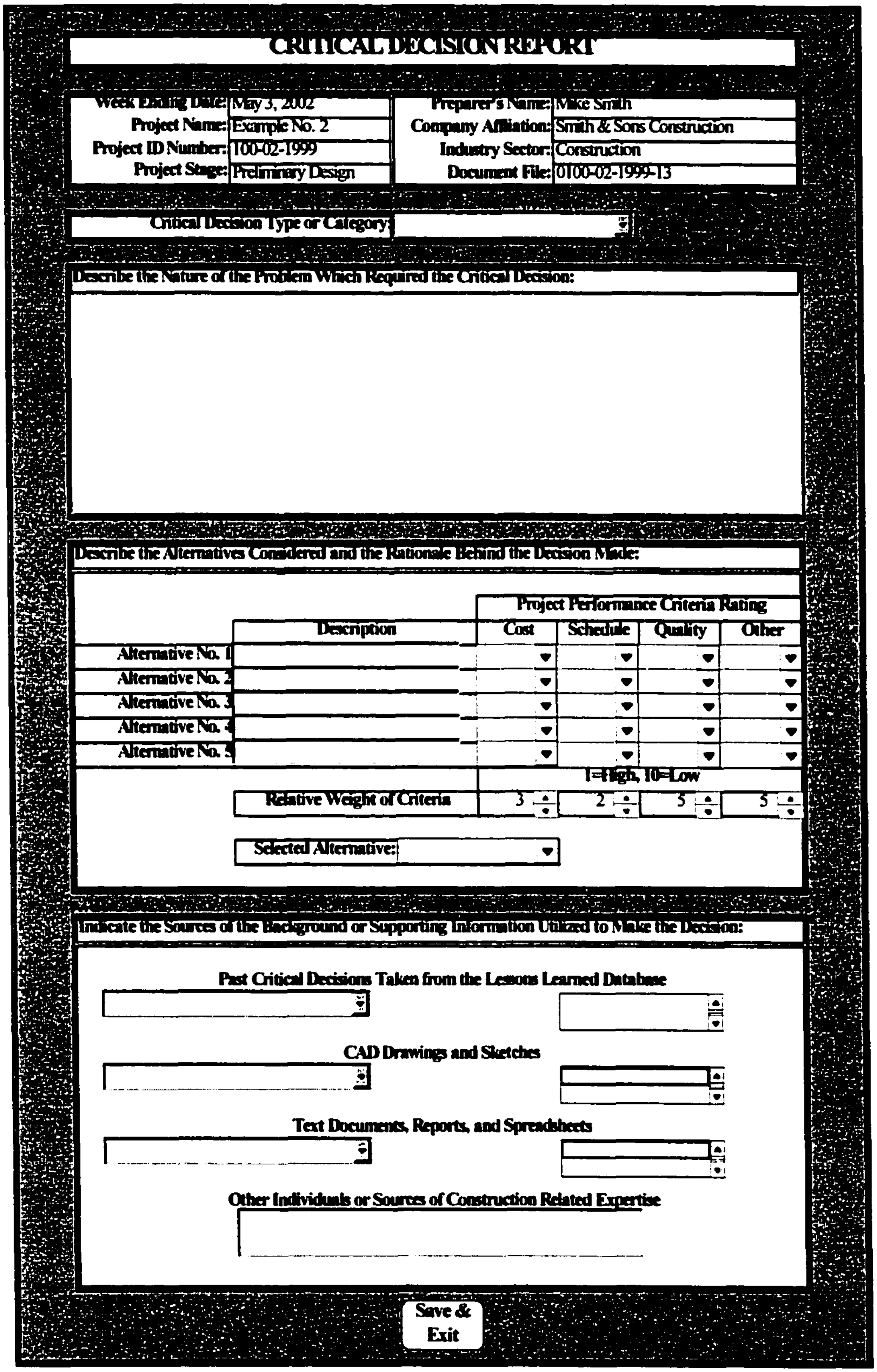
The critical decision report module allows users to both generate and evaluate alternatives using multicriteria decision analysis (MCDA) techniques and to document the rationale behind the ultimate decision made or lessons-learned. The user would either enter the module directly so that it could be used as a decision making aid during the course of a decision or be automatically directed to the module if a critical decision had been noted on the weekly project status report. In either case, upon entering the module the user would be presented with a form similar to Figure 5-7.

The user would first indicate the category of the critical decision being considered through a drop-down list box and the decision support system would then query the lessons-learned database to compile a list of previous critical decision reports and other information pertaining to the general critical decision category indicated. To further facilitate the screening and retrieval of relevant past lessons-learned, the module would then connect the user to the lessons-learned database query module of the decision support system, which is described in detail latter within this chapter. Through the use of additional key words and sub-categories the database of lessons-learned would be filtered sufficiently by the user until the user was presented with a list of only those past records that best reflect the current problem or decision under consideration.

The next text box would then be used to describe the nature of the problem or circumstances that required a critical decision. The user would want to provide sufficient detail so future reviewers of the document would have enough information to understand the basis of the decision made. Also, this free structured information could be used with Internet search engine technologies to improve the efficiency of the database query function of the decision support system.

Once the decision support system has returned the list of relevant past lessons-learned, through the use of hyperlink technology the user could then review the information and compile a list of alternatives and supporting information that will be considered during the decision-making process. Selected alternatives would then be included in the next portion of the form that contains the alternative evaluation matrix shown. Alternatives could be taken from either from the lessons-learned database or could be supplied by the user himself.

The user would then rate each of the alternatives against the criteria of cost, schedule, quality, and other performance criteria established for the project. The rating could be done



CRITICAL DECISION REPORT

Week Ending Date:	May 3, 2002	Preparer's Name:	Mike Smith
Project Name:	Example No. 2	Company Affiliation:	Smith & Sons Construction
Project ID Number:	100-02-1999	Industry Sector:	Construction
Project Stage:	Preliminary Design	Document File:	0100-02-1999-13

Critical Decision Type or Category:

Describe the Nature of the Problem Which Required the Critical Decision:

Describe the Alternatives Considered and the Rationale Behind the Decision Made:

	Description	Project Performance Criteria Rating			
		Cost	Schedule	Quality	Other
Alternative No. 1					
Alternative No. 2					
Alternative No. 3					
Alternative No. 4					
Alternative No. 5					
		1=High, 10=Low			
	Relative Weight of Criteria	3	2	5	5

Selected Alternative:

Indicate the Sources of the Background or Supporting Information Utilized to Make the Decision:

Past Critical Decisions Taken from the Lessons Learned Database

CAD Drawings and Sketches

Text Documents, Reports, and Spreadsheets

Other Individuals or Sources of Construction Related Expertise

Save & Exit

Figure 5-7: Critical Decision Report Form for Prototype Decision Support System through a series of drop-down list boxes, which for the prototype includes a rating scale of good, average, poor, or not applicable. The user would also be able to indicate the relative weight or importance of each criterion on a scale from 1 to 10. Then, using the weighted average method or some other appropriate MCDA analysis technique, the decision support system would return the scores indicating the preferred alternative and the selected alternative indicated in another drop-down list box.

The importance of alternatives in any decision-making process cannot be overemphasized. If there are no alternatives to consider then there is no decision to be made as the required course of action, no matter how unsatisfactory, has already been established and there is little that others can learn about the decision-making process from such a situation. However, when there are multiple alternatives there is an opportunity for others to learn, when faced with similar situations or problems, from the decision-making rationale used. Therefore, it is important that the user document all the alternatives considered no matter how informal or brief the actual evaluation process may have been.

The last portion of the form allows the user to indicate the documents or information that were relied upon when making the decision. If the user relied on past decisions included in the lessons-learned database, the particular document file(s) would be selected from the drop-down list box. Also, the user could indicate from additional drop-down list boxes drawing files or text documents such as cost estimates, geotechnical reports, etc. that were developed or utilized during the evaluation of alternatives. As the appropriate background documentation files are selected, hyperlinks are created that permanently link the location of the documents to the critical decision report form. Finally, a text box is provided where the user can indicate any other sources of construction related knowledge used or considered during the decision-making process.

Once the form is complete, the user would save the report to the database and exit the module. If more than one critical decision had been initially indicated on the weekly project status report, the user would be automatically redirected back to the critical decision report module so that the additional decision(s) could be documented. Once all of the critical decisions have been documented and saved the user would be finished and returned to the homepage of the decision support system.

Under the proposed framework, users would not be required to use the MCDA capabilities of the critical decision report module when analyzing their decisions. However, users would be contractually required to use the module to document any critical decisions made or lessons-learned. Whether or not to utilize the lessons-learned database as a resource to improve their decision-making is a choice left up to the individual project participants. But, the owner still has the right to demand that all critical decisions made, regardless of the process used to make the decisions, be documented in the lessons-learned database so that the information can be available for use on future projects.

When it comes to accessing or reading background documents and reports that may be linked to the critical decision report form it is envisioned that an actual web-based decision support system would include generic file viewing software tools such as Adobe's Acrobat Reader and AutoDesk's Volo View Express. Text type documents would have to be scanned and saved in PDF file formats while AutoCAD drawings could be viewed directly using Volo View Express without users having to have the actual AutoCad software program. Both these and other similar type products are available for free download and distribution from the respective software companies.

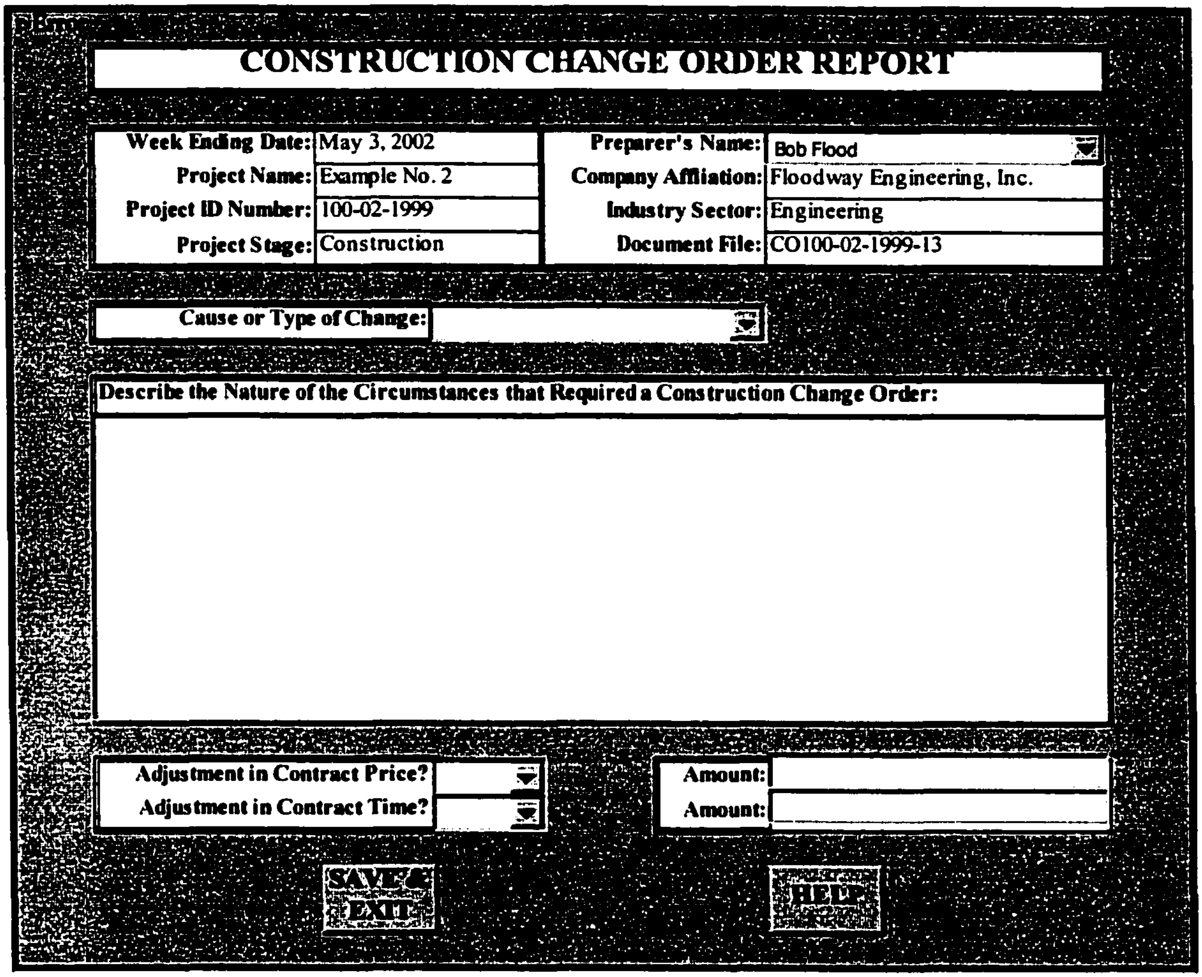
B.5: Construction Change Order Report Module

The fourth module of the decision support system was developed to document and track construction change orders. Construction change orders were considered significantly different than the critical decision discussed previously and, therefore, a separate module was created to specifically address the issue of change orders. Critical decisions can be considered proactive and are usually directed or controlled by the project participants. Change orders, on the other hand, are reactive and are usually symptomatic of problems or shortcomings with earlier portions of the project development process.

Using the analogy of a manufacturing assembly process, change orders are equivalent to feedback or complaints from the assembly line workers that need to be addressed by the engineering or design section to improve the product or assembly process. As such, change orders are valuable markers or indicators of problems that, if tracked and systematically analyzed, could identify reoccurring problems in the project development process so that corrective action can be undertaken, thereby improving project performance from project-to-project. Unfortunately, according to the expert industry group, few project entities are currently routinely tracking change orders particularly in the owner and engineering sectors.

Like the previous module, access to the Construction Change Order module would be restricted to authorized personnel with the appropriate login name and password. Once granted access, the "greetings" form described previously would appear noting the project's goals and objectives. The user would then be presented with the Construction Change Order Report form shown in Figure 5-8. The user would then select the category or type of change order involved. Categories of change orders correspond to classifications commonly found in the industry such as changed site condition, design omission or error, ambiguity in contract language, owner initiated change, contractor initiated change, etc.

The user would then use the available text box to describe the nature or circumstances surrounding the change order and the necessary course of action undertaken. After indicating the resulting change in project cost and schedule, if any, the user is finished and can save the report and return to the decision support system's homepage. The Construction Change Order Report module and form is in addition to the Weekly Project Status Report and the Critical Decision Report modules that would still be required to be used throughout the duration of the construction of the project.



CONSTRUCTION CHANGE ORDER REPORT

Week Ending Date: May 3, 2002
Project Name: Example No. 2
Project ID Number: 100-02-1999
Project Stage: Construction
Preparer's Name: Bob Flood
Company Affiliation: Floodway Engineering, Inc.
Industry Sector: Engineering
Document File: CO100-02-1999-13

Cause or Type of Change:

Describe the Nature of the Circumstances that Required a Construction Change Order:

Adjustment in Contract Price?
Adjustment in Contract Time?
Amount:
Amount:

SAVE & EXIT
HELP

Figure 5-8: Construction Change Order Report Form in Prototype Decision Support System

The actual negotiation of construction change orders is an involved, often contentious process that includes the consideration of alternatives and important decisions. As such, the change order module could have been developed similar to the Critical Decision Report form with an alternative evaluation matrix, attached supporting documentation, etc. However, because of their potential significant adverse impact on the project cost and schedule, construction change orders are usually already highly documented on most public works projects. In addition, because blame or responsibility normally has to be assigned to one of the project contractual entities, change orders can contain sensitive issues or information that project participants may not want to make commonly known. If there is a potential for litigation, the information can even become more sensitive and people even less reluctant to openly discuss problems for fear of exposing themselves to additional legal liability.

As one of objectives is to increase the incentive for project entities to use the proposed decision support system, for the aforementioned reasons it was decided to keep the change order report form simple and not request the user to supply a significant amount of supporting documentation. Hopefully, this would encourage project participants to document problems occurring on construction projects in a generic way without fear of exposing themselves to undue criticism or liability. The potential loss of detail is not deemed important as the key concept of the module is the ability to categorize change orders so that reoccurring difficulties can be identified and the overall project development process improved.

B.6: Post-Project Evaluation Report Module

The next module developed was a Post-Project Evaluation and Report module. The purpose of the module was to provide a mechanism that would allow all of the reports prepared during the course of a project to be compiled and to allow the user to review and critique the decisions made. As illustrated by the results of the process modeling effort, the project development process consists of a series of decisions occurring over the life of a project. Often the impact or result of a decision, even if made during the earliest stages of a project, is not fully known until the project is completed. Unfortunately, both the literature review and the expert industry group indicated that the industry as a whole does not routinely engage in a post-project evaluation or critique of those decisions.

Therefore, an attempt was made to develop a module that addresses this issue. Like previous modules, access to the module would be restricted to authorized project personnel with the proper login name and password. After logging in, again like previous modules, the user would be presented with a "greetings" screen that highlights the goals and objectives established for the project. The user would then be presented with the Post Project Evaluation Form as shown in Figure 5-9.

POST PROJECT EVALUATION REPORT

Week Ending Date:	May 3, 2002	Preparer's Name:	Sue Manager
Project Name:	Example No. 2	Company Affiliation:	Urban Flood Control District
Project ID Number:	100-02-1999	Industry Sector:	Owner
Project Stage:	Post Project	Document File:	FR100-02-1999-13

Summary and Evaluation of Critical Decisions

Materials or Equipment

Document File	Date	Evaluation	Comments

Schedule or Sequencing

Document File	Date	Evaluation	Comments

Installation Methodology

Document File	Date	Evaluation	Comments

Location or Alignment

Document File	Date	Evaluation	Comments

Facility Size

Document File	Date	Evaluation	Comments

Contract Strategy

Document File	Date	Evaluation	Comments

Summary List of Weekly Reports

Document File	Date

Summary List of Change Orders

Document File	Date

SAVE & EXIT

HELP

Figure 5-9: Post Project Evaluation Form for Prototype Decision Support System

When opened, the decision support system automatically compiles a list of all of the documents that had been created and stored in the lessons-learned database for the particular project. The critical decision documents would appear in their separate categories and would be accessible by the user for review through encoded hyperlinks. After reviewing a particular critical decision report, the user would then qualitatively evaluate the impact of that decision on the final overall project performance through the use of an adjacent drop-down list box. In the prototype the rating categories include highly effective, effective, no impact, adverse impact, and highly adverse impact. The user would then add any supporting comments in the adjacent text box. In this manner, the user would complete an evaluation for every critical decision report that was listed on the form.

At the bottom of the form all of the weekly project status reports and construction change orders reports created during the project would be attached to the post-project evaluation report through the use of drop-down list boxes. Once completed, the user would save the report and return to the initial homepage. The report could then be printed out and included as part of any formal project completion report that may be required for the project.

B.7: Lessons-learned Database Query Function

The last module developed was a lessons-learned database query function. In many ways this can be considered the most important function of the decision support system because without a way to efficiently retrieve and sort documents from the database there would be no way for anybody to learn from past decisions or lessons-learned. In addition, unlike the previous modules, this module would have unrestricted access and would be available for use by the general public. Therefore, anybody in the industry could access the database and learn from what others have done on other similar projects, thus allowing the industry as a whole to improve and not just a particular utility or agency.

Figure 5-10 shows the database query form developed for the prototype system. Through the use of drop-down list menus, users would be able to search and sort the database according to

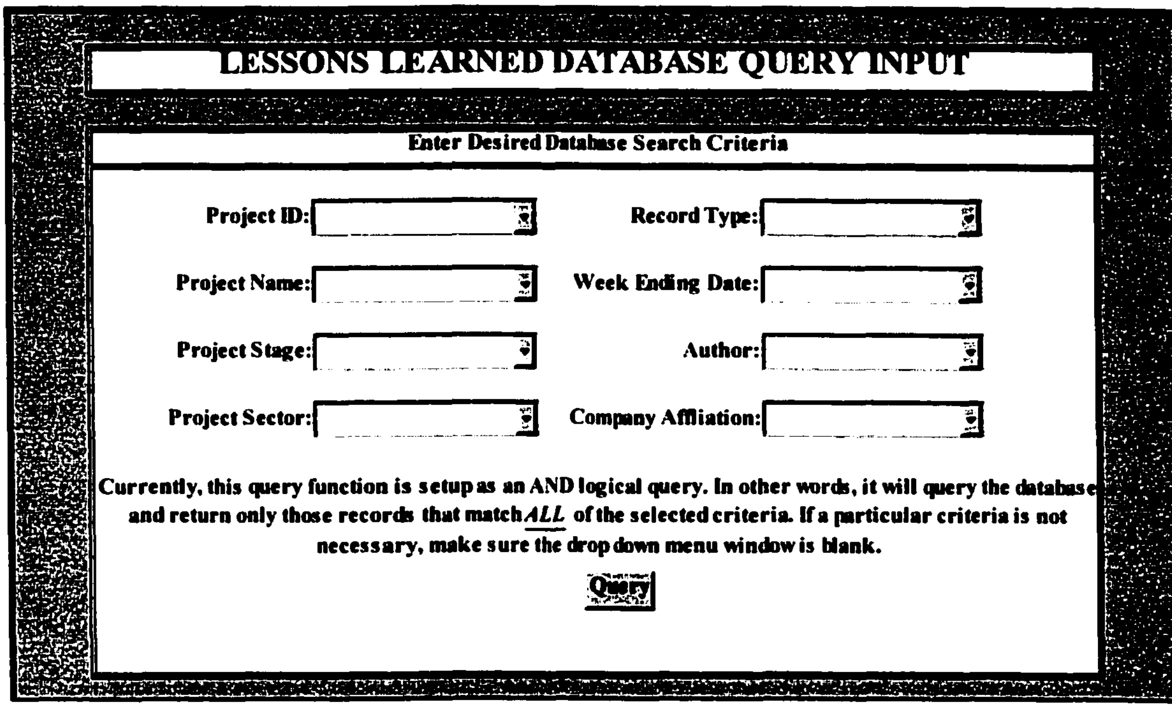
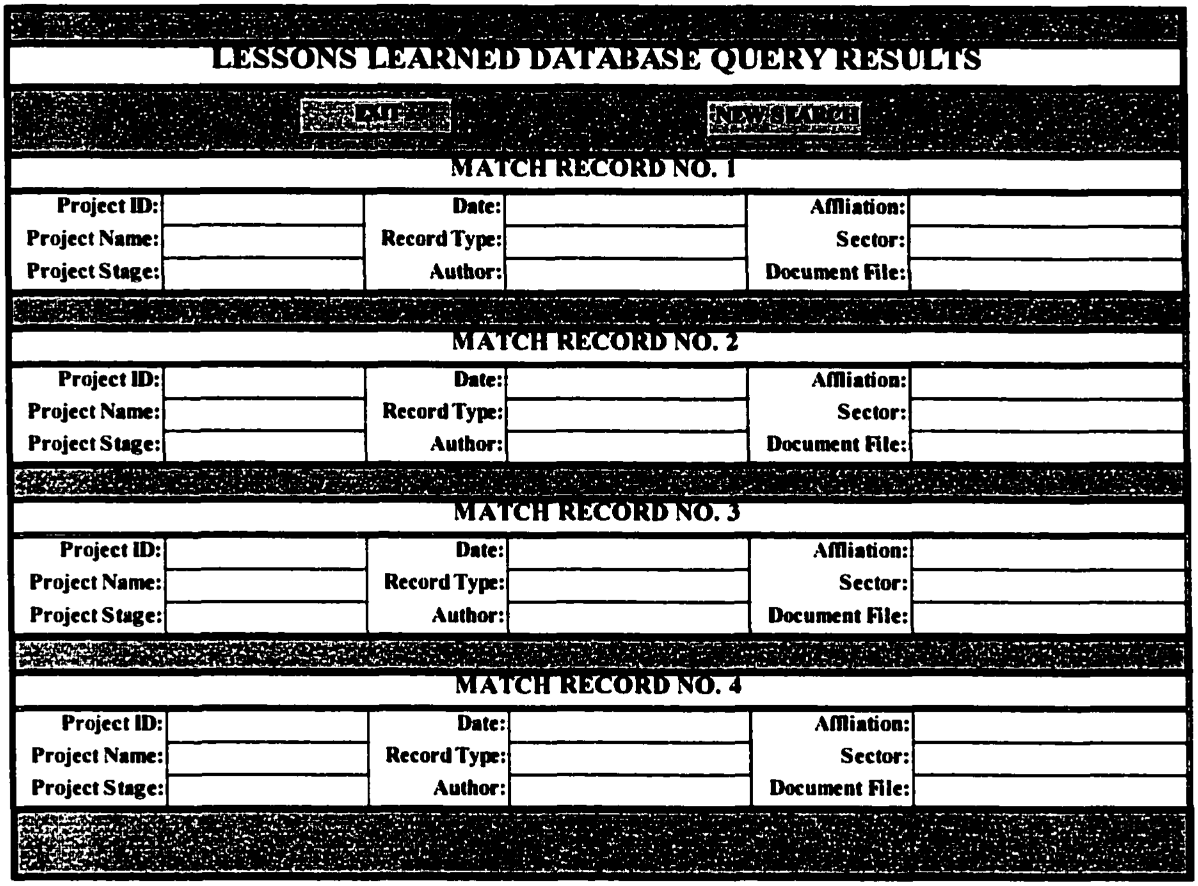


Figure 5-10: Lessons-Learned Database Query Form for Prototype Decision Support System

their particular needs or interest. Records could be searched based on project name, identification number, project sector (owner, engineering, or construction), project phase (planning, preliminary design, final design, construction, or operations), date, author, or affiliation. Once the desired query search fields have been completed, the user would query the database and the results would be displayed in the form shown in Figure 5-11. The user could then access the desired records by selecting the appropriate hyperlink in the Document File box and read and/or print out a copy of the document as deemed necessary.

It is important to note the potential of improving the efficiency of the database query function by incorporating Internet search engine technologies and knowledge or rule-based systems. In the prototype, database records can currently be searched and filtered according to the record or decision types listed in Table 5-1 and refined further by the attributes described previously and illustrated in Figure 5-10. Once the database becomes large, these limited categories will likely prove insufficient in screening applicable lessons-learned of interest. The



LESSONS LEARNED DATABASE QUERY RESULTS

MATCH RECORD NO. 1

Project ID:		Date:		Affiliation:	
Project Name:		Record Type:		Sector:	
Project Stage:		Author:		Document File:	

MATCH RECORD NO. 2

Project ID:		Date:		Affiliation:	
Project Name:		Record Type:		Sector:	
Project Stage:		Author:		Document File:	

MATCH RECORD NO. 3

Project ID:		Date:		Affiliation:	
Project Name:		Record Type:		Sector:	
Project Stage:		Author:		Document File:	

MATCH RECORD NO. 4

Project ID:		Date:		Affiliation:	
Project Name:		Record Type:		Sector:	
Project Stage:		Author:		Document File:	

Figure 5-11: Lessons-Learned Query Results Form for Prototype Decision Support System

results being similar to searching the Internet and having thousands of sites returned when only a few are of real relevancy to the topic at hand.

By including additional sub-classifications and key words that further define critical decisions in more detail, systems could be developed that could aid the user in refining their search of the database. For example, knowledge or rule-based systems could be developed and incorporated into the decision support system that would automatically give the user options on how to refine their search further based on their initial queries. In the case of a critical decision concerning location, the system may respond with options allowing the user to select horizontal or vertical. After the user responds, the system then may return options such as high traffic area, rural area, etc. Thus, the system would lead the user down a logic path in filtering the database.

Table 5-1: Categories of Records or Decision Types Available in the Prototype Query Module

Weekly project status reports
Final project reports
Materials or equipment critical decisions
Scheduling or sequencing critical decisions
Installation methodology critical decisions
Location or alignment critical decisions
Facility size critical decisions
Contract strategy critical decisions
Changed site condition change orders
Design omission or error change orders
Ambiguity in contract language change orders
Owner initiated change orders
Contractor initiated change orders
Other change orders

The use of hyperlinks in the decision support system is significant. For example, if an individual was interested in learning about past decisions made concerning the alignment or location of underground utility facilities, he could query the lessons-learned database to call up all of the records dealing with alignment decisions. He could then use the available hyperlink to access a particular critical decision report. While reviewing the selected report he would come across the hyperlinks embedded in the report that are linked to supporting documentation or other records in the lessons-learned database. He then would be able to follow or trace the hyperlinks from one document to another creating a complete history or background of a particular decision made concerning facility alignment. Hyperlinks could be used in a similar manner with the post-project evaluation reports.

In addition to learning from past critical decisions as illustrated above, users could use the system to track and analyze construction change orders. For example, a user could query the database to find all past change orders with the identified root cause of an ambiguity in the contract language or specifications. After reviewing the resultant change orders returned by the module, the user could determine whether or not there was a portion of the contract or specifications that was causing repeated confusion or difficulties. If such a reoccurring problem were identified, the user would be in a position to modify the language with the hope of avoiding similar problems on future projects.

As there would typically be one project representative from each project sector of owner, engineering, and construction contributing reports to the database on a routine basis, the database query function could also be used as a tool to improve communication or understanding among project participants. During portions of a project there could be as many as three weekly project status reports being submitted during a week, one from each of the project representatives or sectors. Therefore, three different views or perspectives concerning the project could be available. For example, a project manager for the owner might query the database to determine what the engineer and contractor have recorded for the project and find out that they have noted a problem that he was unaware of or have a different opinion on the status of the project. The parties could then work together to resolve the apparent differences before they became major impediments to the project. In other words, participants could be kept better informed of what other participants on the project were doing and thinking thus creating an avenue for better understanding and communication between the entities.

Section C: Summary and Conclusions

During the development of any facility, knowledge is gained and lessons are learned and over time those involved have the opportunity to accumulate a plethora of knowledge [Kartam]. This creates an opportunity to develop a knowledge base of past experience that could be applied to improving future projects. However, because of insufficient efforts to document the lessons-learned by public utility owners, the experience gained remains with the engineering consultants or construction contractors who, because of the nature of public contracting, may or may not be involved with the owner's future projects. Thus, an opportunity is being loss that could improve the performance of underground utility projects within the public sector.

The challenge, therefore, lies in developing the public works agency's organizational capability so that others can learn from the successes and difficulties of past projects and the same actions either repeated or avoided on future projects [Russell & Swiggum]. To address this challenge, the research developed a decision support system framework that could be used to document and disseminate lessons-learned on public sector projects. The framework relies on the repeatable nature of the project development process both within project phases and from project-to-project. The framework utilizes this repeatable structure to link the decision support system to the project development process through the key decision-making activities of generating and evaluating alternatives. The recognition of this repeatable structure of critical decision-making activities as potential links to a decision support system is considered a significant contribution of the research effort.

The decision support system framework develops the concept of considering the rationale behind these critical decision-making activities as a valuable lessons-learned commodity. Critical decisions have been defined as decisions concerning a project's development that could benefit from construction related input or expertise. As the project development process has been shown to contain within each phase a series of repeatable activities involving the generation and evaluation of alternatives, critical decisions represent the outcome of those evaluations. Documenting the rationale behind the critical decisions can allow others to learn from the decisions so that future similar decision-making activities can be improved.

From the expert industry group interviews, it was determined that critical decisions for underground utility projects include materials or equipment, scheduling or sequencing, location or alignment, and installation methodologies. On some projects, critical decisions could also include facility size and contract strategy. Focusing on these construction sensitive critical decisions offers the best opportunity for improving the decision-making activities and project performance on such projects. The ability to characterize underground utilities according to the type of critical decision and utilizing that characterization to categorize lessons-learned is considered another significant contribution of the research effort.

To facilitate its use, a framework was developed that would allow the system to be easily integrated into the typical activities and project management control tasks found on public sector projects. The basic component of the framework used to achieve this integration with industry practices is that of the periodic project status report routinely found in the industry. During the course of completing the typical project status report, project participants would also document critical decisions made or lessons-learned during the period. This allows lessons-learned to be documented on a routine basis and in a predetermined fashion while the information is still fresh in the memory of the participant. Thus improving the accuracy of the information when compared to the post-project evaluation mechanisms currently used in the industry to document lessons-learned

However, for the concept to work effectively utility owners or public work agencies would have to contractually mandate that engineers, contractors, and other consultants working on their projects use the decision support system. Research has shown that integration or constructability is not a natural process and must be actively planned for and promoted by the owner [Anderson, CII (1987), Nam, Radtke, Vanegas]. By contractually mandating use of the system as part of the project management control mechanisms for a project, engineers and contractors would be able to incorporate the additional cost of participation into their fees or bids for the work. In essence, project participants would be directly reimbursed for documenting their experienced gained and lessons-learned on a project. In effect, contractually mandating the use of the system creates the incentive structure that, if they want the owner's work, engineers and contractors will use the system.

The proposed decision support system also includes a function for documenting and tracking construction change orders. Construction change orders are viewed as symptomatic of problems or deficiencies in earlier project development processes. Categorizing and documenting the root cause of the change orders can allow for the identification of reoccurring problems so that they can be addressed and eliminated, thus improving the project development process on future projects. Common industry categories of construction change orders include changed site conditions, design omissions or errors, ambiguity in contract language, owner initiated changes, and contractor initiated changes.

The decision support system framework demonstrates a mechanism for conducting a post-project evaluation of critical decisions made during a project. The project development process consists of a series of critical decisions occurring over the life of a project. Often the impact or result of a decision, even if it is made during the earliest stages of a project, is not fully known until the project is completed. Therefore, the methodology allows for the compiling and post-project critiquing of critical decisions when the full impacts of the decisions are known. Again, such information could then provide valuable feedback to the project development process on future projects.

The essential key that effectively unlocks the potential benefit of the decision support system framework is the database query function. The prototype database system is structured in a such a manner that users can search and sort stored records according to any of the aforementioned categories for critical decisions and construction change orders. Therefore, users could learn about past decisions made concerning particular aspects of a project's design or construction, track and identify reoccurring construction change orders, keep abreast of the activities and perspective of other project participants, etc. Opportunities exist to improve the efficiency of querying the lessons-learned database by incorporating Internet search engine technologies and knowledge or ruled-based systems into the system.

The use of hyperlink technology was incorporated into the prototype decision support system in order to allow users to easily access previously stored documents within the lessons-learned database. Outside documents such as CAD drawings or text-based reports used as background or supporting documentation in the critical decision-making process can also be attached to the lessons-learned database through the use of hyperlinks. Freely distributed generic file reading software could be used to allow users to view the supporting documents without having to have access to the creating software programs. The hyperlinks can create an easily followed chain between related documents creating a thorough history of a particular decision.

It is envisioned that the decision support system would be a web-based application hosted by the utility owner or public works agency. Access to the query function of the database would be open to the general public, as it is believed that any knowledge or experience gained on a project falls within the public domain. This includes knowledge or experience gained by engineering consultants or construction contractors since the owner, and ultimately the taxpayers, paid the money that allowed the project to be built and the experienced to be gained. Such open access has the potential to improve design and construction integration not only in the longitudinal or project-to-project direction within a particular owner's domain but across the industry as a whole. This potential expansion of integration to include an industry wide focus is considered another significant contribution of the framework and research effort.

It is recognized that, if implemented, the methodology would not have an immediate impact on project performance since it would take time to build up the lessons-learned database. Nor is the decision support system viewed as an equal replacement to having actual individuals with construction related expertise involved on a project. Project participants should still take the opportunity to actively seek out construction related expertise during the earliest stages of the project development process.

However, after the lessons-learned database has grown sufficiently over time, the decision support system could be used as a surrogate resource for construction related expertise in cases where it is infeasible to contract with actual individuals or entities. Owners, engineers, and others would be able to access the system to determine what others have done in the past in similar circumstances and then proceed accordingly. On more routine projects, such information would most likely prove adequate and in any case would expected to be better than no information at all.

It is believed that the decision support system framework presented will improve design and construction integration and project performance on public sector underground utility projects. The concept would improve integration in the longitudinal or project-to-project direction by allowing experienced gained on earlier projects to be incorporated on current projects. In addition, the concept would improve integration in the vertical direction or across project phases as project participants will be able to readily access previous decisions made on the project so that a better understanding of the project's design intent can be gained. Finally, integration could be improved industry wide and not just on a particular owner's projects.

CHAPTER 6: INDUSTRY EXPERTS' EVALUATION OF RESULTS

Section A: Formulation of Evaluation Methodology

Once the conceptual framework for the decision support system had been developed and the demonstration prototype completed, the concept was independently evaluated in order to determine what, if any, impact the proposed methodology would have on improving design and construction integration and project performance on public sector underground utility projects. The method chosen to accomplish this evaluation was that of a peer review of the concept by potential industry users of the system. Therefore, a series of presentations and group discussions with representatives from various industry sectors were conducted in order to elicit their comments and opinions concerning the proposed decision support system.

This evaluation technique was dictated by limitations or constraints imposed by both the current state of design and construction integration research and the lessons-learned database component of the proposed decision support system. First, one of the primary difficulties in performing research within the domain of design and construction integration is the lack of established performance indicators or markers to measure the actual degree of integration occurring on a project [Fergusson, Vanegas]. Because the establishment of such indicators has been frequently mentioned as an area requiring additional research, researchers have made attempts to measure or quantify the degree of integration on projects [Fergusson, Pocock]. However, the resultant methods depend on qualitative or anecdotal data gathered through interviews with project personnel to obtain the quantified results. As a result, the models provide subjective results and lend themselves more to post-project evaluation rather than the prediction of specific future project outcomes.

Since it is not currently possible to predict and quantify the expected degree of design and construction integration on a project in advance, it is also not possible to quantify any changes in the degree of integration that may result from attempted improvements in the project development process. This makes it difficult to quantify the exact impact the decision support system may have on design and construction integration. In any case, since a quantifiable cause and effect relationship between the degree of integration and project performance has not yet been described in the literature, it would still not be possible to estimate expected improvements in project performance even if a degree of integration could be calculated.

However, because there are readily available indicators of project performance, in theory it would be possible to directly test the concept's impact on overall project performance. This would require the proposed decision support system to be implemented and field tested over a period of time. The system would have to be used for an indeterminate period of time over the course of numerous projects to sufficiently build up the lessons-learned database before meaningful results from any test could be collected. There is also the difficulty of establishing a control sequence of similar projects against which the system could be tested and evaluated. Because of the extensive amount of time required to conduct such a test this methodology was considered to be beyond the scope of the current research effort and such a strategy is left to others that may be interested in pursuing additional research into the concept.

Therefore, based on the aforementioned reasons, a review of the research results by industry experts was selected as the most appropriate methodology for evaluating the effectiveness of the research. The format chosen for the industry expert's evaluation of the proposed decision support system framework was that of a series of group presentations and discussions. Group meetings were selected rather than the one-on-one structured interviews held previously in the hope that a group setting would encourage more discussion and exchange of opinions among participants. Two meetings were conducted during the first part of June 2002 with one being hosted by the Denver Water Department and the other by the City of Fort Collins Stormwater Division.

A total of eight individuals participated in the meetings, six at the Denver Water Department and two at the City of Fort Collins. All of the individuals who were interviewed as part of the CHAPTER 4: AN INSPECTION OF CURRENT INDUSTRY PRACTICES were invited to participate although two, Experts No. 3 and No. 5, were unable to attend due to prior commitments or other scheduling conflicts. Others in attendance included interested employees of the hosting agencies that were invited by their respective employers.

The format for the meetings was a presentation and overview of the research effort and results by the author followed by an open discussion of the strengths and weaknesses of the proposed decision support system framework. The meetings required three hours at the Denver Water Department and 1.5 hours at the City of Fort Collins. Results were tape recorded for ease of documentation and future transcription.

Section B: Summary of Group Interviews and Responses

B.1: Evaluation of Proposed Project Development Process Model

Since the basic framework for the decision support system relies in part on the project development process model presented in CHAPTER 3, the first research area that participants were asked to evaluate was the appropriateness of the proposed process model. Participants were not asked to review the process model in detail but rather to evaluate the basic structure of the overall model and the conclusions drawn from the model by the author. The intermediate decomposition schematic of the public works project development process shown in Figure 3-9 was used to provide the basis for the discussion.

The first aspect of the model that was verified was the repeatable nature of the project development process, both within a project and across multiple projects. Participants agreed that each phase of the project development process could be described as three basic activities:

planning and organizing to perform the particular task, generating and evaluating alternatives, and making a decision on how to proceed. They agreed that these three primary activities were repeatable between project phases and from project-to-project.

Participants also agreed that the project development process is structured as a series of decision-making activities focused around the key decision-making activities of generating, evaluating, and selecting alternatives. They also agreed that the process required the establishment of consistent project goals and objectives against which all alternatives and decisions should be evaluated. Participants also did not voice any disagreement with the concept that the alternative generation and evaluation activities represented key opportunities for seeking construction-related input or expertise.

The last aspect of the model reviewed was the activities associated with organizing the project management structure for the project. Participants agreed that properly structuring the project management and control mechanisms for a project was a critical project performance variable. However, little comment was received concerning the importance of planning for construction-related input before a project begins and incorporating into the project management structure the mechanisms for getting the input. This may be due in part to the continued misunderstanding of constructability by many participants, as many still view the process as nothing more than periodic design reviews at major project milestones that has already been incorporated into routine industry practices.

B.2: Evaluation of Inspection of Current Industry Practices

The next aspect of the research that participants were asked to review was the results obtained from the inspection of current industry practices presented in CHAPTER 4. The primary purpose of this review was to provide an assurance that the author had properly interpreted the expert industry group's interviews and accurately characterized the public works underground utility industry. Such an assurance would provide additional validity for the conceptual framework used for decision support system.

First, the participants were asked to review the characterization of the industry's knowledge of project delivery methods and practices. Participants generally agreed with the characterization presented by the author. However, several took exception to the use of absolute terms such as "all" or "none" by the author when referring to the industry as a whole. Admittedly, in most cases it is more appropriate to use less restrictive terms such as "most", "few", etc. to properly categorize the full spectrum of knowledge within the industry. This also emphasizes the importance of using caution when attempting to draw broad inferences from the expert industry group interviews.

Beyond the semantics used in the presentation, there were only a few comments on project delivery methods. One concerned characterizing a disadvantage of design-bid-build as the inability to produce a perfect set of plans and specifications. This seemed to imply that design-bid-build resulted in imperfect contract documents while the other project delivery methods did not. This is obviously incorrect as imperfect contract documents can be and are produced under any of the project delivery methods. The disadvantage with design-bid-build in this regard lies in the fact that the owner assumes more of the risk of such errors under design-bid-build then under the other project delivery methods.

Participants from the City of Fort Collins also took exception to characterizing an advantage of construction management-at-risk as the ability to get around low-bid selection procedures. This seemed to imply that owners who used the project delivery method were circumventing the law or doing something illegal. That characterization is absolutely false. Rather, the advantage of construction management-at-risk lies in the fact that the owner can structure the contracts and selection procedures in a manner that provides more flexibility in selecting the contractor while still conforming to established competitive low-bid procurement regulations.

Finally, several participants had comments concerning some of the reasons why constructability had been lost from the industry over the years. Most agreed that the university engineering educational system could be reformed to improve constructability in the industry by emphasizing more practical applications and skills. However, several felt it was unfair to place blame on the educational system for the decline in constructability as they could not recall being taught construction-related topics when they were in school 30-years ago and, therefore, could not see any real difference between education then and education now.

Next, participants were asked to review key points taken from the interviews concerning constructability utilization practices. Participants made no exceptions to the industry characterization presented by the author. Of particular interest to the current research effort, participants reaffirmed that there were few formal procedures for documenting lessons-learned or the rationale behind decisions made, for tracking reoccurring construction change orders, or for passing on experience gained from senior staff to younger staff.

Participants also had little disagreement with the manner that the author characterized underground utility projects. They agreed that project performance specifications and facility sizing fell within the engineering domain while project scheduling and sequencing fell within the contractor's domain. Facility location and selection of materials and equipment was agreed to fall within a dual or mixed domain. Concerning installation methodologies, the author reported that there were mixed opinions on whose domain covered this parameter. After discussion by the participants, no clear resolution of the matter was achieved and it appears that the author's initial assessment of a mixed opinion over this function's domain to be correct.

Lastly, the participants reviewed and agreed with the design-build contracting assessment performed. There appeared to be a consensus that there were few actual barriers within the industry that would prevent owners from implementing alternative contracting methods. It was generally agreed that the biggest obstacle is the institutional inertia of the public works agencies.

B.3: Evaluation of Decision Support System Framework

The last and most important aspect of the research the participants were asked to evaluate was the framework for the decision support system proposed in CHAPTER 5. The author first presented the schematic framework and rationale behind the development of the decision support system and then demonstrated the prototype decision support system. The meetings were then opened up for general discussion of the proposed methodology.

The most critical aspect of the evaluation was to determine whether or not the proposed concept of a decision support system utilizing a lessons-learned database to document, organize, and retrieve lessons-learned or experienced gained on projects would be beneficial to project performance within the public works industry. When asked to specifically focus on the underlying framework of the decision support system, participants were in general agreement that there was a need in the industry to document lessons-learned and, if implemented properly, the concept of the decision support system would be beneficial. Many participants noted how they regularly encounter situations on projects where they wished they could find out *why* someone did something in the past.

Although the concept was viewed to be potentially beneficial, none of the participants were willing to hazard a guess on how much impact the proposed decision support system would have on improving overall project performance. Project participants, particularly from the owner sector, would like to have the additional information but how much that information is worth in terms of project performance is indeterminate. Therefore, all that can be safely concluded is that industry experts believe that the proposed decision support system framework could have a potential beneficial impact on project performance within the public works industry.

Although participants were willing to note the potential benefit of the system, participants were quick to point out what they believed were several key obstacles or barriers to implementation within the industry. First, there are concerns surrounding the issue of documenting lessons-learned. All participants agreed that the owner or public works agency was the logical depository for the decision support system and accompanying lessons-learned database. There was also agreement with the concept that any lessons-learned or experience gained, whether by the owner, engineer, or contractor, fell within the public domain and the owner had the right to collect and disseminate such information. However, the lack of sufficient incentive to the engineer and contractor in providing such information was noted as a major obstacle.

Participants representing the engineering and contracting communities acknowledged that they would use the system if contractually mandated as proposed by the author. However, they admitted that they would be less than fully forthcoming in providing the complete rationale behind decisions made or alternatives selected because it would give away their competitive advantage, particularly if the information were made available for general public access. This unwillingness to provide complete disclosure of their experience gained would reduce somewhat the potential benefit that could be derived from the decision support system. But it does not necessarily defeat the proposed concept as many participants agreed that even partial disclosure or documentation of lessons-learned would be better than no documentation at all.

Another concern raised related to documenting lessons-learned was the question of who should be responsible for documenting lessons-learned. Although participants agreed that the best source of information for providing the rationale behind a decision is the actual decision-maker, there was disagreement on who should be responsible for collecting and documenting the information. The engineering and contracting communities felt the owner should bear the sole responsibility for investigating and documenting lessons-learned on a project, as it was the owner who was going to derive the most long-term benefit from the information.

Again, this is a stance related to the issue of incentive as the engineering and contracting communities could not see sufficient benefit to their own operations or businesses from the proposed decision support system to justify the additional time and effort required to document their lessons-learned information for the owner. However, this desire not to want to document lessons-learned on for the owner's behalf is not viewed as a major obstacle to implementation of the decision support system as the engineering and contracting communities have already indicated that they would participate in the system if contractually mandated to do so.

The last major concern raised about the proposed decision support system dealt with the mechanics of documenting and retrieving lessons-learned. From the discussions it became readily apparent that the goal of easily documenting lessons-learned was in direct conflict with the goal of easily extracting lessons-learned from the database. Concerning the documentation side of the decision support system, participants indicated no difficulty with the concept of a weekly project status report or with the idea of classifying lessons-learned according to predetermined categories of critical decisions. They agreed that this narrowed the focus of the type of information being collected and would make it easier and quicker for users to enter the required information.

However, many participants questioned whether the format for providing and entering information provided sufficient structure to the database to allow for the easy retrieval of relevant lessons-learned by end-users of the system. Although the concept of classifying lessons-learned according to a short list of categories of critical decisions simplifies the task of entering information into the system, it is likely that it provides an insufficient number of classifications to allow the database to be effectively queried and filtered. For example, once the database has grown to a significant size there could be hundreds or even thousands of entries concerning a particular critical decision type. However, only a handful of those documented critical decisions within the specified category may be relevant to the current problem at hand.

Adding more structure and classifications to the lessons-learned documentation form would aid in correcting this problem. However, this would make the form more complicated and difficult to complete. This would increase the administrative burden for users of the system which several participants indicated was already a concern with the proposed decision support system. If the administrative burden is increased too much the concept becomes impractical and the decision support system would not be used or implemented. Therefore, there is a trade-off or balance that needs to be reached concerning the structure and classification of lessons-learned information that makes it easy enough for users to document the information while still allowing end-users to readily extract relevant information from the database.

Clearly, this is an area that would require additional research to determine the appropriate balance. As discussed in CHAPTER 5, a fully developed and functional database query system could incorporate Internet search engines and knowledge or rule-based systems as an aid to users in improving the querying, filtering and retrieval of records from the lessons-learned database. Therefore, difficulties with the proper structuring of the lessons-learned database is not viewed as a fundamental flaw in the underlying concept of the decision support system but merely a technological obstacle that can be addressed by additional research in fields not associated with the proposed framework as a whole.

One participant noted that the demonstrated prototype decision support system used forms and required information that was crudely similar to proprietary project management software found in the industry. It was explained that this was intentional as one of the underlying concepts of the decision support system was to utilize documentation forms and information collection procedures that were already in common use within the industry. This was done to make it easier to integrate the decision support system framework into the normal business practices found in the industry in hopes that it would increase the likelihood that the concept might be adopted.

However, it was emphasized that the difference between the system proposed by this research and the aforementioned proprietary project management software packages is the way the collected information is used. The proposed decision support system utilizes the commonly collected project control information to aid in the extraction of lessons-learned on a project while the proprietary project management software found in the industry is concerned with project monitoring and document management. As discussed in CHAPTER 5, it is highly conceivable that such project management software could be incorporated into any full-scale operational decision support system that may be developed in the future.

Participants also made several miscellaneous comments on other aspects of the proposed decision support system. First, one participant felt that traffic control issues should be added as one of the critical decision categories for underground utility projects. Others expressed concern with allowing general public access to the lessons-learned database. They felt that such access might expose project participants to additional liability if problems or mistakes were noted in the system.

Section C: Conclusions

Based on the evaluation of the research by industry experts, it appears that the public works project development process model developed as part of the research effort is an accurate representation of the process followed in the industry. The basic project development process can be described as a series of three primary activities consisting of organizing and planning for the particular task, generating and evaluating alternatives, and making a decision on how to proceed. The process was found to be repeatable both across phases within a project and from project-to-project. In addition, the process was structured around the critical decision-making activity of generating and evaluating alternatives, which was found to be a key opportunity for inputting construction-related advice or expertise into the project development process.

The industry experts also confirmed the results derived from the inspection of current industry practices. Of particular interest to the current research effort, the evaluation reaffirmed that there were few formal procedures for documenting lessons-learned or the rationale behind decisions made, for tracking reoccurring construction change orders, or for passing on experience gained from senior staff to younger staff. Also, it was agreed that the design of underground utility projects could be properly characterized according to facility size, project scheduling and sequencing, facility location, selection of materials and equipment, and installation methodologies.

The industry experts' evaluation also determined that the proposed concept of a decision support system utilizing a lessons-learned database to document, organize, and retrieve lessons-learned or experienced gained on projects would be beneficial to project performance within the underground utility public works industry. However, although the concept was viewed to be potentially beneficial, the evaluation was unable to produce an estimate on how much of an impact the proposed decision support system would have on improving overall project performance. Despite this promising evaluation of the potential of the decision support system framework, several potential barriers or obstacles were noted that would have to be addressed before such a system could be successfully implemented and adopted by the industry.

The first barrier to the proposed concept raised by the industry experts focused on the area of providing sufficient incentive for project participants to want to actively participate in collecting and documenting lessons-learned on a project. The proposed decision support system has a natural owner-centric viewpoint or bias as the owner is going to benefit most over time through the collection of lessons-learned information from a variety of sources and projects. Therefore, they would be reluctant to voluntarily take on the additional administrative burden of documenting their lessons-learned on the owner's behalf.

Also, due to the public domain component of the proposed system, the engineering and construction sectors would be hesitant to fully divulge lessons-learned or the rationale behind decisions made for fear of sacrificing their competitive advantage in procuring future work. This further reduces the incentive for the engineering and construction sectors to actively participate in the system.

The fact that the industry experts raised incentive as an issue was not surprising, as the author had identified the potential issue earlier in the research effort and, in response, incorporated the idea of contractually mandating the use of the decision support system into the proposed framework. Based on the industry expert's response, it appears that the author's approach was an appropriate means of addressing the issue since they indicated that they would participate in the decision support system framework if they were contractually mandated to do so. Therefore, the author does not view the issue of incentive to be a significant flaw in the proposed framework.

However, it would be incorrect to assume that the issue of incentive would have no impact on the performance of the decision support system framework. Obviously, the more information that can be collected about a lessons-learned or a decision made the more useful the lessons-learned would be to future users. As a result, the reluctance by the engineering and construction community to provide the complete background of lessons-learned would likely reduce the maximum benefits to be derived from the system. But this is not considered a fatal flaw with the proposed concept as the industry experts indicated that some documented lessons-learned information would be better than no information at all. Therefore, to maximize the potential of the framework, more research would be required to determine how to best encourage project participants to fully participate in such a lessons-learned methodology.

The second potential barrier raised by the industry experts concerned the appropriate structure of the lessons-learned database. The proposed concept was developed around classifying lessons-learned according to predetermined categories of critical decisions in order to facilitate the documentation of lessons-learned by the user. Although the evaluation indicated that this approach might work well for simplifying the documentation of lessons-learned, it would likely create inefficiencies when it came to extracting applicable lessons-learned from the database.

A trade-off is required between the competing objectives of ease of documentation versus the ease of data extraction. Ease of documentation requires less classification and structure of the data while ease of data extraction requires the opposite. If too much data and structure is required during documentation of lessons-learned the additional administrative burden on users becomes too great and the decision support system becomes impractical to use. On the other hand, if too little classification or structure is provided, the lessons-learned database cannot be sufficiently filtered to return only applicable lessons-learned and the end-user is overwhelmed by irrelevant information that detracts from the potential usefulness of the system.

Therefore, more research is required in developing more efficient means for querying, filtering, and retrieving relevant records from the lessons-learned database. Such research could involve developing a fully functional database query system incorporating Internet search engines and knowledge or rule-based systems as an aid to users. Additional research could also performed in developing further sub-classifications and key words for defining critical decisions. Therefore, difficulties with the proper structuring of the lessons-learned database is not viewed as a serious flaw with the proposed framework but merely a technological obstacle unrelated to the underlying concepts behind the decision support system framework.

The industry expert evaluations supported the concept of utilizing periodic project status reports as an aid in collecting and documenting lessons-learned. The structure of the forms contained in the prototype decision support system appears to be reflective of the type of project management documentation currently being used within the industry. Therefore, it seems conceivable that currently available project document management software found in the industry could be incorporated into the development of any actual decision support system.

There was no controversy among the industry experts concerning the concept of lessons-learned or experienced gained on a project, whether by the owner, engineer, or contractor, falling within the public domain. Project participants agreed that the owner had the right to collect, document, and disseminate such information. Despite this, there were some reservations concerning actually making such information available to the general public due to fears it might expose project participants to additional liability or litigation concerning any project difficulties that might be documented with the database. However, as long as the owner is willing to make the database public, since users would be contractually mandated to document information within the system there appears to be no significant barriers to allowing public access to the database.

CHAPTER 7: A HYPOTHETICAL CASE STUDY EXAMINATION OF THE DECISION SUPPORT SYSTEM FRAMEWORK

Section A: Introduction

In order to address some of the concerns raised during the industry experts' evaluation of the proposed decision support system framework and to more fully illustrate the underlying principles of the concept, a hypothetical case study was developed to demonstrate the potential operation of the decision support system. The case study has been structured to highlight the repeatable nature of the project development process, the types of typical decision-making activities that occur within the process, and how project entities would interact with the decision support system and use it to improve the decision-making and communication processes on a project. By comparing the differences between the same typical project with and without the decision support system, the case study will demonstrate the potential benefits and incentives accruing to project entities from the proposed lessons-learned based framework.

The hypothetical project created for the case study involves a small urban city with a public works agency. As part of its responsibilities, the public works agency is charged with operating and maintaining the potable water system within the city and has a small planning and engineering staff capable of handling the day-to-day operations of the water system. However, the size of the staff is insufficient to perform the engineering design and construction required for capital improvements projects and, as a result, the agency has traditionally employed the design-bid-build project delivery method on its projects to contract for engineering and construction services. An appointed Board of Directors governs the agency and must approve all contracts and financial obligations.

Recently, the public works agency has been receiving several complaints of low-water pressure within one of its service areas located in the southwest part of the city. In addition, a new commercial development has been proposed for the same area. Therefore, to improve service to the area, hydraulic modeling of the water system was performed and it was determined that a new 24-inch diameter pipeline needs to be installed. The pipeline will be the first new pipeline for the city in several years and during that period of time the agency has experienced some normal turnover in staff personnel.

Before commencing with the case study, it should be noted that the case study presented is a overly simplified description of a complex process. No attempt has been made to provide a detailed description of the actual design and construction processes involved on an underground utility project and there are many more decisions and tasks involved then those presented. Rather, an attempt has been made to include tasks and decisions representative of the basic process based on the author's personal professional experience with such projects. This is reflective of the intent of the case study process, which is to provide a structured means of illustrating the proposed decision support system framework and not a study of the project development nuances of underground utility projects.

It should also be noted that the project case utilizing the decision support system includes examples of possible additional sub-characterizations for critical decisions. Although these additional sub-categories have not been rigorously researched or evaluated, they were included to illustrate the potential of using the sub-categories in conjunction with Internet search engine technologies and knowledge or rule-based systems to aid in both the documenting and retrieving of lessons-learned from the database. A fully developed framework employing such aids would significantly address the concerns raised regarding the trade-off between minimizing the database structure for ease of documentation of lessons-learned versus maximizing the database structure for ease of retrieval of relevant lessons-learned.

Section B: Hypothetical Project without Decision Support System

B.1: Planning Phase

Once the need for a new 24-inch water pipeline had been identified, the public works agency (referred to hereafter as the Owner) commences to organize their staff to perform the additional planning needed to further define and prepare the project for approval by the Board of Directors. The Owner evaluates its current workload and available staff and selects an appropriate planning team. The planning team then proceeds to further define the project and to establish the project objectives.

The primary task undertaken by the planning team is to determine the corridor to be used for the pipeline. Based on the defined service area in question and the existing configuration of the water system, there are two self-evident alternatives for the pipeline corridor. The alternatives are either Street A, a 2-lane east-west urban arterial running within a residential area or Street B, a 4-lane east-west urban arterial within the commercial district. Based on the larger right-of-way that provides greater room for construction access, Street B is selected by the planning team as the preferred alternative.

Having made this decision concerning the corridor, the planning team performs an initial cost and schedule analysis for the proposed pipeline. Through the analysis, a budget of $1,000,000 and a delivery schedule of 12 months are established for the project. Armed with this information, the Owner presents the project to the Board of Directors for approval and is granted permissions to proceed with the project. At the same time, the Board also obligates and approves the necessary funds required to design and construct the project.

B.2: Preliminary Design Phase

Having received authorization to proceed with the project, the Owner reorganizes the project staff and selects the project management team. The project management team then takes the project definition package developed during the planning phase and uses it as a guide in developing a Request for Proposals for Engineering Services. Once completed, the RFP is advertised within the local engineering community and the Owner receives several proposals from interested parties. The project management team evaluates the proposals and selects a qualified engineering firm (hereafter referred to as Engineer) whose contract for services is approved by the Board of Directors.

The Engineer then commences to complete the preliminary design for the project. The first task is to determine the exact horizontal alignment to be used within the previously determined pipeline corridor. Evaluation of the 4-lane roadway reveals three possible options: the north side of the road, the center of the road, and the south side of the road. Further investigations into the options disclose that the south side of the roadway contains existing utilities and that the north side of the roadway would restrict access to businesses along the corridor. Therefore, for these reasons both the north and south sides of the road are rejected as options and the decision is made to place the pipeline in the center of the road.

Based on the selected horizontal alignment, the pipeline will have to intersect existing utilities within one of the major road intersections. Therefore, the Engineer next investigates how best to address the situation. Relying on his past professional experience, the Engineer determines that there are three options: to go over the existing utilities, to go under the existing utilities, or to relocate the existing utilities. A cost analysis of the three options indicates that routing the pipeline under the existing utilities would be the most cost-effective solution. Therefore, the decision is made to design the vertical alignment of the pipeline to go under the existing utilities.

Having finalized both the horizontal and vertical alignment for the pipeline, the Engineer prepares an updated cost and schedule estimate for the project. The revised estimate indicates that it will cost $950,000 and take 11 months to complete the project. When presented with the information, the Owner is satisfied with the estimate and the project manager gives the Engineer approval to commence with the final design for the project. Also, according to the project management system established for the project, at this stage of the project both the Owner and the Engineer have been completing and submitting monthly project status reports.

B.3: Final Design Phase

As the project enters the final design phase, the Owner adds representatives from both the procurement and legal sections of the agency to the project management team. This is done in recognition that their assistance will be necessary during the development of the contract bid documents and public construction bid solicitation process. During this phase, the Owner and the Engineer both continue to complete and submit monthly project status reports.

The final decision to be made before the plans and specifications can be completed and the contract documents finalized concerns the selection of the appropriate type of pipe. Within the local market area, the Engineer knows from past experience that the three viable options are steel pipe, concrete pipe, and PVC pipe. The Engineer makes several telephone calls to local suppliers and finds PVC pipe to have the lowest cost and, therefore, selects PVC pipe for use on the project.

With the design now completed, the Engineer prepares the contract documents for use by the Owner in bidding the project. The Owner advertises the project to the contracting community and receives several sealed bids. At the appointed time, the Owner publicly opens the sealed bids and announces that the low bid received was in the amount of $965,000. The proposed bid and contract is then presented to the Board of Directors, which approves the contract and authorizes the expenditure of the funds.

B.4: Construction Phase

Once the project enters the construction phase, the Owner reorganizes the project team to perform the required construction contract administration. The Engineer also reorganizes his participation in the project by selecting a project inspection team that will monitor the constructed project for conformance with the project specifications. In addition, the Contractor selects his construction crew and assigns a project superintendent to oversee the construction operations. The project management reporting requirements also change, as the Engineer is required to submit to the Owner a daily inspection report for the project. As part of his own internal operations, the Contractor will also be completing a daily project progress report, however, these reports are not typically submitted to the Owner.

During construction of the pipeline, three problems occur that result in construction change orders. The first problem involved the Contractor encountering an existing telephone conduit that interfered with the alignment of the pipeline. Investigations indicated that the telephone conduit was not shown correctly on the plans provided by the telephone company during design. As a result, the vertical alignment of the pipeline has to be altered, which resulted in an additional cost of $10,000 and resulted in a delay of 5 days.

The next problem was caused by a faulty manhole detail shown on the plans. Although the manhole provided conformed to the project plans, once installed it proved to be incompatible with the equipment specified for installation within the manhole. The required modifications cost an additional $5,000 and resulted in a delay of 2 days.

The final problem was a dispute over contract language concerning the assigned responsibility for obtaining the necessary construction stormwater discharge permit. The contract language was ambiguous and the Owner felt is was the Contractor's responsibility while the Contractor thought it was the Owner's responsibility. After several days of arguing and intense discussions, the Contractor reluctantly agrees to obtain the permit in order to keep the project moving forward and in return the Owner agrees to split the cost of the permit with the Contractor. The dispute results in an increase in cost of $5,000 and a delay of 5 days.

Once negotiations concerning the construction change orders had been completed, the change orders were submitted to the Board of Directors for final approval. With the change orders, the final cost of the project was $985,000 and the total project delivery time was 11.5 months. As both of these figures fell within the original budget and schedule established for the project, the Owner was satisfied with the final outcome of the project. However, the dispute over the construction permit resulted in damaged business relationships between the Owner, the Engineer, and the Contractor.

To close out the project, the Owner prepares a final report summarizing the project and routes the report to staff personnel for review. The report is then read in detail by some, only given a cursory review by others and then placed in a file cabinet for long-term storage.

Section C: Hypothetical Project with Decision Support System

C.1: Planning Phase

Once the need for a new 24-inch water pipeline had been identified, the public works agency (referred to hereafter as the Owner) commences to organize their staff to perform the additional planning needed to further define and prepare the project for approval by the Board of Directors. The Owner evaluates its current workload and available staff and selects an appropriate planning team. The planning team then proceeds to further establish the project objectives and setups the new project into the decision support system for the Owner. Once the project is established in the system, the Owner commences the activity of completing weekly project status reports for the duration of the project.

The primary task undertaken by the planning team is to determine the corridor to be used for the pipeline. Based on the defined service area in question and the existing configuration of the water system, there are two self-evident alternatives for the pipeline corridor. The alternatives are either Street A, a 2-lane east-west urban arterial running within a residential area or Street B, a 4-lane east-west urban arterial within the commercial district. To aid in the comparison of the two alternatives, the Owner's staff enters the critical decision module of the decision support system and queries the database for facility alignment. Through a series of questions, the decision support system helps the user narrow the search to records pertaining to the planning phase and then further to those referring to arterial roadways. A review of the returned lessons-learned information indicates the larger right-of-way provided by the 4-lane road is preferable since it will provide greater room for construction access. As a result, the planning team selects Street B as the corridor for the pipeline.

Having made this decision concerning the corridor, the planning team performs an initial cost and schedule analysis for the proposed pipeline and documents the decision rationale in the lessons-learned database. Through the analysis, a budget of $1,000,000 and a delivery schedule of 12 months are established for the project. Armed with this information, the Owner presents the project to the Board of Directors for approval and is granted permissions to proceed with the project. At the same time, the Board also obligates and approves the necessary funds required to design and construct the project.

C.2: Preliminary Design Phase

Having received authorization to proceed with the project, the Owner reorganizes the project staff and selects the project management team. The project management team then takes the project definition package developed during the planning phase and uses it as a guide in developing a Request for Proposals for Engineering Services. Once completed, the RFP is advertised within the local engineering community and the Owner receives several proposals from interested parties. The project management team evaluates the proposals and selects a qualified engineering firm (hereafter referred to as Engineer) whose contract for services is approved by the Board of Directors.

As stipulated in the RFP, the Engineer's contract with the Owner mandates the use of the decision support system during the project. Therefore, the Owner adds the Engineer to the list of authorized project personnel with permission to access the decision support system and, per the contract with the Owner, the Engineer commences to join the Owner in completing weekly project status reports during the course of the project.

The Engineer then starts to complete the preliminary design for the project. The first task is to determine the exact horizontal alignment to be used within the previously determined pipeline corridor. Evaluation of the 4-lane roadway reveals three possible options: the north side of the road, the center of the road, and the south side of the road. To aid in the evaluation of the available alternatives, the Engineer queries the decision support system for records concerning pipeline alignment and then filters the returned records further by reducing the list to only those pertaining to horizontal alignments within traffic areas.

A review of the retrieved lessons-learned records discloses that the south side of the roadway contains existing utilities and that the north side of the roadway would restrict access to businesses along the corridor. It also reveals that placing the pipeline in the center of the road would restrict the available construction work area and reduce productivity during construction. To determine the best alignment, the Engineer uses the decision support system to perform a MCDA analysis of the alternatives. Based on the results of the analysis, the decision is made to place the pipeline in the center of the road and the Engineer documents the decision-making rationale in the lessons-learned database.

Based on the selected horizontal alignment, the pipeline will have to intersect existing utilities within one of the major road intersections, therefore, the Engineer next investigates how best to address the utility situation. Relying on his past professional experience, the Engineer is aware of three options: to go over the existing utilities, to go under the existing utilities, or to relocate the existing utilities. Accordingly, the Engineer queries the decision support system pipeline alignment, and filters the records to retrieve only those to vertical alignment and utility interference.

However, the Engineer is also astute enough to recognize that the problem is really a dual problem of not just vertical alignment but also installation methodology. Therefore, the Engineer also queries the lessons-learned database for installation methodologies in circumstances of utility interference. The query results reveal two additional alternatives, tunneling and directional boring. Utilizing all of the information retrieved for the five possible alternatives, the Engineer uses the decision support system to perform a MCDA analysis and, based on the results, selects the option of boring under the utilities. The Engineer then documents the decision-making rationale in the lessons-learned database.

Since existing utilities have been identified as a potential concern on the project, the Owner takes the opportunity to query the decision support system for past construction change orders relating to changed site conditions caused be existing utilities. Reviewing the results, the Owner discovers a reoccurring problem with the location of the existing telephone conduit not being indicated correctly on the telephone company's drawings. As a result, the Owner directs the Engineer to pothole the actual location of the telephone conduit before finalizing the alignment of the pipeline.

Having finalized both the horizontal and vertical alignment for the pipeline, the Engineer prepares an updated cost and schedule estimate for the project. The revised estimate indicates that it will cost $930,000 and take 11 months to complete the project. When presented with the information, the Owner is satisfied with the estimate and the project manager gives the Engineer approval to commence with the final design for the project.

C.3: Final Design Phase

As the project enters the final design phase, the Owner adds representatives from both the procurement and legal sections of the agency to the project management team. This is done in recognition that their assistance will be necessary during the development of the contract bid documents for use in the public construction bid solicitation process. During this phase, the Owner and the Engineer both continue to complete and submit weekly project status reports.

During the course of reviewing the Owner's weekly project status reports previously saved within the lessons-learned database, the Engineer discovers a recent instance where the Owner had expressed some concern with the Engineer's ability to complete the design of the project on time. Being proactive, the Engineer takes the opportunity to meet with the Owner to discuss the schedule for the project. Based on this meeting, the Engineer was able to alleviate the Owner's concerns with the progress of the project.

One of the remaining decisions to be made before the plans and specifications can be completed and the contract documents finalized concerns the selection of the appropriate type of pipe. Within the local market area, the Engineer knows from past experience that the three viable options are steel pipe, concrete pipe, and PVC pipe. To obtain past information concerning the three alternatives, the Engineer queries the decision support system for past lessons concerning pipeline materials. From the query results, the Engineer learns that PVC pipe has the lowest cost, concrete pipe can be delivered the quickest, and that steel pipe has the better long-term durability. Using the decision support system to perform a MCDA analysis, it is determined that PVC pipe is the better choice.

However, as a double check on the suitability of PVC pipe for the project, the Engineer takes the opportunity to query the lessons-learned database for post project evaluation reports prepared for past projects that had utilized PVC pipe. Based on these reports, it was learned that O&M personnel had encountered problems on the projects when attempting to connect service taps to PVC pipe. Relying on this additional information, the Engineer makes the decision to use steel pipe instead of PVC pipe on the project and documents the decision within the lessons-learned database.

To finalize the pipeline design, the Engineer queries the decision support system for past construction change orders concerning design errors and omissions. The returned results highlighted a reoccurring problem with an incompatible manhole detail that was requiring modifications to be made in the field. As a result of the investigation, the Engineer reviews the manhole detail and makes the needed modifications to correct the situation.

With the design now completed, the Engineer prepares the contract documents for use by the Owner in bidding the project. Before releasing the contract documents, the Owner queries the decision support system for past construction change orders concerning contract language ambiguities. The investigation uncovers reoccurring past confusion concerning the responsibility for obtaining the required construction stormwater discharge permit. Since the Owner wants the Contractor to handle this, the Owner modifies the contractual language making it clear that the responsibility has been assigned to the Contractor.

The Owner then advertises the project to the contracting community for bids. While preparing his bid, a potential bidder has concerns with the pipeline being in the center of the road. To gain a better understanding of the rationale behind the decision, the bidder uses the general public access feature of the decision support system to query the lessons-learned database to find the relevant critical decision. The bidder queries the system for critical decision reports screens the list to retrieve those related to the current project and then filters the list further to access only the records pertaining the pipeline's horizontal alignment.

Once the potential finds the relevant critical decision support, he discovers that one of the reasons the north side of the road was rejected for the alignment of the pipeline was concern with maintaining access to adjacent businesses. Based on this information, the bidder investigates the project site more fully and determines that he could build some temporary business access along some of the side streets. Further analysis also showed that the cost of the additional temporary access would be more than offset by the savings that would be realized from the increased efficiency of laying the pipe on the north side of the street.

To preserve his competitive advantage, the bidder does not want at this point to reveal this possible construction strategy to the Owner since the Owner would then be in position to relay the information to other potential bidders. Rather, the bidder decides to assess the risk of being able to convince the Owner to approve the change in alignment after the construction contract has been awarded. Based on the perceived risk, the bidder decides to assume the risk that the change in alignment will be approved by the Owner and prepares his bid accordingly, hoping that his construction strategy will give him a competitive advantage in procuring the work.

At the appointed time, the Owner receives several sealed bids and publicly announces that the low bid received was in the amount of $955,000. The proposed bid and contract is then presented to the Board of Directors, which approves the contract and authorizes the expenditure of the funds.

C.4: Construction Phase

Once the project enters the construction phase, the Owner reorganizes the project team to perform the required construction contract administration. The Engineer also reorganizes his participation in the project by selecting a project inspection team that will monitor the constructed project for conformance with the project specifications. In addition, the Contractor selects his construction crew and assigns a project superintendent to oversee the construction operations.

As the Contractor has been selected, the Owner includes the Contractor in the list of project participants with permission to access the decision support system during the project. Like the Engineer, the Contractor is also contractually mandated to complete weekly progress status reports and to use the decision support system. Therefore, at this stage of the project, the Owner, the Engineer, and the Owner will all be completing and submitting weekly project status reports. These reports are likely to be in addition to the daily inspection reports typically completed during construction.

Once construction commences, the Contractor initiates the first construction change order to move the alignment of the pipeline from the center to the north side of the road. After the Contractor describes his plan for providing the temporary access to the businesses, the Owner is convinced of the viability of the construction strategy and approves the change. This change results in net savings to the Owner of $20,000 and a 14-day reduction in the project schedule. The Contractor uses the decision support system to document the rationale behind the change in alignment and categorizes the lessons-learned as a critical decision concerning horizontal alignment. The same decision is also documented as a contractor initiated construction change order.

During construction of the pipeline, the Contractor encounters unstable soils while attempting to perform the directional boring required when crossing the existing utilities. The unstable soils required the Contractor to provide additional sheet piling shoring for the boring pits. This change order results in an additional cost of $10,000 and a delay of 5 days. The Owner documents the construction change order as changed site condition within the lessons-learned database.

Also, while backfilling around the manholes the Contractor employs a new, innovative method for placing and compacting the fill. As a result, the Contractor uses the decision support system to document the rationale behind the method and categorizes the lessons-learned as critical decisions relating to installation methodology.

Once finalized, the change orders were submitted to the Board of Directors for final approval. With the change orders, the final cost of the project was $945,000 and the total project delivery time was 10.5 months. As both of these figures fell within the original budget and schedule established for the project, the Owner is satisfied with the final outcome of the project. However, the Owner recognizes that the project was actually delivered for less money and on a shorter schedule than originally thought possible and, as a result, determines to use the just completed project outcome as a higher standard for future projects.

To close out the project, the Owner uses the decision support system to prepare the post project evaluation report. When critiquing the critical decisions made during the course of the project, the Owner notes the difficulties encountered with the decision to bore under the existing utilities. As part of the evaluation, the Owner recommends that either a different methodology be used on future projects or that a more thorough geotechnical investigation be performed before selecting the technique. Once saved, this and all the other reports completed during the course of the project are available for use on other projects by both the Owner's staff and the general public.

Section D: Comparison of Processes and Project Outcomes

A comparison of the two case studies highlights some interesting implications concerning the proposed decision support system framework. First, as illustrated during the planning phase of the two case studies, the author does not presuppose that all decisions will be changed or improved by the proposed framework. This is because it would be incorrect to assume that all decisions currently being made during the design and construction of underground utility projects are flawed or less than optimum. In fact, most current decisions are likely based on sound engineering principles and professional judgement. However, this does not mean that the opportunity to improve the decision-making process is insignificant on such projects as improving just one or two critical decisions could have a positive impact on overall project performance.

Nor does the author presuppose that the decision support system is infallible and will have a positive impact on all decision outcomes. As illustrated in the second case study, despite using the decision support system, the decision to use directional boring to cross under existing utilities resulted in a negative outcome during construction. This is because any lessons-learned database is going to be limited in its domain and will not contain an infinite amount of knowledge concerning all things or situations. In addition, one of the risks unique to underground utility projects is the inability to fully characterize underground conditions prior to commencing construction and no methodology is capable of completing removing this risk.

This having been said, the case study comparison does highlight the decision support system framework's potential for improving the decision-making process. Again referring to the directional boring decision, the case study illustrates how the decision support system can be used to expand the range of alternatives during the decision-making process. In the cases of the horizontal alignment and pipeline materials, although the decision support system did not expand the available alternatives, it did provide the decision-maker with additional background information to consider during the evaluation of the alternatives. Thereby, improving the likelihood the decision-maker will make the correct or better decision.

The case study comparison also demonstrated how the decision support system could be used to aid in the actual evaluation of alternatives through the use of its MCDA capabilities. This provides a tool for the decision-maker to compare alternatives where the best choice may not be readily apparent. In the case of the selection of pipeline material, it also showed why the post project evaluation of critical decision outcomes is important and how such information can be used to supplement or improve the MCDA analysis of alternatives.

One of the major potential benefits highlighted by the case studies is that created by the documenting and tracking of reoccurring problems on projects. The decision support system framework demonstrates how such information allows project participants to discover potential problems earlier in the project development process before they can cause difficulties during later stages. The three construction change orders that occurred in the first case study did not occur in the second case as the problems were identified and corrected before construction commenced. This minimized the contractual difficulties and disputes and improved the business relationship between project entities.

The case studies also demonstrated how communication could be improved between project entities. One example illustrated how the weekly project status reports could be used to discover potential misunderstandings or concerns on a project so that the surrounding issues can be identified and resolved before they become large problems on a project. In addition, the case studies highlighted how documenting the rationale behind decisions can aid in communicating the desired design intent to others. In the example of the potential bidder, how the decision rationale could be used to identify opportunities to improve a project was demonstrated. It was then shown how that same information could be used to improve an entities competitive advantage.

Although fictional, the project cost and schedule figures contained in the case studies demonstrate the potential improvement in project performance possible with the decision support framework. As the numbers are fictional, it is impossible to infer how much of an actual improvement in project performance might be experienced. But, is seems logical to assume that even small improvements in the decision-making process will translate into some type of improvement in project performance. It is this potential in project improvement that provides the primary incentive for owners to adopt and implement the decision support system framework.

The owner gains this improvement in project performance because the decision support system framework allows the owner to prepare better requests for proposal and contract documents. This in turn results in less contractual difficulties, disputes and changes on a project and encourages more and better qualified engineers and contractors to pursue the owner's work. This improved pool of potential engineers and contractors then results in improved future projects and the cycle continues.

As stated in previous chapters of this report, the primary incentive for engineers and contractors to participate in the proposed decision support system framework is the contractually mandating of its use. If they want the owner's work, then they will participate albeit reluctantly. However, the engineering and construction sectors also have several indirect incentives to participate. The improved requests for proposals and contract documents prepared by the owner allow them to submit better, more responsive proposals. This also levels the playing field among competitors for the work as there is less opportunity for taking advantage of weaknesses in the documents and forces everybody to evaluate and bid projects on the same basis.

The potential improvement in project performance is another indirect incentive accruing to the engineers and contractors. Their involvement on projects that perform well gives them an opportunity to market themselves to other owners who will be impressed by their proven ability to deliver a good product. Thereby, strengthening their competitive advantage on future projects.

A critical analysis of the case studies might cause some to question the likelihood of some of the decision-making activities described. For example, it is unlikely that either the owner would be unaware of an installation methodology like boring or tunneling if the owner had previously used it on projects. The assumption being that the additional alternatives would only be found in the lessons-learned database if the owner had previous experience with the methodology. Such criticism would most likely be valid.

However, such an instance could be used to demonstrate how the decision support system framework could expand integration to an industry-wide level. For example, if it was assumed that the owner had never before used boring or tunneling on its projects, no mention of either alternative would likely be found within the owner's lessons-learned database. But, if the decision support system framework was adopted by multiple organizations, the owner (or its engineer) could take the opportunity to query other agencies' databases to determine what types of installation methodologies they may have employed on their projects in similar circumstances. In such a situation, information on the additional methodologies would almost assuredly be found. Thus, the owner would have gained additional knowledge or experience from other similar organizations. It is the public domain aspect of the information proposed by the decision support system framework that would allow this industry-wide expansion of integration. As private sector organizations are not likely to make their lessons-learned public, this opportunity is considered to be unique to the public sector.

CHAPTER 8: CONCLUSIONS, RESEARCH CONTRIBUTIONS AND FUTURE RESEARCH NEEDS

Section A: Conclusions

The world's civil infrastructure systems have become increasingly complex and interconnected but are eroding due to age, neglect, misuse, and excessive demand [Bordongna]. As a result, public works agencies are faced with the task of building new facilities and upgrading existing systems in order to provide adequate levels of service. However, constrained by both limited financial resources and inefficient procurement methods for engineering design and construction services, such agencies have found it difficult to design and construct the required improvements in a timely manner or within the available budget.

One of the factors contributing to this difficulty has been the segmented and sequential nature of the traditional project development process. Such a process restricts feedback between project phases and entities and obscures much of the information and rationale used during the decision-making process. This impedes communication and obstructs understanding between entities and results in a lost opportunity for collaborative innovation that could improve project performance, reduce costs, or shorten construction schedules.

The field of design and construction integration research is concerned with developing methods that could be used to improve or optimize the overall project development process. Research has shown that improvements in integration can be achieved in three principle directions, across project phases, across disciplines within a single phase, and across time or from project-to-project [Fergusson]. Research has also shown that the ability to influence a project's performance decreases over the life of a project and that decisions made early in the project development process have a greater impact then later decisions [ASCE (1990), Gibson]. Methods that have been developed and used to improve integration and the early project decision-making process include project delivery methods such as design-build or construction management-at-risk, management philosophies such constructability or partnering, and using information technology to improve the transfer and sharing of project information.

The current research effort was focused on improving design and construction integration and project performance within the specific domain of public sector underground utility projects. Based on the literature review and expert industry interviews into current industry practices conducted as part of the research effort, it can be concluded that significant improvement in the performance of such projects could be achieved if owners and engineers actively engaged in activities that sought or encouraged construction related input during the development of a project. There appears to be few, if any, significant barriers that would prohibit public work agencies from engaging in alternative project delivery methods or from hiring other consultants or individuals with construction expertise to assist during the planning and design of a project. The biggest obstacle appears to be institutional inertia, which won't be overcome until utility owners make construction integration a priority on their projects.

Although the performance of public sector underground utility projects could be improved if existing integration methodologies were incorporated, an inspection of current industry practices indicated an additional opportunity for improving design and construction integration on such projects. That opportunity lies in the longitudinal or project-to-project direction of integration as described by Fergusson. Results from the expert industry group interviews indicated that the group was weak in documenting lessons-learned or experience gained on a project and, therefore, this information is not been efficiently transferred from one project to the next. This creates a climate of continually "recreating the wheel", as project participants are unable to learn from past project successes and mistakes and reduces the potential improvement of future project performance.

Therefore, the research engaged in an effort to develop a decision support system framework that utilizes a lessons-learned database that could be used to document, organize, and disseminate lessons-learned or experienced gained on projects in order to improve the performance on public sector underground utility projects. Results from the effort indicate that it is possible to develop a framework for such a decision support system that could be integrated into traditional project management and control systems used within the engineering and construction industry. In addition, evaluations of the proposed concept by industry experts indicated that such a decision support system, if fully implemented, would have a beneficial impact on the performance of public sector underground utility projects.

The proposed decision support system framework relies on the repeatable nature of the alternative generation and evaluation activities within the project development process to establish links between the project development process and the decision support system. It also attempts to utilize commonly collected project information and record keeping procedures found within the industry to aid in the documentation of lessons-learned by adopting the concept of the periodic project status report. This was done to reduce the increased administrative burden that the decision support system might impose on users with the hope that it would make the concept more palatable for adoption by the industry.

The conceptual framework defines lessons-learned as critical decisions that could benefit from construction related input or expertise and represent the outcome of the alternative evaluation activities found in the project development process. Based on results from interviews with the expert industry group, critical decisions were categorized according to materials or equipment, schedule or sequencing, installation methodology, facility location or alignment, facility size, and contract strategy. The system relies on the decision-maker from the owner, engineering, and construction sectors to document the lessons-learned and the rationale behind the decision made.

The system also incorporates modules for documenting construction change orders, for performing post-project evaluations of critical decisions made, and for querying and extracting lessons-learned from the database. The envisioned decision support system would be a web-based application hosted by the utility owner that would employ hyperlinks, drop boxes, text boxes, etc. to add users in entering and extracting information. It is also proposed that the general public would be given access to query the lessons-learned database.

Although the proposed decision support system framework received a favorable evaluation concerning its potential benefits from industry experts, several potential barriers or obstacles were noted that would have to be addressed before such a system could be successfully implemented and adopted by the industry. The first is concerned with providing sufficient incentive for all project participants to actively participate in collecting and documenting lessons-learned on a project. The proposed system has a natural owner-centric viewpoint or bias as the owner is going to benefit most over time from the collection of lessons-learned information from a variety of sources and projects. This bias reduces the incentive for the engineering and construction sectors to actively participate in the system and makes them reluctant to voluntarily take on the additional administrative burden of documenting their lessons-learned on the owner's behalf.

In addition, due to the public domain component of the proposed system, the engineering and construction sectors would be hesitant to fully divulge lessons-learned or the rationale behind decisions made for fear of sacrificing their competitive advantage in procuring future work. This reluctance, however, is not considered a major flaw with the framework as the industry experts indicated that some documented lessons-learned information is better than no information at all but the reluctance would reduce the maximum effectiveness of the concept.

That the issue of incentive was raised was not surprising as the issue was identified earlier in the research effort. Therefore, to address the issue the idea of contractually mandating the use of the decision support system by project entities was incorporated into the proposed framework. Based on the industry experts' evaluations, it appears that the idea successfully addressed the issue of incentive as the experts indicated they would use the system if contractually mandated. Therefore, the issue of incentive is not viewed as a major barrier or obstacle.

A hypothetical case study performed as part of the research highlighted several potential benefits or incentives accruing to users of the system. The primary potential benefit accruing to the owner is an overall improvement in project performance and delivery. Engineers and contractors potentially benefit from improved request for proposals and contract documents issued by the owner, allowing them to submit more responsive proposals for the work and reduces misunderstandings and disputes. They also benefit from the overall improvement in project performance as it strengthens the business relationship with the owner and provides an opportunity to market their participation in the success to other owners and clients. The end result is an improved competitive advantage, not a reduce one. Therefore, the issue of incentive may be due more to unfamiliarity with the decision support system concept and its potential benefits than to actual disincentives existing within the concept.

The second obstacle focuses on the trade-off required between the ease of documenting lessons-learned versus the ease of extracting lessons-learned from the database. Ease of documentation is achieved through less classification and structure of the data while ease of extraction requires the opposite. If too much data and structure is required during documentation of lessons-learned the additional administrative burden on users becomes too great and the proposed system becomes impractical to use. On the other hand, if too little classification or structure is provided, the lessons-learned database cannot be sufficiently filtered and the end-user is overwhelmed by irrelevant search results that detracts from the potential usefulness of the system.

The industry experts indicated that the proposed concept and categories for critical decisions might work well for simplifying the documentation of lessons-learned, however, it would likely create inefficiencies when it came to extracting applicable lessons-learned from the database. But the decision support system framework as the potential to incorporate Internet search technologies and knowledge or rule-based systems that could aid in making the database query operation more efficient. Therefore, the obstacle is considered more of a technological one and not an indication of a fundamental flaw with the proposed framework.

In conclusion, the research effort has demonstrated that it is possible to develop a decision support system framework utilizing a lessons-learned database that would improve design and construction integration and project performance on public sector underground utility projects. The concept would improve integration in the longitudinal or project-to-project direction by allowing experienced gained on earlier projects to be incorporated on current projects. In addition, the concept would improve integration in the vertical direction or across project phases as project participants will be able to readily access previous decisions made on a project so that a better understanding of the project's design intent can be gained.

However, it is recognized that, if implemented, the methodology would not have an immediate impact on project performance since it would take time to build up the lessons-learned database. Nor is the decision support system viewed as an equal replacement to having actual individuals with construction related expertise involved on a project. Project participants should still take the opportunity to actively seek out real individuals with construction related expertise during the earliest stages of the project development process.

Section B: Research Contributions

The research effort provided several contributions to the collected body of research found in the literature. First, through the project development process modeling effort the research was able to reveal a repeatable structure to the process that could be linked to a decision support system. Each phase of the process was found to include three primary activities: organizing to perform a task, generating and evaluating alternatives, and decision-making or selecting the preferred alternative. The entire project development process is also repeatable from project-to-project. This repeatable structure is important and necessary when attempting to link a decision support system framework to the project development process.

The project development process model also identified the repeatable activities of generating and evaluating alternatives as key opportunities for providing construction related input that could be used to improve the decision-making process. These decision-making activities become natural links between the project development process and a decision support system. Through the inspection of current industry practices, the research was able to characterize the nature of these critical decision-making activities within the domain of public sector underground utilities. The ability to identify and characterize the critical decision-making activities found within the project development process is considered a significant contribution of the research effort.

From the inspection of current industry practices, the research identified the documenting, organizing and retrieval of lessons-learned on projects as a major industry weakness that could be strengthened through the development of a decision support system. As classification of lessons-learned has been noted in the research literature as a continued difficulty in developing lessons-learned database systems [Kartam], the research then used the previously identified characterizations of the critical decisions to categorize lessons-learned in an attempt to structure the lessons-learned database used within the decision support system. This narrows the focus of the lessons-learned collection effort, provides guidance to users concerning what lessons-learned should be documented, and reduces the administrative burden required in documenting lessons-learned. The concept is also flexible and could be adapted to other types of public works projects once the critical project characteristic had been identified for the particular type of project. While the proposed concept does not fully solve the classification problem, it does represent a step forward in the documentation of lessons-learned within the public works industry.

The next contribution of the research was the effort to integrate the documentation of lessons-learned and the decision support system into standard project management and control systems found within the engineering and construction industry. To accomplish this, the decision support system framework employs the strategy of extracting lessons-learned information from currently utilized reporting mechanisms such as periodic project status reports. The system also utilizes the decision-maker to document the lessons-learned or decision made, which reduces the need for the hiring of additional database technicians and provides the most accurate information since the person most familiar with the decision is providing the documentation. This approach is different than the post-project expert interviews and "suggestion box" techniques for documenting lessons-learned proposed by others in the research literature. The concept of incorporating new methodologies into current business practices is an important contribution if the goal is to encourage the adoption by industry of the proposed methodologies.

Finally, the research effort potentially expands the scope of integration improvement beyond that described by Fergusson. With access to the lessons-learned database open to the general public, there is the possibility that integration could be improved industry wide and not just on a particular owner's projects. This would represent an expansion of the longitudinal integration from just project-to-project to also agency-to-agency.

Section C: Future Research Needs

Before it can be adopted and implemented by industry, a fully functional decision support system needs to be developed and evaluated under actual industry conditions. To accomplish this requires research in two separate areas. First, methods or indicators need to be developed to measure the improvement in design and construction and project performance. This is a research area noted by several others in the research literature [Fergusson, Pocock, Vanegas].

The other area is devising a control set of projects from which to evaluate and test the concept. This is a continual difficulty in public works engineering as no two projects are ever exactly the same making it impossible to implement the concept on one project and comparing the outcome against the outcome of a similar control project that did not use the concept. The difficulty is compounded when attempting to develop experiential controls against which to test the pertinent lessons-learned database concept, as one would need to establish a similar sequence of successive projects since the expected benefits of the proposed system will only be experienced over time or from project-to-project.

As noted previously, another future research need is in developing a more satisfactory classification system for lessons-learned that strikes the correct balance between the competing objectives of ease of documentation and the ease of extraction of lessons-learned. This may also encompass the development of better search engines such as those used on the Internet and the development and incorporation of knowledge or ruled-based systems to aid the user in documenting and screening lessons-learned. The solution to the classification trade-off problem is likely to be found through a combination of research in all these areas.

Additional research is also required in determining ways to increase the incentive for project participants, particularly those from the engineering and construction sectors, to fully participate in the documentation of lessons-learned. The current research effort proposed contractually mandating the participation of project entities. Although this solves part of the problem, the industry has indicated that they would still be guarded in fully disclosing lessons-learned in fear of losing their competitive advantage. How to overcome this fear and to get the project participants to step back from their own self-interest and to focus instead on the larger picture of the overall project development process is a difficult problem. As the hypothetical case study illustrated potential benefits accruing to users of the system, part of solution may lie in educating the industry of the potential benefits. This could be accomplished in part through the actual implementation and evaluation of the decision support system.

On a somewhat different scope then the current research effort, both the literature review and the inspection of current industry practices suggested that the current university engineering educational system could be a contributing factor in the lack of adequate design and construction integration within the industry. Some have noted that disintegration appears to begin at a college or university where students are channeled into specialized fields of study such as architecture, engineering (civil, structural, mechanical, etc.) or construction management [Thomas]. Others have indicated that ways need to be developed for educating engineering and construction students in the importance of professionalism and leadership for promoting integration within the industry [Nam]. Therefore, how the engineering educational system can be used to improve design and construction integration is an area requiring additional research.

THE END

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APPENDIX A: PROJECT DEVELOPMENT PROCESS MODEL SCHEMATIC

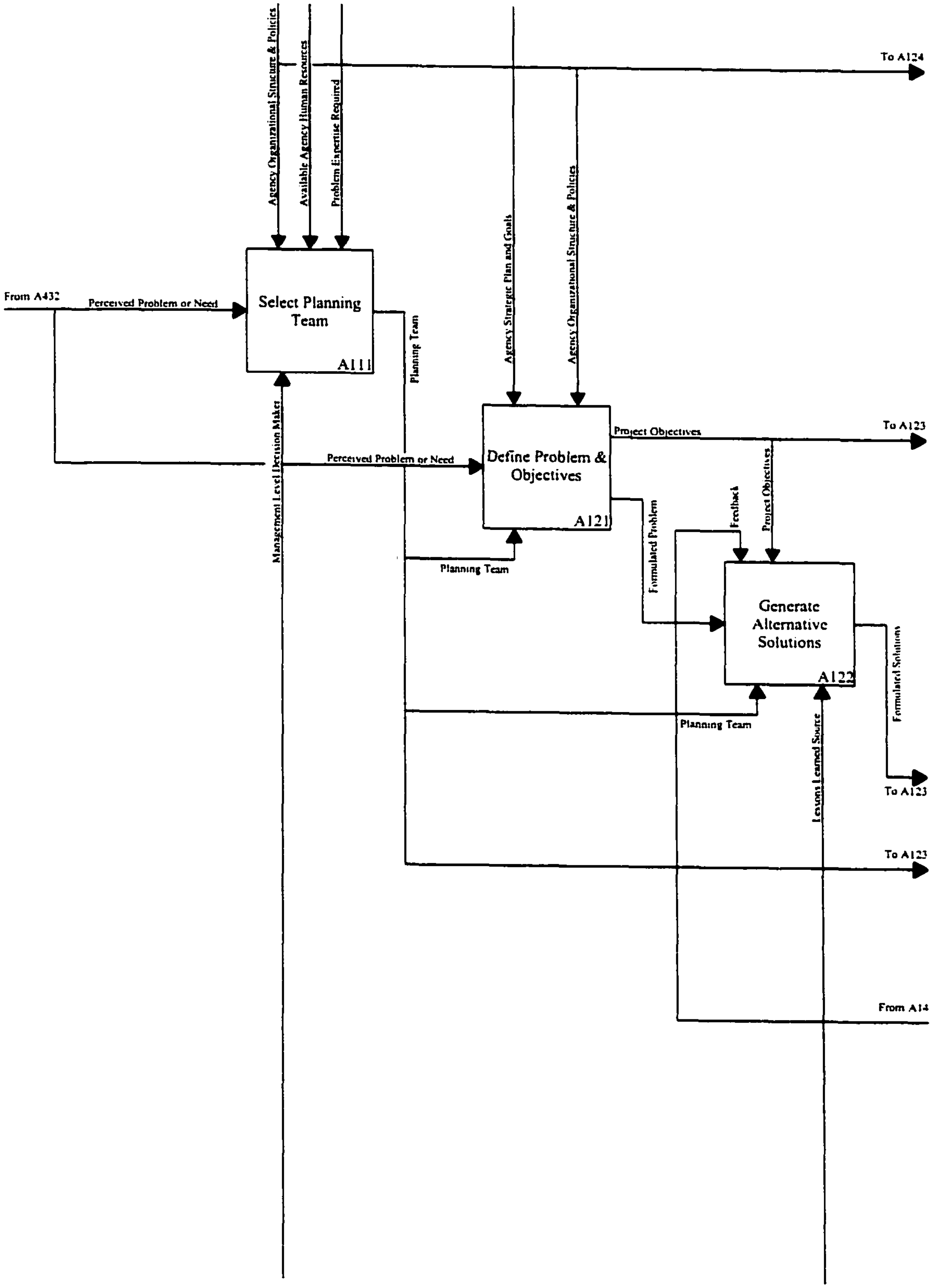

Figure A-1: Project Development Process Model Planning Phase Tasks A111 to A122

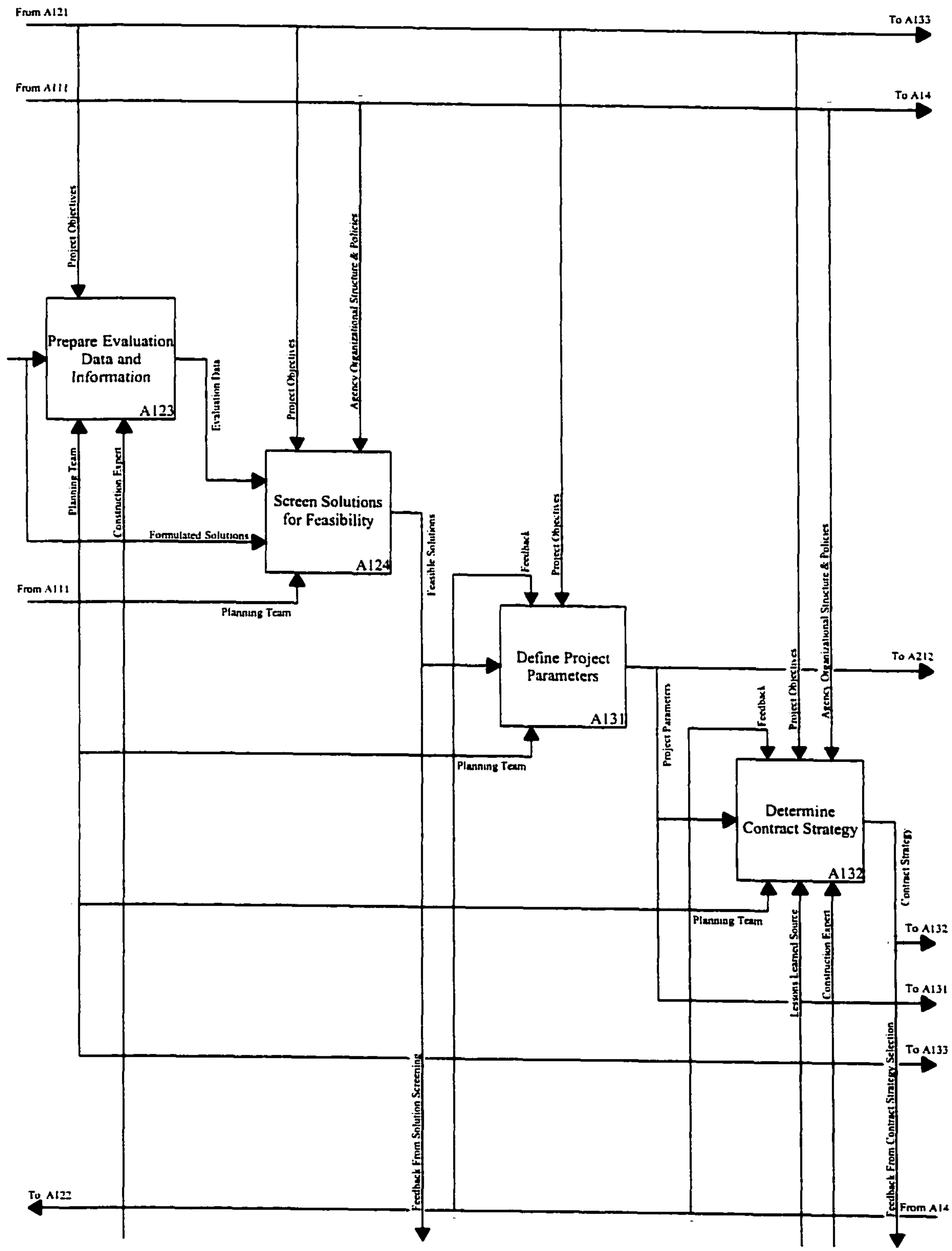

Figure A-2: Project Development Process Model Planning Phase Tasks A123 to A132

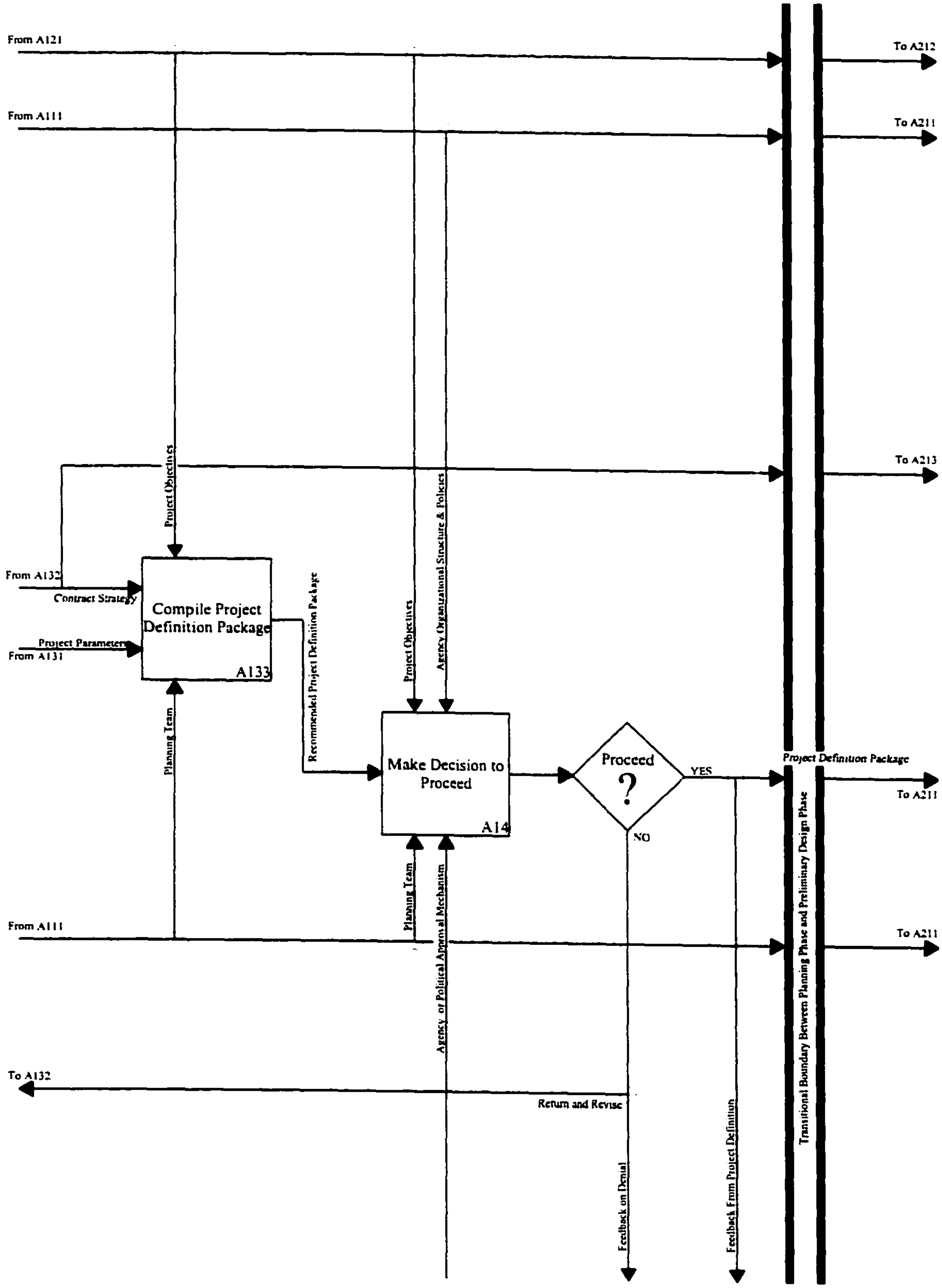

Figure A-3: Project Development Process Model Planning Phase Tasks A133 to A14

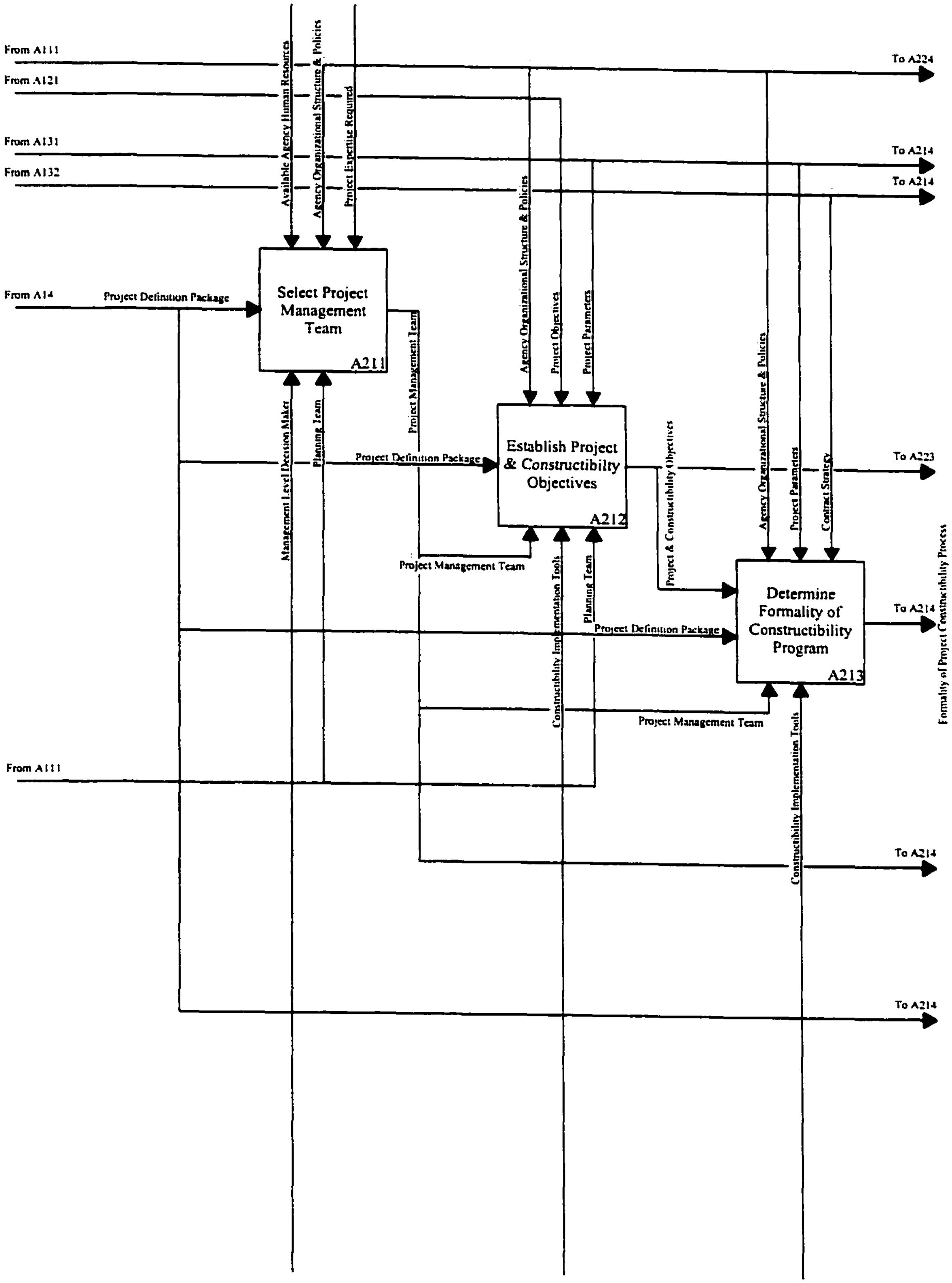

Figure A-4: Project Development Process Model Preliminary Design Phase Tasks A211 to A213

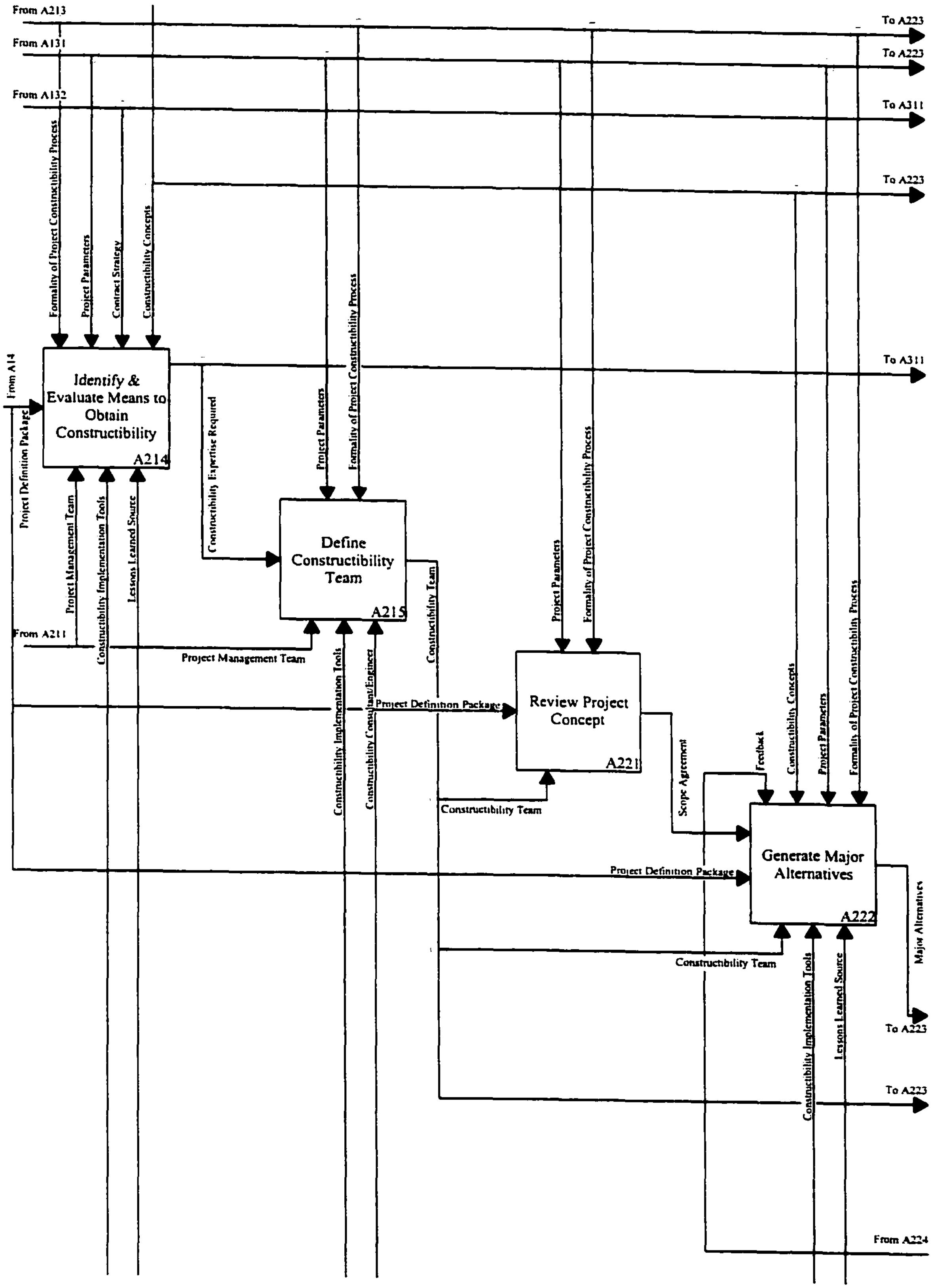

Figure A-5: Project Development Process Model Preliminary Design Phase Tasks A214 to A222

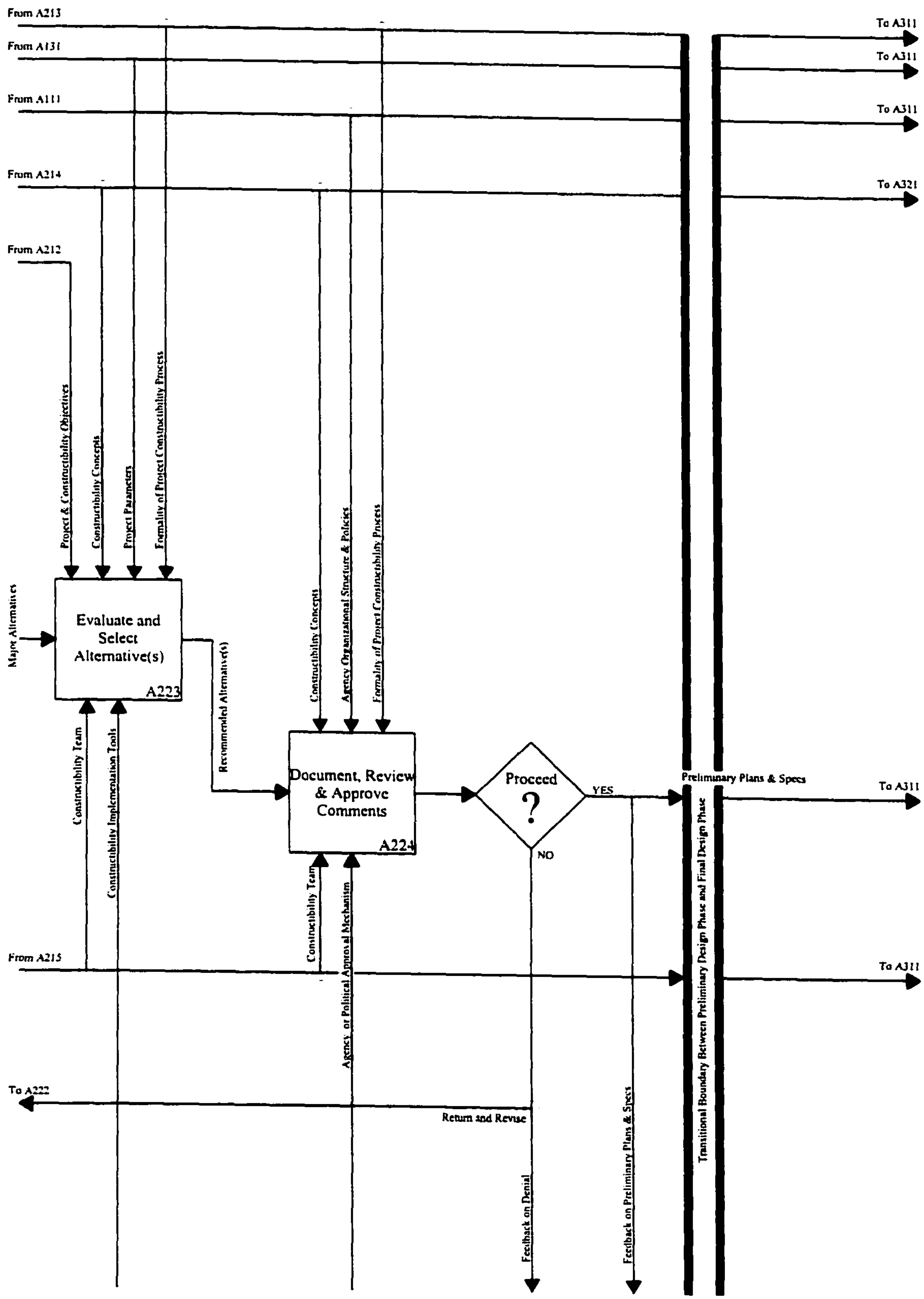

Figure A-6: Project Development Process Model Preliminary Design Phase Tasks A223 to A224

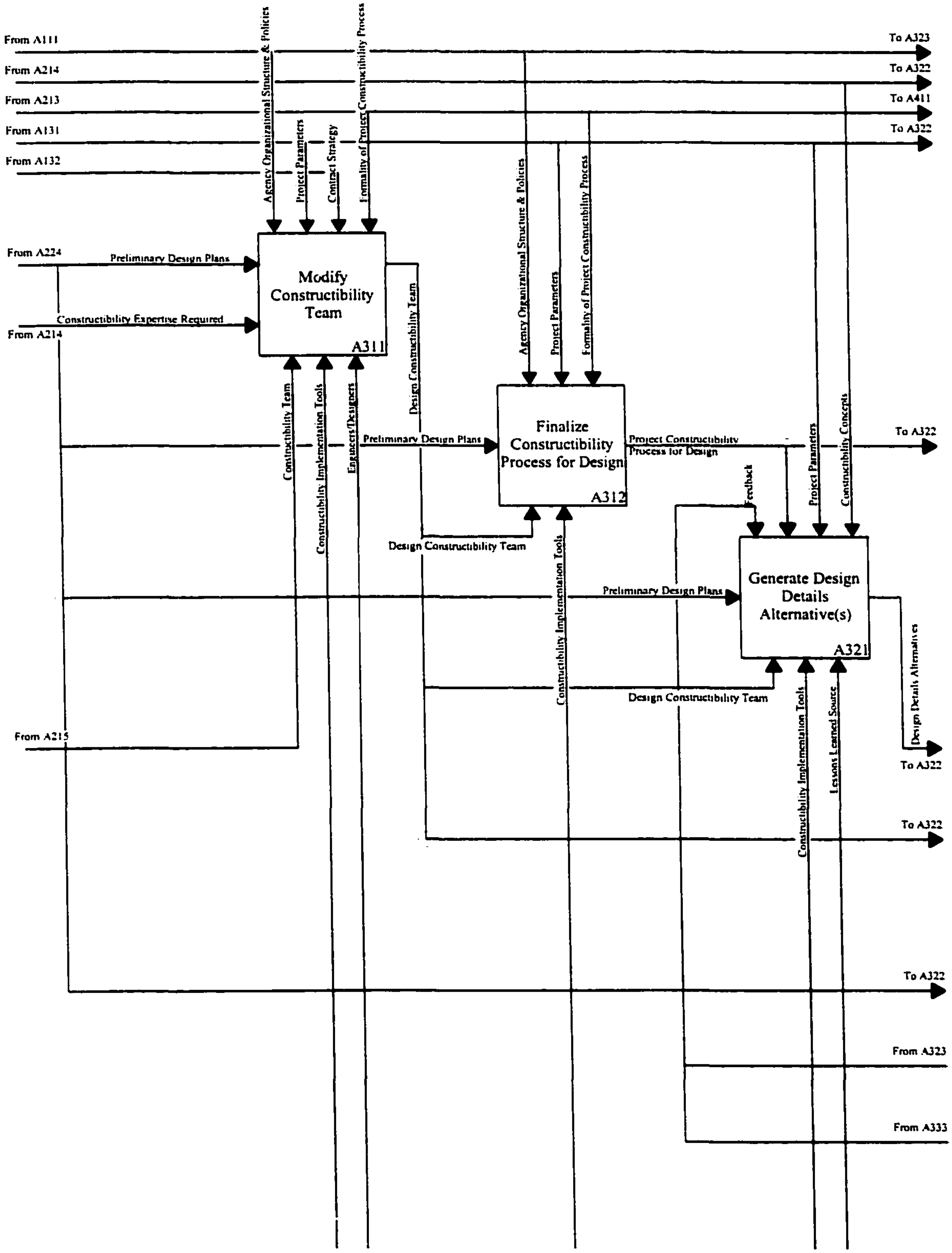

Figure A-7: Project Development Process Model Final Design Phase Tasks A311 to A321

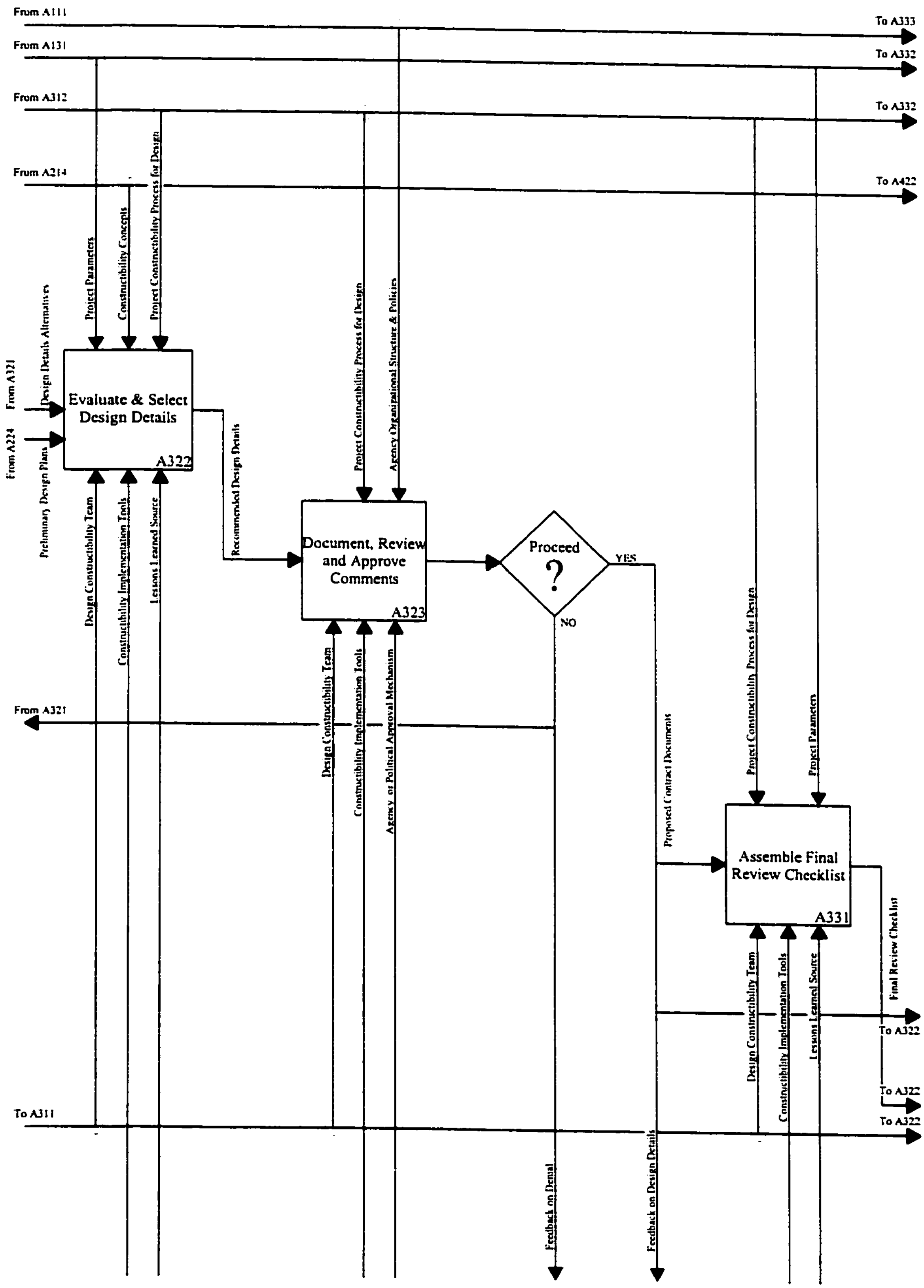

Figure A-8: Project Development Process Model Final Design Phase Tasks A322 to A331

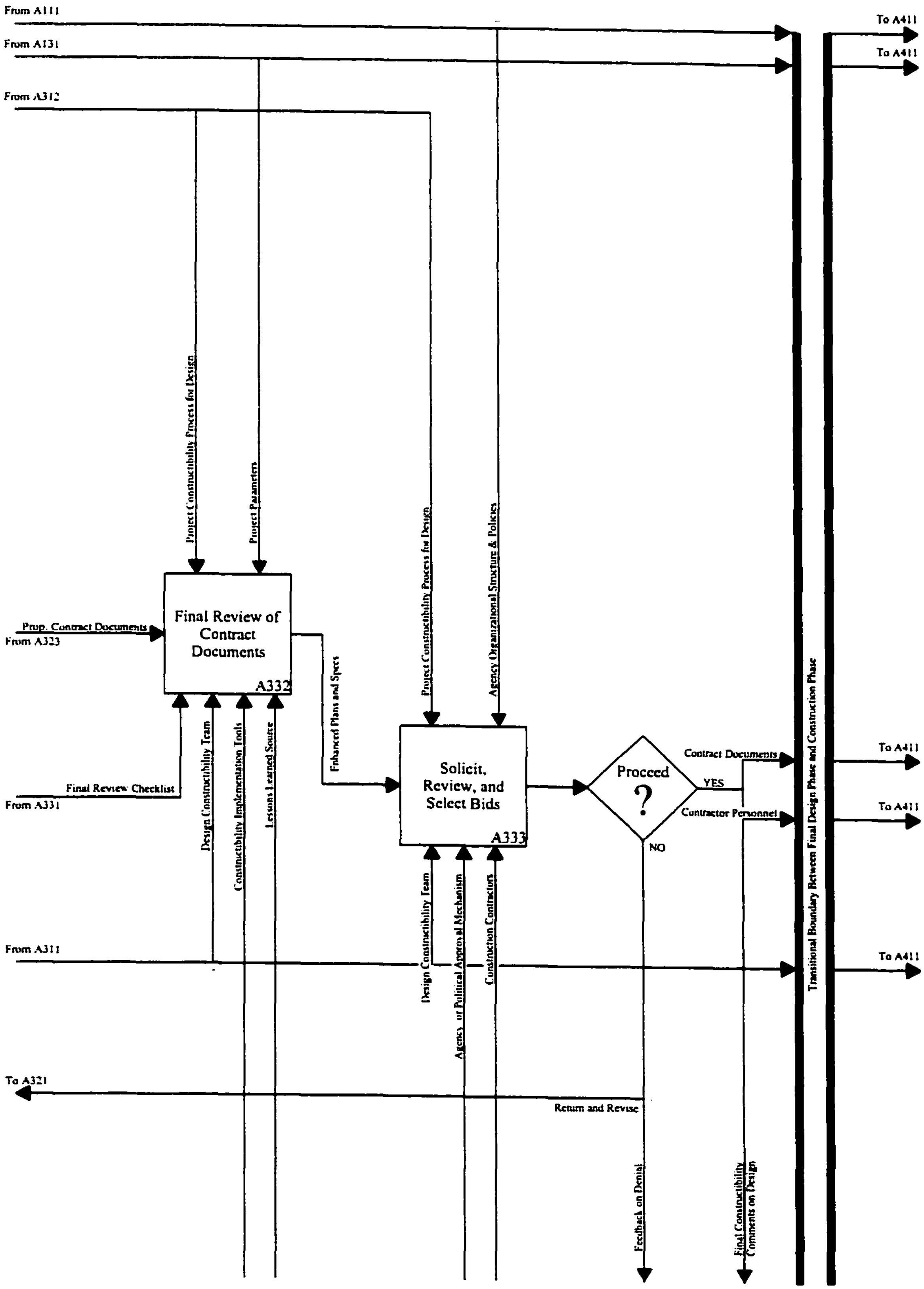

Figure A-9: Project Development Process Model Final Design Phase Tasks A332 to A333

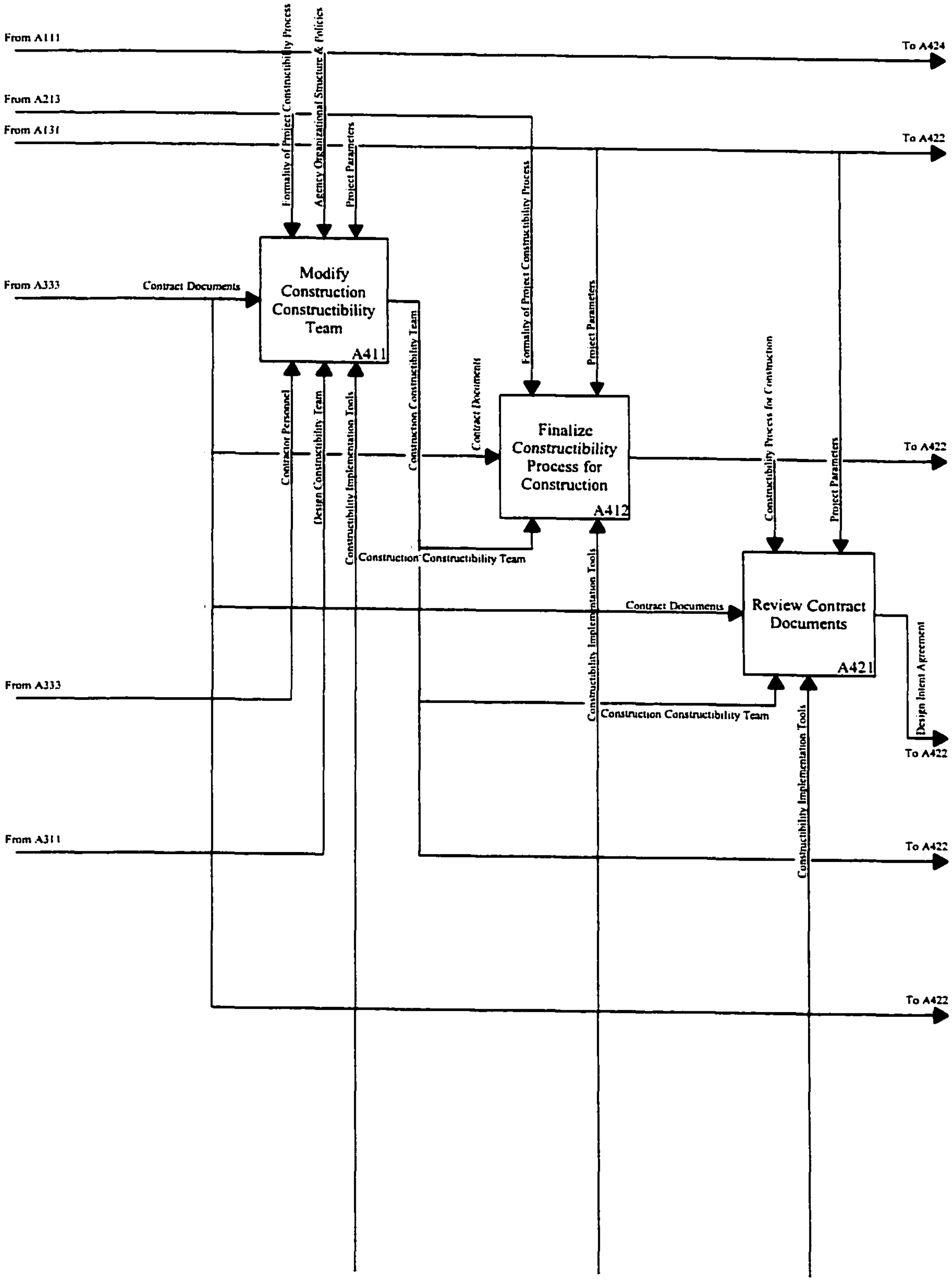

Figure A-10: Project Development Process Model Construction Phase Tasks A411 to A421

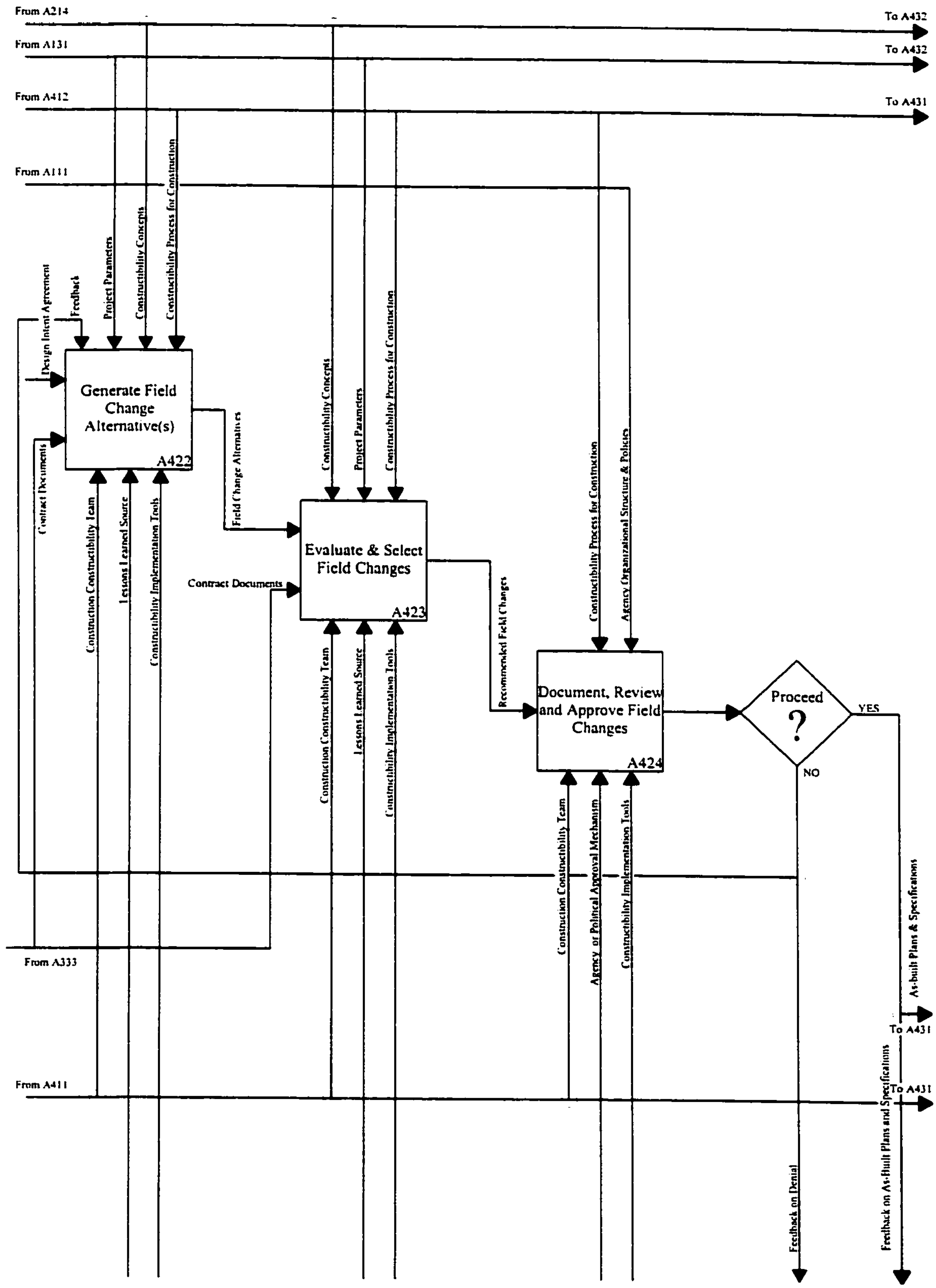

Figure A-11: Project Development Process Model Construction Phase Tasks A422 to A424

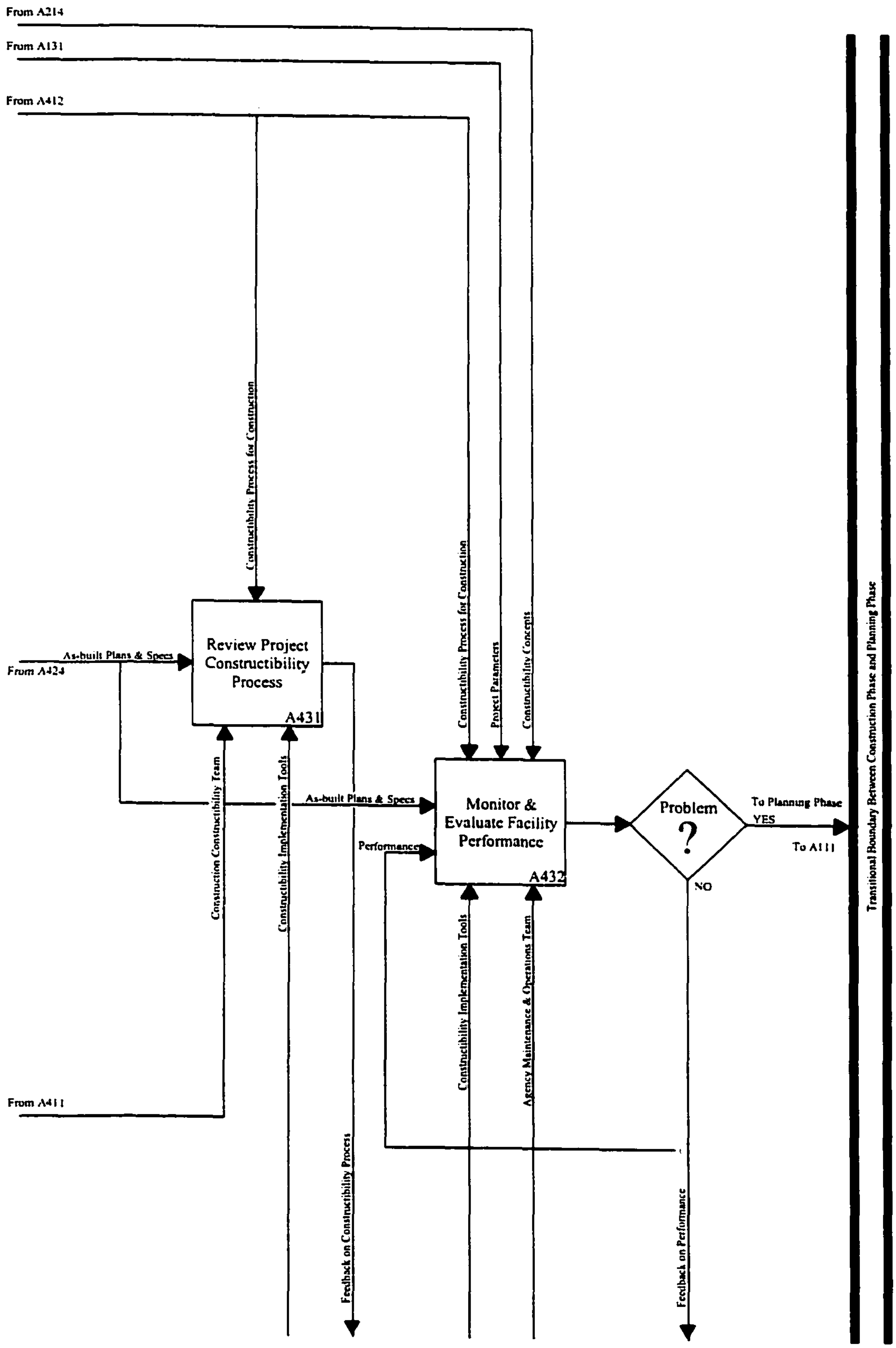

Figure A-12: Project Development Process Model Construction Phase Tasks A431 to A432

APPENDIX B: EXCERPTS FROM INITIAL INDUSTRY INTERVIEWS

Section A: Outline of Interview Questions

STEP ONE INTERVIEW OUTLINE AND QUESTIONS
Dissertation Research Project

The basic objective of my research is to improve the performance of public sector underground utility projects by developing a methodology that allows for greater construction input and exchange of expertise during the design phase of such projects. The purpose of this first interview is to develop some background on the current project delivery practices being used on underground utility projects and to determine opportunities for possible improvement in the process. The results will then be used to formulate a process methodology that addresses the improvements and enhances the overall project delivery. Later, after the methodology has been developed, you will be asked to participate in a second interview where you will be given the opportunity to evaluate the proposed methodology.

1. PROFESSIONAL BACKGROUND

(Purpose is to establish the basis for using the individual as a knowledgeable resource)

A. NAME
B. EDUCATIONAL BACKGROUND
C. PROFESSIONAL EXPERIENCE
D. REGISTRATIONS, AFFILIATIONS, ETC.
E. RELEVANT PROJECT EXPERIENCE

2. ORGANIZATION BACKGROUND

(Purpose is to establish the organization's capability of providing relevant knowledge or information)

A. NAME OF CURRENT EMPLOYER
B. INDUSTRY SECTOR (Owner, Engineer, Contractor, etc.)
C. GENERAL DESCRIPTION OF ORGANIZATION
D. TYPE, SECTOR, SIZE AND FREQUENCY OF PROJECTS

3. KNOWLEDGE OF PROJECT DELIVERY METHODOLOGIES

(Purpose is to gage the individual's knowledge and experience with various project delivery methods and construction integration processes)

A. DESIGN-BID-BUILD
B. DESIGN-BUILD

C. CONSTRUCTION MANAGEMENT AT RISK
D. PARTNERING
E. CONSTRUCTABILITY
F. CONCURRENT ENGINEERING

1. Are you familiar with the (*insert one of the above*) method of project delivery?

2. How would you briefly describe the process?

3. Have you personally been involved with a project that used the methodology? Frequency?

4. Has your current employer ever used or been involved with the methodology? Frequency?

5. In your opinion, what is the potential or suitability, if any, of the methodology for public sector underground utility projects? Disadvantages?

4. CONSTRUCTABILITY UTILIZATION AND PRACTICES

(Purpose is to gage the current state of integration or interaction between design and construction and to begin to uncover opportunities for improved integration)

Research by ASCE and others has indicated that the quality and total life-cycle cost of a facility are most strongly influenced early in the project life. In addition, research has shown that maximum benefits occur when experienced construction personnel are involved with the project from the earliest stages. One concept that has been proposed to facilitate this early input of construction expertise is "constructability" which has been formally defined as:

> *"The optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives."*

1. With this understanding, how would you describe the process you currently utilize to gather construction related input during the design or pre-bid phase of a project? In other words, what is your current constructability review practice as it relates to public sector underground utility projects?

   - What types of construction-related knowledge or advice do you seek?
   - What are the sources used for such information?
   - At what stages of the project do you seek the information? Why?
   - What procedures do you use to document "lessons learned"?

IF THE RESPONDENT IS A CONTRACTOR

1. What opportunities or steps are currently available for you to provide construction input on public sector underground utility projects prior to the bidding of a project?

2. If it were possible, what opportunities would you like to have to comment or advise on a project during the design or pre-bid project phase? Why?

3. What type of procedures do you use for documenting "lessons learned"?

5. UNDERGROUND UTILITY PROJECT CHARACTERIZATION

(Purpose is to find out how proscriptive underground utility designs really are and to determine if there are any reasonable opportunities for contractor innovation)

1. Now, addressing specifically underground utility projects, what pre-bid design parameters would you consider to be strictly engineering functions? For example, sizing of the facility. Is that something that only the engineer should do or could that be left up to a contractor? Why or why not?

    - Location of facility? Why or why not?
    - Selection of materials or equipment? Why or why not?
    - Project scheduling and sequencing? Why or why not?
    - Installation methodologies? Why or why not?
    - Are there other parameters you would consider to be strictly within the engineering domain?
    - Any others that you would consider to be strictly within the contractor's domain?

2. In order to improve the quality (cost, schedule, or performance) of a project, what areas do you think would benefit most from contractor input during the design of a project? At what stage of the design process would such input be most beneficial to the overall project?

3. If a project were to be awarded on some basis other than strictly lowest cost, what criteria would you use or like to see used to evaluate proposals? What would be the general order of preference for the criteria?

6. DESIGN-BUILD CONTRACTING ASSESSMENT

(Purpose is to gage the viability of design-build for underground utility projects and to determine some of the issues or barriers that any proposed methodology would have to address.)

Research has indicated that projects delivered using the design-build contracting method generally perform better for both cost and schedule than similar projects utilizing traditional design-bid-build contracting methods. The advantage stems from the increased incentive for contractor innovations and from the ability to perform design and construction concurrently. Because of the improved performance, many public works agencies have begun to investigate the use of design-build for their projects.

1. With this in mind, would you consider design-build to be a viable option for underground utility projects? Why or why not?

2. What are some of the barriers or obstacles to implementing design-build on such projects?
    - Legal and Regulatory
    - Contractor qualification
    - Project complexity
    - Lack of incentive
    - Reduced competition
    - Proposal evaluation
    - Cost of proposals
    - Etc.

3. On Federal design-build projects, a short-list of pre-qualified contractors is usually prepared. What is your opinion on the use of such a pre-qualification system on public sector projects?

7. INFORMATION EXCHANGE CAPABILITIES AND TECHNIQUES

(Purpose is to determine the formats of information currently being exchanged, to ascertain the technological capabilities of the organizations, and to uncover possibilities for improving the efficiency of communication and data exchange.)

1. What types of computer hardware do you have access to in your organization?
   - Desktop and mainframe computers
   - Servers and networks
   - Printers or plotters
   - Copiers and scanners
   - Fax machines
   - Modems and Internet connections
   - Other

2. What types of software applications does your organization utilize?
   - Word processing
   - Spreadsheets
   - Database
   - CAD
   - GIS
   - Modeling and design
   - Project Management
   - Other

3. How would you classify your organization's general Internet skills?
   - E-mail
   - Web search and access
   - Company web page
   - Web application programming
   - E-business applications

4. How do you currently transmit or access the following information (hard copy, floppy disk, CD-ROM, Internet)?
   - Plans or drawings
   - Specifications
   - Technical reports
   - Bid advertisements
   - Addendum
   - Bid submittal packages
   - Change orders
   - Invoices

5. What would be the advantages, if any, of electronic bid submittals? Disadvantages?

6. What are the primary concerns and obstacles that would have to be overcome to make electronic bid submittal a feasible and practical option?

Section B: One Example of Transcribed Interview

Interview No. 1

November 1, 2001
Respondent No. 1, Denver Water Department

Gehrig: Okay, the objective of my research is to improve the performance of public sector underground utility projects by trying to come up with some sort of methodology that allows for greater input from the construction side into the design. The purpose of this first interview is to get some background information of how things are actually being done currently in the industry and to find out what opportunities might be available for improvement. Then, after this interview and when all my other interviews are over I'll put together my proposed methodology then, if you are willing, I'll come back to give you a chance to evaluate it, follow up and see whether it makes any difference or not. Obviously, I have some ideas what might be possible because I have experience in the field myself but I don't want to bias you by going into too much depth into what I think might be possible because you would then be evaluating in this stage my methodology instead of giving me your own input.

Respondent: Okay

Gehrig: The first question is basically to establish why I consider you to be an expert. So, just give me a little bit, for the record, some of your educational background and professional experience.

Respondent: Okay, my educational background is a Bachelor of Science degree in civil engineering from Colorado State University. Professional experience I guess... Back to my educational background I have taken, as I would explain in court situations, that I have taken other graduate level courses from time to time and other training classes that are technically oriented. Professional experience, I have worked at the Denver Water Department since 1974 which makes that 27 years, a long time. And I worked for a private consultant in the Denver area for 2½ years after I got out of school. The consultant, I believe, was doing water and sanitation district work designing and installing water mains, sewers, that sort of thing. Here at the water department, been in the design area since I have been here so my whole experience here has been in design. Registrations, affiliations, Colorado register engineer license number *****. On AWWA committees for steel pipe and I am also on the AWWA standards council which does almost all of the final approvals for AWWA standards. Technically, that's it. I am also on the Board of Directors of the Metro Water Reclamation District. Just over two years now. What are you looking for in relevant project experience?

Gehrig: Well, since I am looking generally at underground utilities, you don't need to go project by project but just give a sense of the types of projects and variety of pipeline projects. New ones, rehabilitation, relocation, that type of thing.

Respondent: I have worked on all types of pipelines from small diameter which would be 6-inch and that size range putting in PRV stations, modifications to the system all the way up to, I guess the largest pipeline I worked on was conduit No. 94, the part we are doing now is a 72-inch but have been in involved in lots of other ones here. Trying to solve problems with failed pipelines like conduit 27, worked on some of that with analysis of what went wrong, materials testing and what we need to with the pipeline. Then, on conduit 94 recently, we had a pre-stressed line and it failed and I've been involved in the investigation of the failure and what to do about it. Also, on the failure of another conduit, conduit 55, which was also a pre-stressed pipe that failed and we had to replace that. But, other than pipelines, I have done lots of stuff on rivers.

Gehrig: For the record, you have done the design, but how much have you been exposed to the construction. Overseeing the construction, etc.

Respondent: Have not been involved in the field end inspection part but in the project management section of it. In fact, I was out doing that just before we started here.

Gehrig: Okay, that's good enough for that. We'll go on. Next thing is to do the same thing but now for Denver Water Department. Obviously, I'm not looking for long descriptions, but they're into water and underground utilities. I would classify the Denver Water Department as a Engineer/Owner basically. Don't you do most of work design work on pipelines in house?

Respondent: Yes. Yea, we would be an Engineer/Owner.

Gehrig: Do you ever contract out or go to a consultant for the design of pipelines? I know you do on treatment plants and things.

Respondent: I'll tell you, we just had a consultant do one on our reuse project for the source water line for the Metro sewage reuse plant. That was a disaster.

Gehrig: Okay, we can talk about that down the road. Just real briefly, kind of give me a general description of the organization, size, service area, that type of thing.

Respondent: The water department is a major water utility serving about a million customers in the Denver area with about 250,000 accounts.

Gehrig: Basically, you cover City and County of Denver and ...

Respondent: City and County of Denver, Jefferson County, some of Adams, some Araphahoe, some Douglas. City and County of Broomfield.

Gehrig: Obviously, you go all over the mountains for the collection system.

Respondent: Yep, we have collection systems at Dillon, Winter Park area, all of that.

Gehrig: You have pipelines associated with all of those. Okay, just generally, approximately how many pipeline type projects do you think you would do in a year? Distribution piping, they do that on a continual replacement basis, so how many feet a year to they do now?

Respondent: I think they are doing 100,000 a year. Either replacement or new. Part of their O&M program. And new development. Big pipelines I suppose right now we're averaging maybe 10 to 20 thousand feet a year. As I look over the last four or five years.

Gehrig: Okay, now to get more into my research. Typically, people have come up with various ways to construct projects, to deliver projects, so I am going to ask you to see what your knowledge is of various methods. The design-bid-build process is one that you typically use where you hire a contractor after the project is designed. I assume you are familiar with that.

Respondent: Yes, that is what we primarily use.

Gehrig: Out of all of your projects, what would you say, 100% of the projects, pipeline projects, use that delivery system.

Respondent: Yes. I can tell you that we have been on our reuse project and out at Marston, we have gone with a little bit of design-build hybrid.

Gehrig: Personally, have you been involved in any thing else besides design-bid-build?

Respondent: No.

Gehrig: Has the Denver Water Department ever been involved in design-build?

Respondent: You know, I think the main administration building was really a design-build project.

Gehrig: So, pretty much everything they do here is design-bid-build. So, in general, in your opinion, how does that methodology work for the Denver Water Department? How would you rate that way of doing business?

Respondent: I think for the projects that we typically do it does pretty well. The advantages of some of the other delivery methods are better if you're against a tight time frame or something like that. You know, most of the time when we do design-bid the timeframe is not an issue.

Gehrig: From my experience, most of them aren't schedule driven. Okay, how about design-build? Are you generally familiar with the process? How would you briefly describe the concept?

Respondent: You go hire a contractor or an engineer, in some combination, you let them decide that. And tell them you want this facility, you give me that or deliver that facility.

Gehrig: Okay, we'll talk more about design-build later. Concerning design-build, are you aware of many underground utility projects that have been built using design-build?

Respondent: You know, it seems like I have, but nothing comes to mind. I know I have talked to some of the contractors. If you get around to it, one of the people you need to talk to is (*identifying name deleted*), he would be able to tell you some that. I know I have had discussions with him about design-build for pipelines. And we have had a few contractors say, why don't you design some of the reuse pipelines you are doing now.

Gehrig: From what you know about design-build, do you see an advantage of design-build for pipeline projects? You wouldn't do it because of this? It would be nice if we did it because of this?

Respondent: I don't see any advantages to design-build on pipelines.

Gehrig: How about construction management-at-risk? Have you ever heard of that term before?

Respondent: I've heard of it but I don't know much about that. I think it is something that is more in line with buildings.

Gehrig: How about partnering? Have you ever heard of the concept?

Respondent: Yes. We've done partnering on our big projects that we done over the last few years. That is a process where everyone gets together at the beginning of the project, talks about the project, before they start construction. And talk about what everyone wants. It's kind of the touchy feely, team building, be nice to each other, do business like business should be done concept. You know, it has its advantages. It really helps in bringing the people together, where they personally get to know each other.

Gehrig: Have you noticed any positive results from doing that compared to other projects which haven't used it? Any advantages to using it? Or is something they use to be politically correct? What were some of the reasons they decided to use partnering?

Respondent: It's just to try to get everybody to work together for a common goal in getting the project completed. Are there any other tangible benefits? I am sure there are.

Gehrig: Have you noticed where it has made much of a difference on how the project actually came out when it comes to like cost, schedule, or number of change orders?

Respondent: No.

Gehrig: Okay, how about the concept of constructability? How would you define the term constructability?

Respondent: Constructability in my mind would be where you are doing design-bid-build for instance you would look for someone who is more experienced in construction. It could actually be a contractor that might not be interested in the project specifically. Would look at it and help you decide making sure your not trying to put a square peg in a round hole.

Gehrig: Does the water department try to incorporate constructability into their projects?

Respondent: We have from time to time. We're doing a job right now, Einfield Pump Station, where the contractor's involved just to sit down with us before hand and we lay out the plan and talk to him about it to make sure that they could construct it.

Gehrig: The last one, have you ever heard of the term concurrent engineering?

Respondent: I haven't heard of that one.

Gehrig: Concurrent engineering is kind of expanded constructability where, instead of just getting the contractor's input, it's kind of like where you look at the whole project life cycle and get people's input throughout the whole life cycle of the project to try to get better projects down the road. It is used in many types of industry where marketing has to talk to the engineers, the engineers talked to the assembly line, that type of thing.

Respondent: I think that is really what we have been doing on the reuse project is a combination of that and design-build where when we really got started design we started with the concept, got comments and then went to work on the design. We had the contractor there at all times, and had O&M involved in all of the design so that the guys who are going to operate the plant have all been there since the beginning.

Gehrig: There is lots of research out there trying to improve the coordination with contractors during the engineering phase by using constructability and obviously the industry has a long ways to go to move up to concurrent engineering.

Okay, that was just to get a little background. This next section of questions is basically going to deal with constructability. Actually, ASCE has written a white paper on constructability. Constructability is really a real formalized process where you make a real effort at various stages of the project for someone with construction expertise to evaluate your project. It is actually more than having the plans reviewed at 30%, or 50% but occurs continually throughout the whole project. They way they defined it was " the optimal use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives."

On typical projects, particularly underground utility type projects, what types of construction-related knowledge or advice does someone at the Denver Water Department typically seek on a project?

Respondent: It kind of depends on the project. On just the straight pipeline, the constructability part would probably be one of our construction folks looking at it from time-to-time and by being asked questions by the designer. Other types of pipeline projects where you are working in really tough situations we would try to get some input from a contractor. We don't have anybody that is strictly there to do the constructability review other than the reviewers that have been here for 27 years look at stuff to give input. A lot of the young engineers come ask questions to the older folks about those issues. Getting a contractor is something that we have found to be pretty valuable.

Gehrig: Do you do that frequently or just on really tough project, like congested right-of-way or difficult soil conditions? What would determine when you would bring in somebody? What type of complexity would the project have, when you would decide that it might be beneficial to have a contractor look at it?

Respondent: Probably, something involving tough traffic conditions. Making sure that you can actually get in the street and do this work and still be able to maintain the traffic. You end up arguing with the traffic department a lot. Traffic conditions is something that the contractor can give you a lot better handle on then any designer can. Trying to make sure that they can put it together as its designed in an orderly fashion. It looks easy on a set of drawings to say let's just start here and go around but sometimes it is not quite like that.

Gehrig: If the contractor wanted to propose that, would you seek it in the design phase or wait until the contractor actually had the project? Such things as boring or tunneling, etc.

Respondent: We've asked contractors ahead of time before we've even designed the project about boring. And of course, some of the facilities like the railroads would even require that.

Gehrig: Okay, what sources of information to you typically rely on? In most cases, is it you in-house expertise that you primarily rely on?

Respondent: Yes.

Gehrig: If you use a contractor, is he then allowed to bid on the project later on? How do you typically handle that?

Respondent: It is probably helpful if you can find at times a contractor that is independent of the project then one who is just interested in trying to bid it. That is easy to do at times. You can find contractors that are busy, that don't have time to bid that project and they will tell you that up front. Other times, we will allow them to bid. Sometimes it hurts them to know more information than it helps them.

Gehrig: Okay, at what stage of the project do you typically seek the information, during the planning phase, design or construction phase?

Respondent: It could be any of those. If you are trying to get a project laid out and you have some constructability concerns you would want to talk to a contractor before you start laying it out. And, of course, if you can get into that even during the bidding process when it is out to bid and the contractor says I can't build this we need to do this. And then look at it then. And some contractors will tell you how to do it after the project is bid to save you money or something.

Gehrig: Okay, one of the big things about the formal constructability process as ASCE as described it is keeping a database for lessons learned that can be incorporated on future projects. When you design a project and it is all finished and evaluated for what went right and what went wrong, is there any formal why that you document that information that designers can build off that information?

Respondent: The most formal way is the project engineer is suppose to prepare a project completion report at the end which those types of items would be included and then that report then gets routed to all of the other engineers for review. And they would learn from that. And, although we have 20 engineers or so, everybody kind of knows about everybody's projects and those kind of things get past around by word of mouth.

Gehrig: Are there routine updates to contract documents?

Respondent: Yes. We do make changes to adjust to things that happen.

Gehrig: Do you have typically someone in charge in deciding what changes need to be included? If an engineer or resident engineer came and said we found this problem, is there some formal process to decide if it was just a one-time occurrence or something that needed to be changed permanently?

Respondent: No formal process but it would sure get brought up and between the engineering managers and I will make the changes and make sure everybody knows about it.

Gehrig: Do you have any type of index system where somebody can go back through and track the change orders and find reoccurring change orders or problems?

Respondent: No, but it sounds like a good idea.

Gehrig: Well, there are some agencies that do that, that have big databases where someone can see if the same things are occurring over and over again, and they can decide what they need to change.

Respondent: That's a good idea.

Gehrig: Well, now basically, we are going to go into coming up with some basic characteristics of utility projects. The first questions is to see what, if any, opportunities are available for contractor input. Who should be responsible for particular aspects of the project, whether or not the contractor can have any input or the engineer should be totally responsible for that. For example, the location of a pipeline, is that something, in your opinion, that should be done by the engineer only, the contractor could have some involvement, or the contractor could be solely responsible for that? On a pipeline job, how would you review the location of the pipeline or utility, is that something that could have contractor input or is that something that should be just done by the engineer? Why or why not? Obviously, I am more interested in the why or why not then just the yes or no.

Respondent: Many of the pipelines we do are in the city and go down the street trying to get from point A to point B. And, you go out and survey a route, gather up all of the utility information, and see if you can physically fit the pipe where it need to go. For the most part, contractor input there is probably not needed. There would obviously be some conditions where some tough locations might.

Gehrig: What if the contractor came to you and said I want to move the pipeline of this side of the road to that side of the road to avoid this. Is that something you would consider?

Respondent: Sure. But I hope that is something we look at from the beginning.

Gehrig: But, you're not the contractor that's going to actually build it and he may see things differently.

Respondent: Yea, sure that's possible.

Gehrig: Vertical alignment, where you could over or under utilities, I know when I worked here we decided that as a engineer but as a contractor, is that something you guys at the water department would be open to if the contractor said, you show it going under, let me go over, let me bore, let me relocate the utilities, is that an avenue for a contractor to have input in?

Respondent: Oh, yeah. We've always accepted comments from the contractor and we have implemented those things many times.

Gehrig: Would that be something it would be helpful to have comment on earlier in the project, before you went real far in drawing it up?

Respondent: In those situations, we should always try to find the constructability issues to make sure that you can do it. You just can't design something that is impossible.

Gehrig: How about selection of materials? Pipelines materials, bedding options. Is that something the engineer should do, or something the contractor should be responsible for?

Respondent: We have our own biases about pipe materials and standards.

Gehrig: I know on conduits, you have specs that gave the contractor the option for concrete or steel pipe.

Respondent: On big pipelines, we have either ductile or steel. The concrete people aren't very competitive here.

Gehrig: So, basically, selection of materials is something that could wait and is not something that needs to be decided early in the design process.

Respondent: Sure. The contractor in the bidding process will decide whether or not he wants the pipeline to be steel or ductile.

Gehrig: How about project schedule or sequencing? Is that something the engineer should be doing, contractor, or in combination?

Respondent: If we establish a schedule, its because we need to have it done within a certain time frame because we need to serve water or get a treatment plant back into service. Something like that we would schedule. Other than that, we usually give them a generous time frame to fit that in.

Gehrig: Are there times when you try to sequence the work for particular reasons?

Respondent: For certain reasons, we might sequence the work.

Gehrig: On most projects, you would let the contractor sequence the work?

Respondent: Yes. Out on conduit 94 right now, I have the contractor laying 2000 feet of pipe under milestone number 1. He can lay the pipe now because it is parallel to the existing pipe. But the tie-ins he has to make must be made next March and April because that is the only time we can take the pipe out of service.

Gehrig: So, there are times when the sequencing of the work can actually effect the design of the project. So, if the contractor came up with a sequence later in the process, it could actually effect the design?

Respondent: Yes.

Gehrig: So, there could be some benefit in getting some feedback from the contractor earlier on what might be a better sequence. Okay, what about installation methodologies? Like, open cut versus boring versus rehabilitation.

Respondent: I think, for the most part, that we have always thought that was our engineer's domain.

Gehrig: Why is that?

Respondent: It's kind of the way it's always been. That's kind of a cop out answer but ... In the big pipelines, the trenchless methods aren't really necessary around here. I think if you were trying to lay a big pipe down a street in St. Louis, New York or something like that, there are lots of alternatives that you need to look at. But around Denver, you are going to open cut everything. It's the cheapest and you can do it. There is going to be a time here that we are going to have to look at other methods.

Gehrig: So, are there parameters where you would absolutely consider to only in the engineering domain? For example, size.

Respondent: You know, that example is a good one. We'll decide the size. And, to some extent, where it needs to go because we need to get from point A to point B.

Gehrig: It's not so critical on pressurized pipelines as gravity lines where the vertical alignment could have a big effect on the size of the line. Whether you went over something or under something. If you just gave them the parameters. Okay, how about things you would consider to the contractor's domain that you wouldn't want to have anything to do with?

Respondent: Obviously, that's the methodology of installation. Sometimes we specify subcontractors but not on pipeline work. I&C work where you don't want just any one.

Gehrig: Going on to the next question. In your opinion, to improve the quality of the project, which is typically defined as the cost, schedule and performance, what areas do you think would benefit most from contractor input doing the design of a project? What area where your not getting the input would be the most beneficial if it was possible to get it?

Respondent: Oh, I think location. Both horizontal and vertical. I think that is the thing you can save the most on.

Gehrig: At what stage during the design process would that be most beneficial? When the project is coming out of planning or when you first start laying it out?

Respondent: It would probably be when you first start gathering information about interferences on the route.

Gehrig: If you had some preliminary information on the drawings, the contractor could look at it at that point, there might be some benefit.

Respondent: The interaction there needs to be actually out in the field. Standing there with a set of drawings showing the alignment.

Gehrig: Okay, if the project was awarded on something besides low bid, what criteria would you use to evaluate a contractor's design? There is a lot of debate in the industry whether low bid is the best way to procure projects. What type of criteria would you use to evaluate a proposal from a contractor besides just cost?

Respondent: Schedule. And tangible things like experience.

Gehrig: I looking out things like if the contractor gave you a set of plans, how would determine if that was an acceptable design?

Respondent: Schedule, cost, materials, his methods.

Gehrig: How about life cycle costs considerations?

Respondent: I suppose that would come into the materials part of it.

Gehrig: How about operation and maintenance concerns? I can see where that could come up in some situations with location. People don't like to climb down a manhole in the middle of a busy street. But, primarily, you think it would be just schedule, cost, and materials. Okay, we're getting to end here, not too much more.

This section is a little on design-build. Research has indicated that, generally, projects constructed with design build perform better for both cost and schedule than similar projects utilizing traditional contracting methods. The advantage stems from increased contractor innovation, more update products, more update methods. And, because a lot of times you are able to use fast-track type methods. You can start building a portion of the project before the entire design is done. With this in mind, would you consider design-build to be a viable option for underground utility projects? Again, your don't going to be the only one commenting on this research.

Respondent: Again, that's a tough one. You've got to believe that there's got to be some benefit to it sometime. And there's going to be a time we do that. I think the only down side is that it's hard to change the philosophy from design-bid-build to design-build.

Gehrig: There is some institutional inertia with public agencies to change.

Respondent: That's right.

Gehrig: They are reluctant unless you can actually document the cost savings, or whatever. One of problems that have come out of my literature review is that a lot of the evidence that design-build is better is opinion like "I worked on this project and it was better" instead of hard numbers like you can expect a 10% savings. Assuming that you decided to use design-build, what are some of the barriers or obstacles to implementing design-build?

Respondent: Institutional inertia is probably the only thing.

Gehrig: How about any legal or regulatory limitations? Would you be allowed to use design-build?

Respondent: We asked that question. Yes, we would be allowed because we specifically asked that question.

Gehrig: Is that specific to just the City and County of Denver or is it general to the State of Colorado?

Respondent: We only asked that specifically for us.

Gehrig: How about contractor qualification?

Respondent: That would be part of the evaluation for the selection of the design-build team.

Gehrig: How about project complexity? Would a project have to reach a certain complexity?

Respondent: Before we would use it, it would have to be a complex issue probably. I think the simple, straightforward things we do, we would continue to do ourselves.

Gehrig: How about incentives? Incentives from the owner's stand point and the contractor's stand point. Do think the contractors would see a benefit if they could take a more design-build approach to projects?

Respondent: That we have applied so far on our modified design-build have been a sharing of value engineering and the cost savings.

Gehrig: When I say incentive, from your perspective as you interact with the contracting community, do you have people coming in saying "if you give me more leeway on how you bid these projects I could get you a better product" or are they saying "all I want is a complete set of plans and specs and I don't want to mess with any of the design decisions"?

Respondent: Some of the contractors are only in tuned to the design-bid and there are others that talk to us about wanting to try to design-build. I thing there are some that would like to get in and do design-build and others that don't. I think there is a mixture of those types.

Gehrig: Do you think it would reduce competition, the number of bidders you would have if you went to design-bid?

Respondent: Probably in the beginning because there would only be a couple of them that would be interested in doing it or having any experience. Once you started in to that, then others would join in.

Gehrig: How about proposal evaluation? Is that something that would be a barrier to the water department?

Respondent: I don't think would be a barrier at all. You would have to have established criteria that you were rating the proposals, you would have to tell the contractors that as part of the proposal process so that they would know what you were going to evaluate them on.

Gehrig: How about contractors' cost of putting proposals together?

Respondent: I don't know.

Gehrig: Would the water department be in favor of reimbursing some of the cost?

Respondent: We talked about that but, I don't know, that's a tough one. If you were going to move in that direction and that was the delivery method that you were going to use, you would probably be strapped with that at some point of trying to reimburse the contractors. It's being done, I know that.

Gehrig: On federal design-build projects, one of the ways of getting around the cost of having whole lots of contractors submitting proposals, they short list 3 or 4 proposals they think are most acceptable and those 3 or 4 contractors bid on the final project.

Respondent: I think that's the way you do it. That's what we did on the reuse project. Started with a bigger group and then cut that down some. And then we asked 3 for real proposals.

Gehrig: What difficulties do you think you would have in pre-qualifying contractors?

Respondent: Losers never like losing.

Gehrig: Establishing and publishing the criteria you were doing the rating on and making it as objective as possible. Do you think pre-qualification is an advantage on any type of project?

Respondent: Yes.

Gehrig: What type of pre-qualification procedures do you use at the water department?

Respondent: Past experience, similar projects, experience of key personnel, and financial considerations. Whether or not they can bond for the project.

Gehrig: How do you ensure that the contractor is actually uses the key personnel? Many times, how the project runs is determined by who they put on the project.

Respondent: If it is a critical project where that is really going to matter to us, we will make that a condition for the bid. We mandate that sometimes.

Gehrig: Okay, the last part will go pretty fast. One of the inefficiencies you have with communicating with contractors on a project is exchanging all of the various types of data that are out there. So, I am just going to go down through here and see currently what and how you are exchanging information inside the office with your design personnel and with the contractor. For hardware, I assuming you have desktops and mainframes.

Respondent: Yes. Everybody has a desktop.

Gehrig: How about servers and networks?

Respondent: Yes.

Gehrig: Internal network, too?

Respondent: Yes.

Gehrig: I assume you have printers and plotters. Copies, scanners.

Respondent: Oh, yeah.

Gehrig: Fax machines, modems? Everybody have access to the internet?

Respondent: Yes.

Gehrig: Unrestricted use of the internet?

Respondent: It is basically unrestricted. We have a firewall that keeps you from going certain places.

Gehrig: Is there any other type computer hardware that you use? How about the survey equipment, is that all electronic data collecting type?

Respondent: Yeah, our survey guys are trying to do all of that.

Gehrig: How about GPS?

Respondent: We just bought a $30,000 GPS.

Gehrig: How about software applications? Word processing standard?

Respondent: We use Word.

Gehrig: Primarily MicroSoft products for spreadsheets, etc.

Respondent: Yes.

Gehrig: How about database programs?

Respondent: That's more for the IT folks downstairs and the customer service representatives.

Gehrig: How about CAD?

Respondent: We use AutoCad 2000.

Gehrig: How about GIS like ArcView?

Respondent: We use ArcView.

Gehrig: How about, again referring to pipelines in general, what type of modeling software?

Respondent: Yeah, the hydraulic modeling section has their own model, H_2O Net. There are a few other little programs like finite element analysis that the engineers use.

Gehrig: How about project management type software, like scheduling and estimating?

Respondent: You know, we have a schedule, we just hired two years ago a guy to help us with our estimating and we have, and I can't think of the name of it, but it is tied into Means.

Gehrig: So, you can look up Means databases to get the cost of various items?

Respondent: Yes. And he'll actually do estimates for us.

Gehrig: Can you input historic data from your projects?

Respondent: We are moving towards that.

Gehrig: Any other particular software that you use that you use for design?

Respondent: We use some of the HEC programs.

Gehrig: Generally, do you have email capabilities at the Water Department?

Respondent: Yes. Everybody has their own email address.

Gehrig: How about web pages.

Respondent: Each division has there own little section on the full web page.

Gehrig: Everybody is basically familiar with doing web searches and how to access information on the web? Does the water department have anybody that does web programming?

Respondent: There must be somebody that takes care of our web page but I don't know who that is.

Gehrig: Has the water department gotten into e-business type applications like where people can pay their bills by the internet?

Respondent: We're trying to get into that.

Gehrig: Does the purchasing department interact with their vendors electronically?

Respondent: They're getting involved in AWWA's efficient utility.

Gehrig: How do you currently access or transmit the following information? Hard copy, floppy disk, CD-ROM, or internet. Plans and specs, how do you transmit those to contractors?

Respondent: It is mostly hard copy but we have been sending them drawings by email. You know, that is something that has been hard for us to move into to but we have gotten contractors to sign waivers.

Gehrig: Is it the control of the design that you're concerned about?

Respondent: We don't want them to take a drawing and changing it.

Gehrig: So, it is a security issue. To make sure the design intent stays intact.

Respondent: Yes.

Gehrig: How the specifications? How do you transmit those?

Respondent: That is all hard copy.

Gehrig: Soil reports and technical reports?

Respondent: All hard copy.

Gehrig: How about bid advertisements? Where are they posted at?

Respondent: They get posted in the newspaper and we also email advertisements to anybody who wants to get them.

Gehrig: You don't have a specific site posted where the contractors can go?

Respondent: There are the Dodge Plan Rooms. I think the plan rooms post them on their websites.

Gehrig: How about addendums?

Respondent: That is all hard copy.

Gehrig: Have you ever tried to make PDF files out of them or anything?

Respondent: No. I think we're behind the curve on some of that stuff.

Gehrig: What about bid submittal packages?

Respondent: I don't think we have received a CD yet. Most of the time it's just hard copy. I don't think we would object to someone sending us a CD with submittals on it.

Gehrig: How about change orders, etc.?

Respondent: All hard copy and via email.

Gehrig: How about the construction offices? Do they have computers out there with internet connections?

Respondent: Yep. But that is probably more applicable to our bigger projects. Pipeline projects you may not have a field office.

Gehrig: Does the contractor still have to submit his invoice by hard copy.

Respondent: Yes.

Gehrig: You don't pay the contractor electronically either do you?

Respondent: No. We still give them a check.

Gehrig: There are some agencies that are going to completely electronic bid submittals. Do you see any advantages or disadvantages in getting some system like that?

Respondent: I suppose the advantage his he can sit at his desk and do all of his work.

Gehrig: Is there any advantage for an owner to go to that type of thing?

Respondent: No, I'm not sure we have ever thought of that.

Gehrig: What would be some of concerns or disadvantages of going to a system like that?

Respondent: Access to the network or something happen so that the contractor couldn't access it at the right time.

Gehrig: Do you allow a contractor to withdraw a bid before they are open?

Respondent: Before they are open? Yes.

Gehrig: Some contractors have said that that would be a concern. Getting access to their bids after they have been submitted. Well, that about it. Any other comments you would like to make?

Respondent: That sounds like a lot of good information. You are going to find lots of different answers.