NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 391

Constructibility Review Process for Transportation Facilities

Workbook

Transportation Research Board
National Research Council

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Report 391

Constructibility Review Process for Transportation Facilities *Workbook*

STUART D. ANDERSON
Texas Transportation Institute
and
DEBORAH J. FISHER
University of New Mexico

on behalf of
Texas Transportation Institute
The Texas A&M University System
College Station, TX

Subject Areas

Planning and Administration
Highway and Facility Design
Bridges, Other Structures, Hydraulics, and Hydrology
Soils, Geology, and Foundations
Materials and Construction
Highway Operations, Capacity, and Traffic Control

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Staff
Transportation Research Board

This workbook supports the development of a process for assessing and improving highway-construction-project contract documents to ensure rational bids and to minimize problems during construction. The contents of this workbook are, therefore, of immediate interest not only to highway planners, facility designers, and construction personnel, but also to state and local government management and policy makers, consulting engineering firms, and highway construction contractors, all of whom can play a role in the process. The workbook amplifies the steps in the process described in *NCHRP Report 390*, "Constructibility Review Process for Transportation Facilities"; specifically the functions, steps, actions, and tools essential to conduct a formal, comprehensive project-level Constructibility Review Process (CRP).

Constructibility can be defined as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. Constructibility review practices should be made an integral part of the project development processes. This integration can be ensured through formalization of constructibility review practices. Formalization will ensure that resources are available, the right expertise is involved, reviews are performed in a timely manner, and constructibility knowledge and experience are captured properly for easy retrieval later.

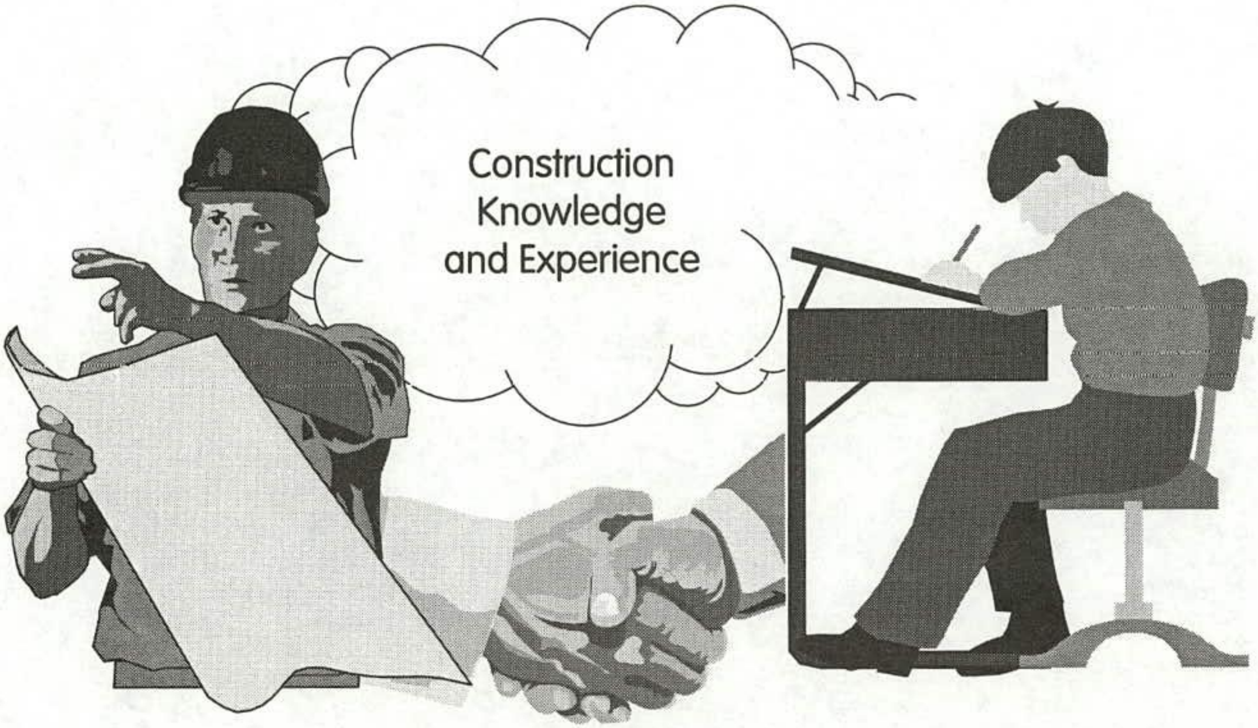
The CRP is presented in a generic format in the workbook. Consequently, the CRP can be tailored to meet the characteristics of different project types and agency-level approaches.

The workbook contains two sections. Section I, Overview, addresses the following issues: WHY formalize the Constructibility Review Processes?; WHAT is a Constructibility Review Process?; and HOW is the Constructibility Review Process implemented? The WHY focuses on benefits such as paybacks from constructibility reviews. The WHAT summarizes key elements of the process, identifying constructibility functions, steps, and review tools available for implementation. The HOW provides guidance on strategies to begin project-level implementation of constructibility reviews. Section I is primarily for agency executive management, but provides an excellent overview for practitioners as well.

Section II contains Implementation Guidelines that provide an easy to understand format on how to implement the CRP by using real project examples. These guidelines correspond to the planning, design, and construction phases of project development. Each phase has constructibility objectives that are achieved through constructibility functions, steps, and actions. These functions are performed using a variety of review tools such as constructibility idea/lessons learned-logs and suggestion forms. Additional information contained in the guidelines include tool application hints, key issues affecting constructibility, and helpful implementation tips. Two project case study applications are used throughout Section II to show how the user can apply the process on real projects.

The workbook also contains three appendices. Appendix A provides a glossary of terms. Appendix B contains an overview of the review tools used in the workbook plus review tools that might be used in the future to enhance the CRP. Appendix C provides schematic plans for each case study project.

Other case studies, contained in Appendix C of the companion *NCHRP Report 390*, show that in a selection of projects that underwent the Arizona DOT constructibility process, the cost of the review effort resulted in a benefit to cost ratio of 25 to 1.



Constructibility Review Process for Transportation Facilities

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PREFACE

Transportation agencies recognize the need for contract documents that will ensure rational bids and minimize problems during construction of facilities. A significant aspect of developing high-quality contract documents is to incorporate a review process in the planning and design phases to assess a project's constructibility. This process must include input from professionals involved in the planning, design, construction, operation, and maintenance of transportation facilities. Constructibility reviews have the potential to minimize the number and magnitude of changes, disputes, cost overruns, and delays during construction. In fact, this research found that *constructibility reviews can return $10 to $25 in project savings for every dollar spent on such reviews.*

This workbook provides a process for constructibility reviews that can be applied by transportation agencies. The process consists of elements subdivided into increasing levels of detail. Specifically, functions, steps, actions, and tools essential to conduct a formal, comprehensive project-level Constructibility Review Process (CRP) are presented. Using information from the project development process, the CRP provides constructibility improvements that can be incorporated into planning and design documents. The CRP is generic in format and can be tailored to meet characteristics of different project types and agency-level approaches.

This workbook, a product of NCHRP Project 10-42, *Constructibility Review Process for Transportation Facilities*, was developed through research conducted by the Texas Transportation Institute and the University of New Mexico. Practical input was solicited from experienced industry professionals through questionnaire surveys, interviews, and case histories. The Research Advisory Team, with members from state agencies, transportation design and construction firms, FHWA, and consultants familiar with constructibility principles, provided feedback and guidance during the research process. This team collectively represents many years of practical experience in the design/construction of transportation facilities.

The workbook contains two sections. *Section I*, Overview, addresses the following issues: WHY formalize the Constructibility Review Process?; WHAT is a CRP?; and HOW is the CRP implemented? The WHY focuses on benefits such as paybacks from constructibility reviews. The WHAT summarizes key elements of the process, identifying constructibility functions, steps, and review tools available for implementation. The HOW provides guidance on strategies to begin project-level implementation of constructibility reviews. *Section I is primarily for Agency Executive Management. Project users can also benefit from reviewing this overview.*

Section II contains Implementation Guidelines that provide an easy to understand format on how to implement the CRP by using real project examples. These guidelines correspond to the planning, design, and construction phases of project development. Each phase has constructibility objectives that are achieved through constructibility functions, steps, and actions. These functions are performed using a variety of review tools such as constructibility idea logs and suggestion forms. Additional information contained in the guidelines include tool application hints, key issues affecting constructibility, and helpful implementation tips. Two project case study applications are used throughout Section II to show how the user can actually apply the process on real projects. *Section II is primarily for use by project teams.*

The workbook also contains three appendices. *Appendix A* provides a glossary of terms. *Appendix B* contains an overview of the review tools used in the workbook plus review tools that might be used in the future to enhance the CRP. *Appendix C* provides schematic plans for each case study project.

The workbook has been designed to have stand-alone sections. Section I provides agency executive management with a brief but comprehensive overview of the process. Section II provides application details for project users. Thus, it can be studied and used in a number of different ways, depending on the reader's perspective and position within an agency or project. Several example approaches are:

- **Senior Policy Maker** — Read the *Overview, Section I,* for a summary of the CRP; skim the *Implementation Guidelines, Section II;*
- **District Design Engineer** — Review the *Overview, Section I,* to understand the CRP and how the CRP can be implemented on projects; study the appropriate *Implementation Guidelines, Section II,* to determine your specific project application, such as applying the CRP during the design phase; and
- **Project Team User** — Skim the *Overview, Section I,* for a summary of the CRP; study the *Implementation Guidelines, Section II,* in detail for those project areas where the guidelines will be implemented. This should also include *Appendix B.1, Workbook Review Tools.*

The CRP presented in this workbook is designed to provide guidelines for implementing constructibility reviews. These guidelines do not provide all the answers. Each agency must adapt them to fit its approach to project development and its organization structure and culture. Innovation and creativity should be used to implement constructibility successfully, commencing with pilot projects and evolving to full agency-level practice. The results will be an improved project development process leading to reduced costs, fewer changes and delays, and increased schedule and quality performance.

The Research Advisory Team is comprised of a unique blend of industry practitioners and academics. This team approach has provided assurance of the practicality and user-friendly nature of the workbook. The NCHRP Project 10-42 Panel also has been instrumental in providing timely insights and direction as the workbook was developed. The following professionals were involved:

Mr. Hugh Thomas, *Chief, Claims Resolution Branch, Caltrans*
Mr. Lauren Garduno, *District Maintenance Engineer,*
Abilene District, Texas Department of Transportation
Mr. Jay Steele, *Construction Engineer, Caltrans*
Mr. L.J. Vinick, *Engineering Manager, Highway and Bridges, Brown & Root, Inc.*
Mr. Travis Cannon, *Vice President, Heavy/Highway Division, H.B. Zachry Co.*
Mr. Roy Mendelsohn, *Manager, Special Projects, Parsons Brinckerhoff Co.*
Mr. Jim Wentworth, *Chief, Advanced Research Team,*
Federal Highway Administration
Ms. Clarisse Molad, *Vice President, Data Exchange Technology, Black & Veatch*
Mr. Dick Wright, *Deputy State Engineer, Arizona Department of Transportation*
Dr. Jeffrey S. Russell, *Associate Professor, University of Wisconsin*

The Research Team would like to express its appreciation for the time and effort of this group of professionals in the development and preparation of the workbook.

Section I

Overview

PART I — WHY FORMALIZE THE CONSTRUCTIBILITY REVIEW PROCESS?

Introduction

The National Quality Initiative (NQI) has focused State Transportation Agencies (STAs) on improving their Project Development Process (PDP) to enhance project performance and increase customer satisfaction. A major NQI effort to achieve these results is the effective *implementation of constructibility*. Some states, such as New Mexico and Kentucky, have included constructibility as a key quality improvement initiative.

Based on this research, constructibility is a milestone-driven and largely informal process as practiced by STAs. Data indicate that constructibility is given minimal attention during project planning and feasibility analysis. It is more often considered informally during design reviews. This milestone-driven process is a less than optimum approach to implementing sound constructibility practices. Construction expertise is frequently not accessed during the planning and design processes, and construction resources are invited only to "review" the design for constructibility at certain points during the design process. Agencies seem to rely heavily on the construction expertise of design personnel, who are well versed in such technical issues as design standards and codes, but who lack expertise in field construction methods and techniques. This approach limits the effective use of construction knowledge and experience during the planning stage and early in the design stage, when the ability to influence cost through changes in project plans and designs can have maximum effect. This concept is illustrated in Figure 1.

This milestone-driven process is a less than optimum approach to implementing sound constructibility practices.

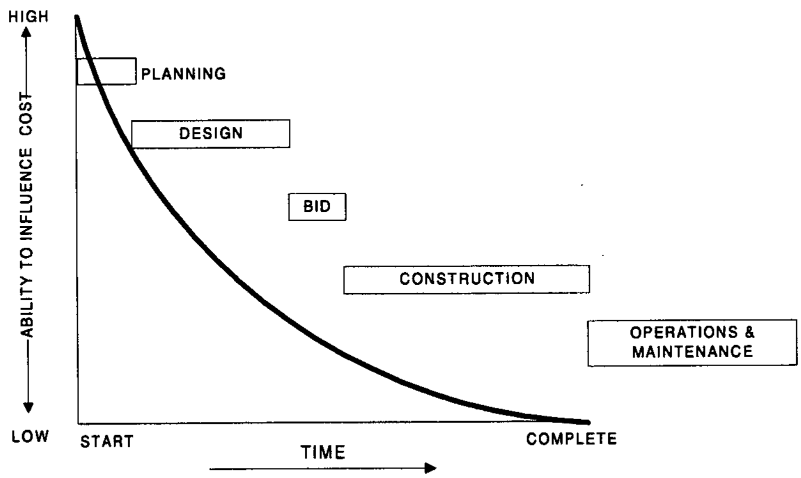

Figure 1
Ability to Influence Project Cost
Adapted from CII Publication 34-2, 1993

This research shows, more specifically, that 77 percent of STAs practice constructibility informally. Only 23 percent of state agencies have formal, documented constructibility programs. The level of formality of these programs varies. Several programs are somewhat formal, as they incorporate constructibility concepts suggested in the literature such as specifying constructibility objectives, forming a constructibility team, determining the level of formality, and mechanisms to obtain constructibility input. Less formal programs incorporate constructibility into design through standard design procedures. These less formal programs often use checklists, with input obtained only at definite points in the design process where reviews take place. While interest in formalizing constructibility reviews is growing, even most formal constructibility programs appear to lack distinct *functions* or *steps* that lead project personnel through the implementation process. Formalization of the Constructibility Review Process (CRP) must tap the right expertise and information when and where needed to achieve maximum benefits.

Only 23 percent of state agencies have formal, documented constructibility programs. ...even most formal constructibility programs appear to lack distinct functions or steps that lead project personnel through the implementation process.

Constructibility: What Is It?

Broadly defined, the concept of constructibility is the integration of construction knowledge and experience into the planning, design, and construction phases of a project. In this context, construction knowledge and experience is a resource that should be accessed and applied as concept plans and designs are developed. During the construction phase, construction knowledge and experience should be documented to facilitate future application of constructibility.

A critical focus of constructibility is to look for and apply construction knowledge and experience, and to store this information in an appropriate format for easy retrieval. Accomplishing this will improve outputs of the planning and design processes and facilitate ease and efficiency of construction. Ultimately, construction knowledge and experience, when properly directed through an improved PDP, can contribute to reduced costs, shortened schedules, improved project quality and safety, enhanced management of risk, and increased customer satisfaction.

Constructibility is a proactive mechanism to improve the project development process. Agencies implementing constructibility must change the conventional approach to project execution by focusing more on front-end planning and by investing additional resources to ensure potential construction problems are addressed early. The importance of early involvement of construction expertise cannot be overemphasized. The dedicated efforts of experienced construction people who have a thorough understanding of how a project is planned, designed, and built are critical to any constructibility effort. There is generally a missing link between design engineers and builders. For example, problems in concrete structures occur most often because of attempts to design slimmer columns. Although satisfying the ACI code, these designs reduce the space for placing concrete and can also create problems in obtaining good vibration. Also, the traditional and required design-bid-build contracting process makes bridging this missing link between design and construction a challenge.

A critical focus of constructibility is to look for and apply construction knowledge and experience and store this information in an appropriate format for easy retrieval.

Constructibility practices should be made an integral part of the project development process. This integration can be ensured through formalization of constructibility practices. Formalization would ensure that resources are available, the right expertise is involved, reviews are performed in a timely manner, and constructibility knowledge and experience are captured properly for easy retrieval later.

Constructibility: What Is the Payback?

Implementation of constructibility requires up-front allocation of scarce resources — time, money, and people. Strong evidence indicates, however, that constructibility pays for itself by reducing project cost. Prior research indicates that, when methodically implemented, front-end constructibility efforts are investments that result in substantial return. For example, owners in the industrial construction sector experienced an average reduction in total project cost and schedule of 4.3 percent and 7.5 percent, respectively. Also, a 10 to 1 return on owners' investment in constructibility was found. These savings are conservative in that they represent only formally documented savings agreed upon between owners, designers, and contractors.

In 1992, the Arizona DOT (ADOT) established a Constructibility Engineer position. This person has an extensive background both in transportation design and construction. Plans and specifications are reviewed by this person to determine possible improvements from a constructibility perspective. Data from these reviews indicate that constructibility efforts applied to transportation projects offer very attractive benefits. For six projects, selected from thirty-five reviewed for constructibility, the savings achieved as a result of constructibility improvements amounted to 1.7 percent of the total cost of the six projects (about $68 million). This percent savings translated to $1.2 million. The cost of the review effort was such that the benefit to cost ratio was 25 to 1. Thus, for every dollar spent reviewing these ADOT projects for constructibility, $25 was returned in project savings.

ADOT projects reviewed ranged from slide repairs and rural intersection improvements to construction phasing for major highway interchanges. Recommended improvements included alteration of the location of access and haul roads to alternate phasing of ramp construction and traffic detours. These constructibility reviews were typically performed by a single individual late in the design process. This limited the scope of the changes and benefits derived. With a more thorough review earlier in the design process, the benefits may have been even greater.

Thus, for every dollar spent reviewing these ADOT projects for constructibility, $25 was returned in project savings.

Other research identified additional benefits of constructibility. Engineers, through constructibility review programs, can be trained more quickly, thus providing better decision support data and knowledge. Also, the probability of successful project schedule performance increases substantially with a formal constructibility program. Implementation of a constructibility program seems to have a significant impact on achieving overall project success as well as schedule performance — especially on fixed-price contracts. The intangible benefits should also be recognized. These benefits include higher productivity, better schedules and sequence of construction, enhanced quality, lower maintenance, safer jobs, and more safety and convenience for the traveling public.

Successful Constructibility Implementation: What New Paradigms Are Needed?

Implementation of a successful constructibility process cannot take place all at once because it requires incorporation of new ideas into existing project management approaches. Before accepting such changes, however, an agency should conduct a self-assessment of current in-house constructibility capabilities and practices. Such an assessment will help the agency identify constructibility program objectives, current and future program benefits, areas of program improvements, and barriers to implementation.

A properly conducted comprehensive self-assessment may indicate that paradigm shifts are needed in the way transportation agencies conceive, execute, and follow up on projects. These paradigm shifts, required at both agency and project levels, are essential in order to properly address the critical issues of constructibility implementation, identified by this research and summarized in Table 1.

Table 1
Critical Constructibility Implementation Issues

Issue Category / Group Perspective	Project Execution Process	Project Planning & Technical Design Documents	Project Resources
Owner	Lack of • Feedback to designers • Timely input from district construction people • Input from construction contractor in the review process • Maintenance and operations inputs • Communications	Lack of • Traffic control • Consideration of geotechnical issues • Consideration of environmental factors • Safety • Balancing with other social, economic factors And • Need to improve plans and specifications	Lack of • Adequate time to review • Practical construction experience of design personnel • Cost considerations • Personnel • An accessible database
Designer	Lack of • Adequate coordination of designs, plans & specifications • Quality communications and feedback • Early review of designs • Contractor input • Interaction with DOT	Lack of • Coordinated timing, phasing and scheduling • Traffic control • Commitment to quality work • Environmental concerns • Site access • Use of standard methods	Lack of • Experience and knowledge • Adequate time and funds for constructibility • Availability of materials and skills
Contractor	Lack of • Communications and feedback • Design review • Interaction with DOT And • Need to remain competitive	Lack of • Clear designs, plans & specifications • Quality scheduling and phasing of construction • Construction operations and safety considerations • Traffic control • Sufficient use of standard designs and methods • Environmental concerns • Site access	Lack of • Experience and knowledge • Availability of materials and equipment • Time and commitment for constructibility

Many barriers to effective constructibility implementation are evident in the critical issues described in Table 1. These barriers frequently occur at both the agency and project levels. Relevant research identifies four basic categories of barriers:

Cultural Barriers — caused by ingrained paradigms (i.e., agency tradition, inflexible attitudes, etc.);
Procedural Barriers — resulting from established practices deemed "set in stone";
Awareness Barriers — caused by a lack of understanding of the goals, concepts, methods, and benefits of constructibility; and
Incentive Barriers — arising from the absence of motivation for constructibility implementation.

Seven common barriers specific to constructibility implementation were also identified:

- Complacency with the status quo.
- Reluctance to invest additional money and effort in early project stages.
- Limitations of lump-sum competitive (*agency*) contracting.
- Lack of construction experience in (*agency*) design organization.
- (*Agency*) designer's perception that "We Do It."
- Lack of mutual respect between (*agency*) designers and constructors.
- Construction input is requested too late to be of value.

These critical issues and barriers point to certain required paradigm shifts. Since most critical issues are related to the project level, a project focus on paradigm shifts is obviously essential.

Project-Level Paradigm Shifts Needed

- Formalize project constructibility processes to include planning, design, and construction.
- Implement use of constructibility review tools.
- Use team approach.
- Enhance plans, specifications and contract documents for constructibility.
- Provide feedback to designers on construction performance of design.
- Collect feedback from maintenance and operations personnel.

Paradigm shifts at the project level are possible but not sustainable if the same does not also occur at the agency level.

Agency-Level Paradigm Shifts Needed

- Establish an agency constructibility policy.
- Allow for alternate contracting strategies.
- Use a constructibility consultant/engineer/coordinator.
- Develop and implement a constructibility lessons learned database.

Successful Constructibility Implementation: What Is Essential?

Support from senior management adequately versed in the basics of constructibility is essential. A second ingredient for success is a process that will provide the necessary framework and tools to facilitate constructibility implementation.

Senior Management Commitment

Paradigm shifts for successful constructibility must start with the initiative of senior agency policy makers. Without their support, constructibility awareness can never be part of the agency culture, let alone be implemented at a project level. Senior management must take an active interest in the implementation of constructibility: create necessary policies, help set objectives, make required resources available to projects, and champion the cause of constructibility with those parties involved in a project such as agency personnel, consultants, contractors, subcontractors, and material suppliers.

Senior management must take active interest in the implementation of constructibility... and champion the cause of constructibility... test the effectiveness of the process on pilot projects.

Implementation of constructibility requires an up-front investment of money and time that in the long term will reduce the cost of construction, operation, and maintenance. This is difficult, given that resources are scarce, especially within state agencies. Such resources will only be available at the directive and support of senior management.

Before agency-wide implementation of the CRP can take place, it is desirable to test the effectiveness of the process on *pilot projects*. Senior management must support such pilot projects, allocating the necessary resources, assessing the risks, and following up on implementation effectiveness.

A Process Approach to Constructibility

In the spirit of the NQI, a process approach to implementing constructibility at the project level is presented in this workbook. This approach consists of describing the process in smaller and smaller pieces, ultimately focusing on the functions, steps, and tools essential to conduct a comprehensive project-level Constructibility Review Process (CRP). At this level, the CRP acts on outputs from the Project Development Process (PDP) to provide constructibility improvements to be incorporated into planning and design documents.

PART II — WHAT IS THE CONSTRUCTIBILITY REVIEW PROCESS?

Introduction

Projects are developed through a process described as the Project Development Process. The PDP is initiated when a transportation need is identified. This process is completed once the need is satisfied through an operating facility. As project scope is sufficiently defined, a Constructibility Review Process can be applied to integrate construction knowledge and experience into the PDP.

As shown in Figure 2, integration of construction knowledge and experience into the PDP necessitates an iterative, recursive exchange of information between the PDP and the CRP. Project information from the PDP flows to the CRP, which then takes this information, acts on it, and returns suggested improvements for incorporation into planning and design.

Project Development Process: What Is the Framework?

The PDP typically consists of three main phases:

1. Planning
2. Design
3. Construction

Each phase can be described in different levels of detail. Figure 3 delineates the PDP hierarchy by phases (AxP), subphases (AxxP), and detailed project activities. Activities shown are considered generic and typical of many PDPs used by State Transportation Agencies (STAs). The framework shown in Figure 3 is intended to orient users to the type of project development activities occurring during planning, design, and construction of a facility. Each STA will have its own unique description and terminology of PDP activities that serve the mission and objectives of its agency.

Constructibility Review Process: What Is the Framework?

The CRP is applied during the planning, design, and construction phases of a project. Similar to the PDP, the CRP is divided into increasing levels of detailed constructibility functions as illustrated in Figure 4. The first two levels of the CRP framework (Ax and Axx) mirror the PDP phases and subphases. The third level (Axxx) represents the proposed individual constructibility functions that are performed during project development. This level is where activities occur in order to integrate construction knowledge and experiences into the PDP. Figure 4 also illustrates the structure of Section II, Implementation Guidelines, which includes parts A0, A1, A2 and A3, and accompanying figures.

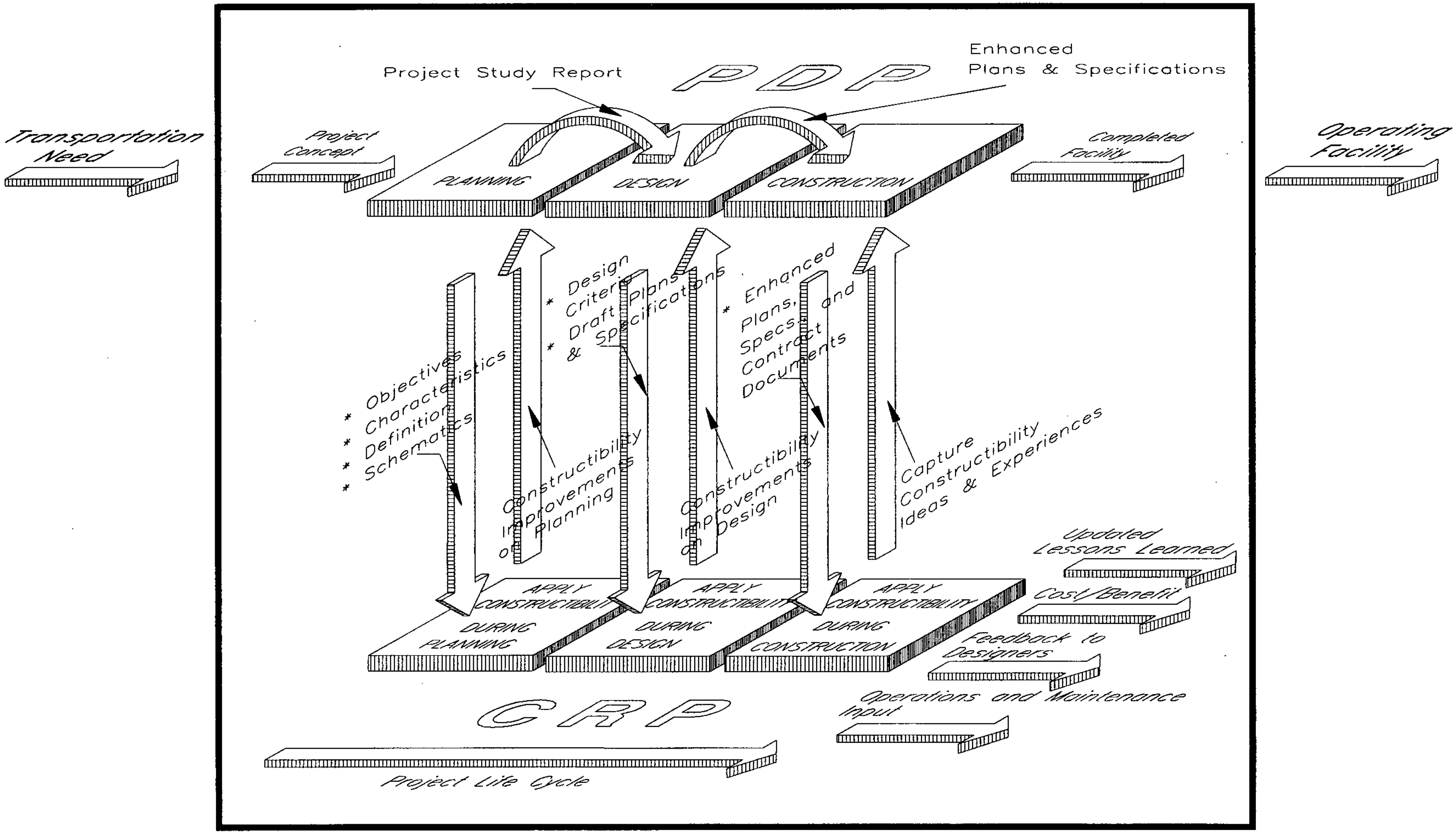

FIGURE 2
Integration of the Constructibility Review Process with the Project Development Process

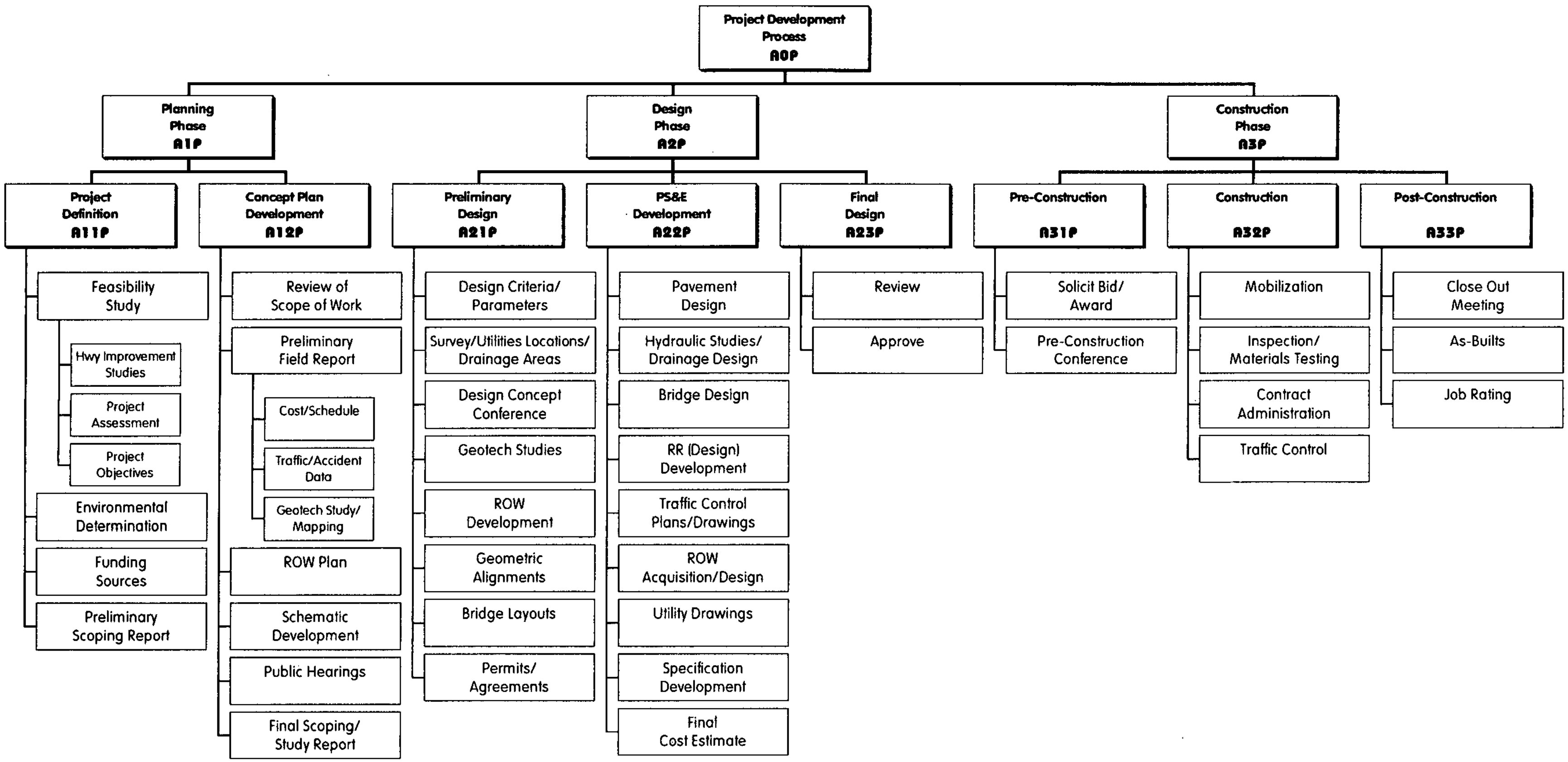

FIGURE 3
The PDP Framework

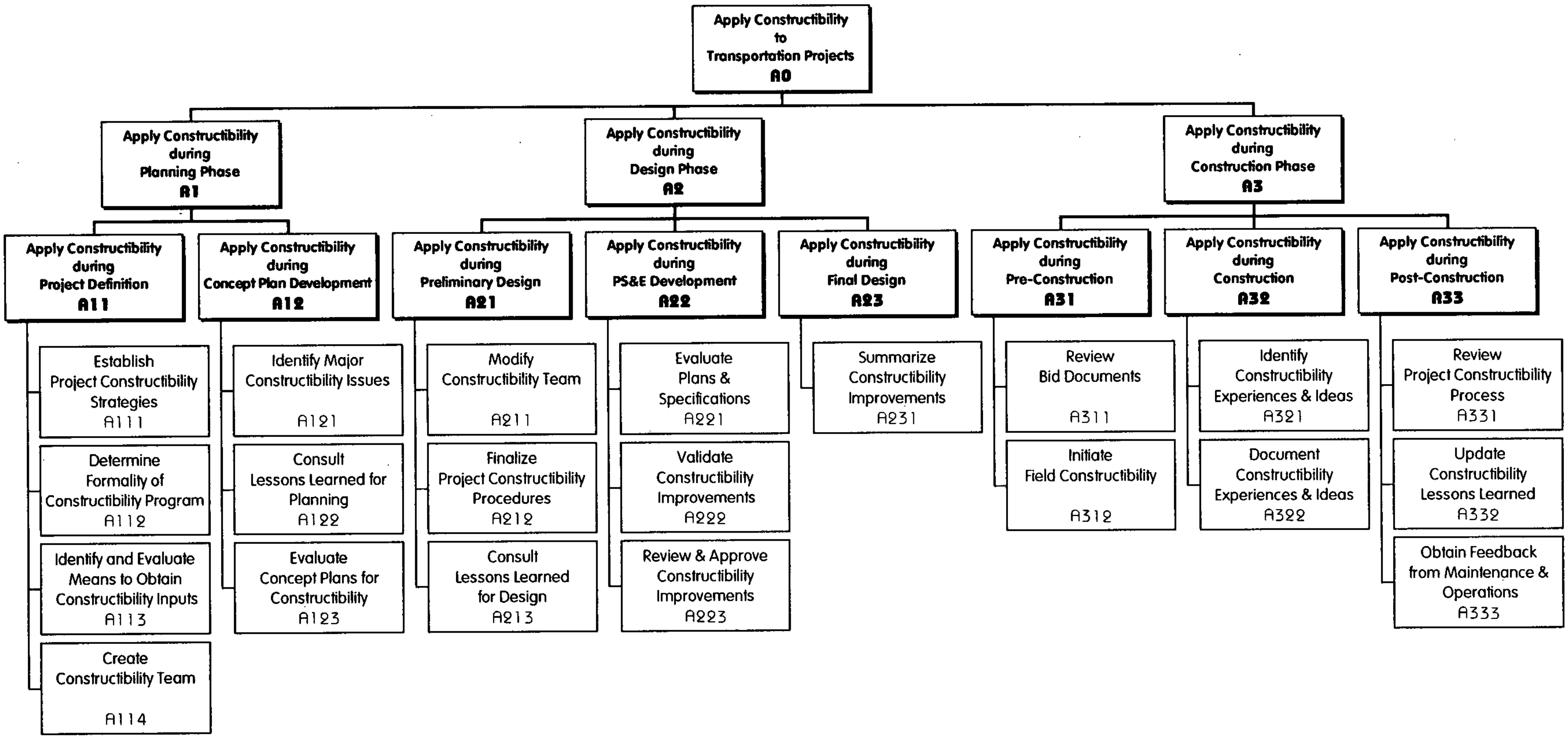

FIGURE 4
The CRP Framework

Project Development and Constructibility Review Processes: How Are They Integrated?

Each set of constructibility functions has specific objectives. To achieve these objectives, inputs from the PDP and from a preceding set of constructibility functions are essential. In the same manner, outputs from performing each set of constructibility functions return information to the PDP and to the next set of constructibility functions. This cyclic process between the CRP and the PDP continues as long as the project proceeds through each phase.

Figure 5a illustrates schematically the exchange of information between the PDP and the CRP during project definition. Figure 5b shows how specific project information, such as project objectives, characteristics, and scope definition, is transformed when performing four constructibility functions (A111 through A114) to form the components of a *project constructibility plan.* This plan is incorporated into the *Preliminary Scoping Report.*

Figure 6a presents the concept plan development phase of project planning. During this subphase, constructibility is initiated when project information, such as a Preliminary Scoping Report, is available as delineated in Figure 5b. A *Constructibility Team,* formed during project definition, performs each constructibility function shown in Figure 6b. As the project develops, new project information, such as schematic drawings, ROW plans, and field data, is analyzed from a constructibility perspective. Constructibility improvements are suggested and returned for incorporation into concept plans. This cyclic concept plan development process is repeated until a *Final Scoping Report* is completed.

The exchange of information between the PDP and CRP is continued in a similar manner during both the design and construction phases. The information generated during these two phases changes and evolves.

Project Development and Constructibility Review Processes: What Is the Timing?

A project develops through answering a series of questions over time. During a project phase, information exchange is initiated through PDP activities and then is followed by specific applications of constructibility functions. This exchange of information between the PDP and CRP is cyclic and occurs throughout each project phase. This phase-time relationship is illustrated schematically in Figure 7, which also identifies *milestones* critical to the project development phase. These milestones delineate transition points during the project life cycle. The CRP is structured to bridge the gap between phases both to sustain the constructibility process and to provide continuity over the project's life.

Within each phase (illustrated in Figure 2), the constructibility process can be tailored to fit individual project characteristics and requirements. For example, constructibility reviews can be continuous as implied in Figure 7 during Plans, Specifications, and Estimates (PS&E) Development or they can occur at prescribed points in time. Alternatively, also shown in Figure 7, constructibility reviews can begin during Preliminary Design.

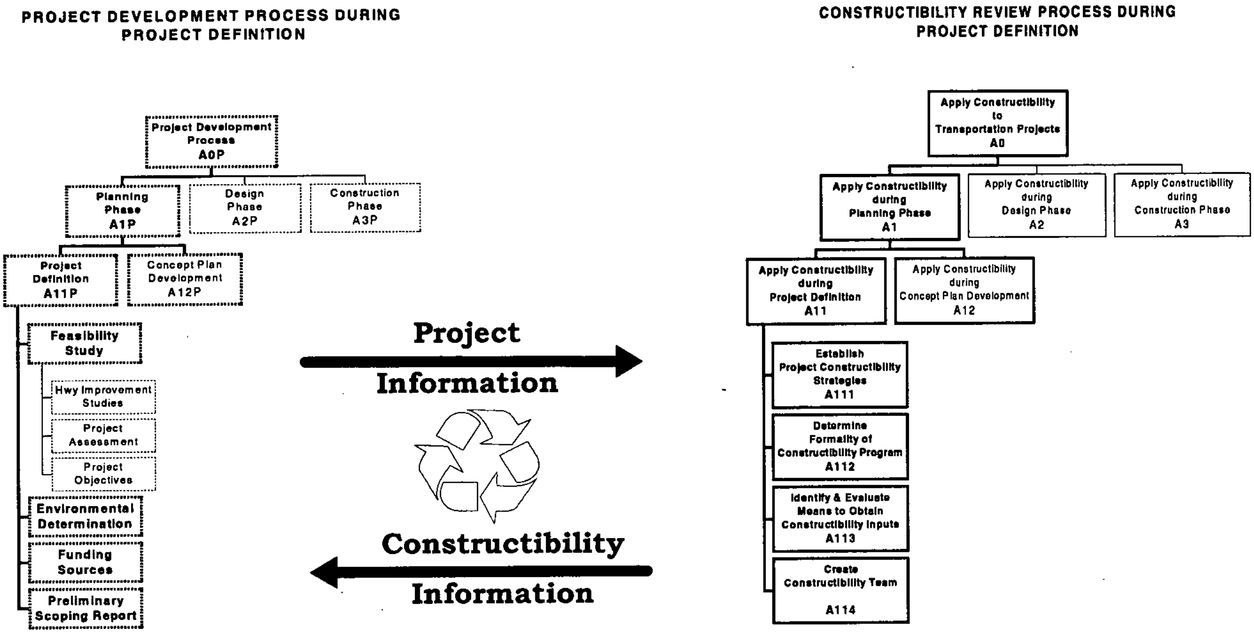

Figure 5a: Exchange of Information during Project Definition

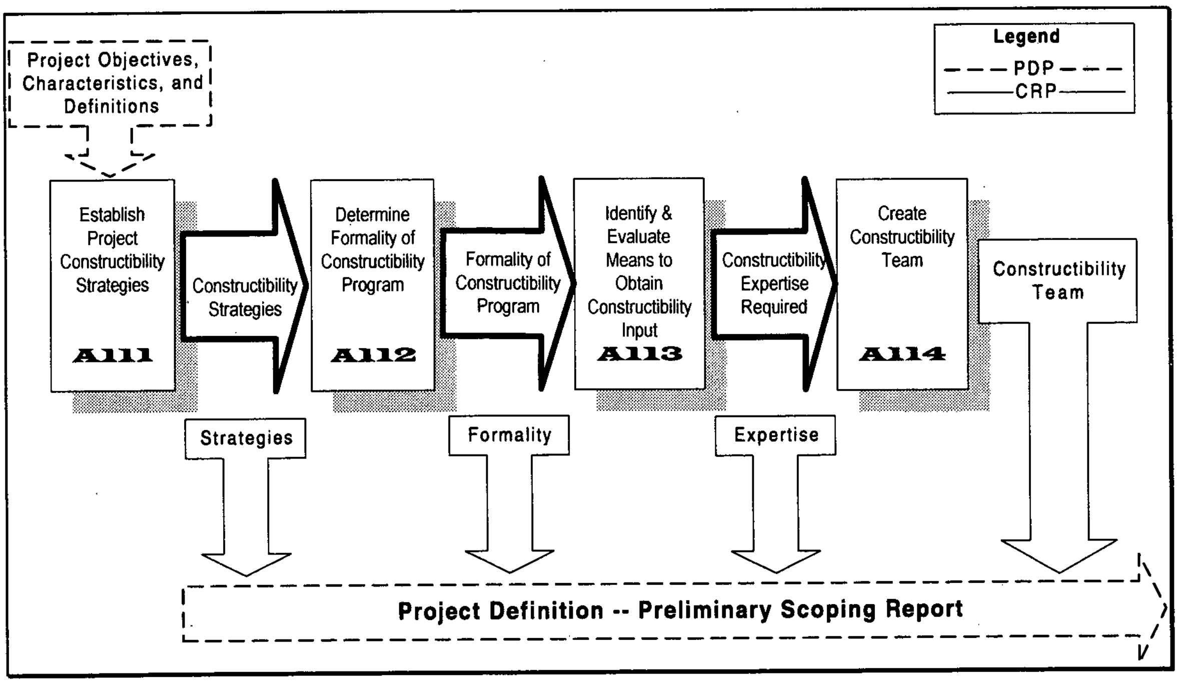

Figure 5b: CPR during Project Definition

FIGURE 5
Constructibility during Project Definition Phase

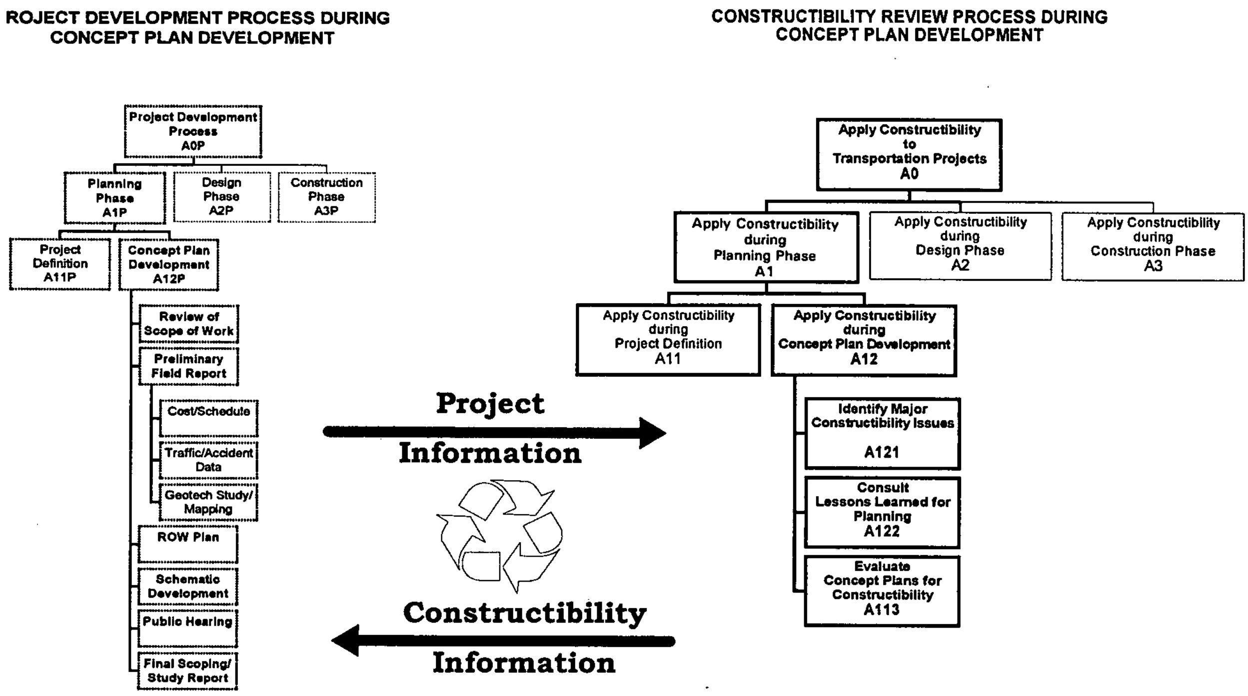

Figure 6a: Exchange of Information during Concept Plan Development

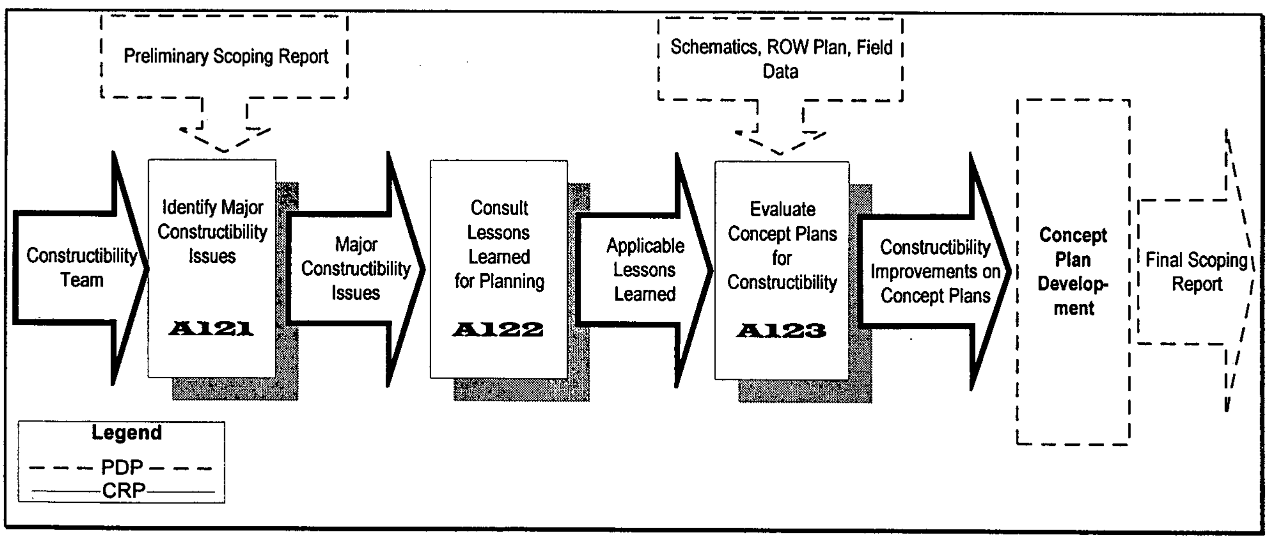

Figure 6b: CRP during Concept Plan Development

FIGURE 6

Constructibility during Concept Plan Development Phase

In cases where constructibility reviews can begin during Preliminary Design, these reviews could commence as early as at 15 percent of design time. Each STA will have to determine the appropriate level of effort for its constructibility process and the timing of the process in relation to its PDP approach.

Constructibility Review Process: A Generic Approach

The Constructibility Review Process is designed to be flexible in order to adapt to specific project characteristics and requirements. Similarly, an agency can modify the CRP to be consistent with its approach to project development, policies, and resources available.

A key driver behind the flexible nature of the CRP is project complexity. Typically, total project cost and total work-hour effort reflect a level of complexity. Also, the type of project has a relationship to complexity. Projects located in an urban setting and those involving reconstruction and/or grade separation are often more complex. Projects that involve many interfaces with other government agencies, the public, consultants, designers and contractors, may indicate a higher level of complexity. For purposes of applying the CRP, the following classification of transportation projects reflects the level of project complexity. This classification is based on extensive input from experienced construction personnel.

Standard or Smaller Projects

- Asphaltic concrete overlays
- Seal/flush coats
- Guard rail improvements
- Bridge widening less than 100 feet in length
- Intersection improvements
- Rural freeways/highways (new alignment — flat terrain)
- Rural traffic interchanges
- City street improvements (curb & gutter, resurfacing)
- Climbing lanes (without earthwork)
- Geotech projects (slope laybacks for slide repair or rock fall)
- Generally smaller projects that do not get extensive review attention

Moderate to Highly Complex or Larger Projects

- Urban freeways
- Depressed freeways
- Bridge widening greater than 100 feet in length
- Major bridges (new construction)
- Urban traffic interchanges
- Rural widening or realignment (under traffic)
- Rural freeways/highways (new alignment — mountainous terrain)
- Retaining walls greater than 15 feet in height
- City street improvements (underground pipelines)

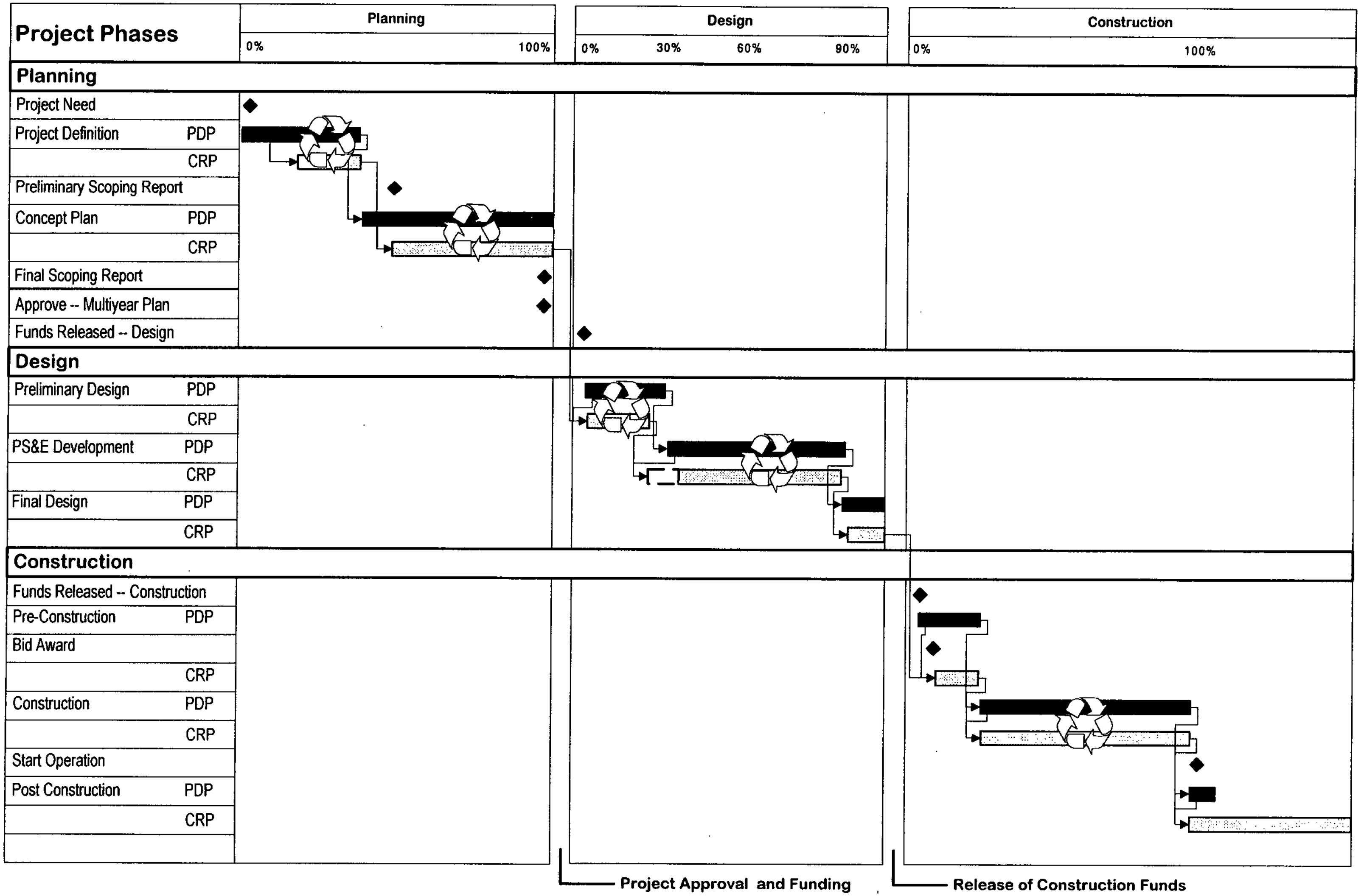

FIGURE 7
Timing of CRP with Respect to PDP

Increasingly complex projects require more formalized constructibility practices. Based on project complexity, the CRP can be classified into three levels of formality :

1. Informal
2. Semiformal
3. Formal

Table 2 shows the relationship between project complexity and corresponding formality of the CRP. Based on the level of formality, the constructibility process has different attributes. The level of formality helps determine, for example, the resources required for the CRP, frequency of reviews, availability of constructibility resources, assignment of constructibility champion, sources of constructibility information, and constructibility procedures. Thus, the CRP can be designed to fit specific project characteristics and requirements.

TABLE 2

Level of Formality of CRP

Project Complexity	**Standard/Small Projects**	**Moderate**	**High/Large Projects**
CRP Attributes	**Informal**	**Semiformal**	**Formal**
Resources	1 Person w/Ad Hoc Assistance As Needed	Multi-Discipline	Team Structure w/ Core and Ad Hoc Members
Frequency of Reviews	Periodic Milestone Reviews	Periodic Reviews w/ Scheduled Reviews at 30/60/90%	Continuous w/ Scheduled Reviews at 30/60/90%
Time/Commitment Required	10% Project Team Time in Constructibility Role	Assigned by Agency Constructibility Coordinator; Part-Time Constructibility Coordinator/Engineer	Full-Time Project Constructibility Coordinator and/or Constructibility Engineer
Leadership	Project Leader	Constructibility Champion	Constructibility Champion
Sources of Constructibility Information	File Cabinet/ Personal Experiences	File Cabinet/ PC/ Personal Experiences	Networked PC/ Databases/ Personal Experiences
Procedural Approach	CRP As Is — No Specific Project Documentation	Modified CRP to Fit Project w/Limited Project Documentation	Develop Project Specific CRP and Document Approach

Implementation Guideline Layout

This workbook is structured to follow the basic hierarchical configuration of both the PDP and the CRP described in Figures 3 and 4. The guidebook format shown in Figure 4 is divided into three parts according to the three *major phases* : **planning (A1), design (A2),** and **construction (A3)**. Each major phase is further divided into *subphases.* Thus, for example, planning (A1) is divided into two subphases: Apply Constructibility During Project Definition (A11) and Apply Constructibility During Concept Plan Development (A12).

A number of *constructibility functions* are performed during each subphase. A constructibility function is described by *steps* and *actions* supported by various *constructibility review tools* that are described in detail in Appendix B.1. Thus, for example, A12 is further divided into three constructibility functions: Identify Major Constructibility Issues (A121), Consult Lessons Learned for Planning (A122), and Evaluate Concept Plans for Constructibility (A123). The tools are divided into three categories:

T100's — used to understand/communicate constructibility
T200's — used to implement/measure constructibility
T300's — cutting edge technology/computer tools.

Descriptions of each function refer to tools to apply, a list of common issues to consider, and helpful tips. Two transportation projects, one standard and the other moderately complex, are used to illustrate the mechanisms of the CRP. The following icons are used as quick reference to these items.

Tool Applications: Describe the characteristics and the usage of tools recommended to perform individual actions for each constructibility function.

Issues to Consider: Point out the issues to be considered while performing a constructibility function. Only generic issues are given in the workbook. These issues can also serve as checklist items.

Tips: Give supplementary information on certain important constructibility tools, issues, or other topics.

Examples: Two example projects, the *Buffalo Gap Intersection* and the *Loop 322 Interchange,* illustrate how the different tools, issues to consider, and actions tie together to provide the output of performing a constructibility function.

Figures 8a, b, and c illustrate a typical constructibility function with all these components.

APPLY CONSTRUCTIBILITY DURING PROJECT DEFINITION **A114**

Create Constructibility Team

Steps		Actions	Tools
1. Assign constructibility leadership	☑	Assign an individual the responsibility to head the constructibility effort. This person must have the highest level of control over available constructibility resources and procedures. *Responsibilities of this person include recruiting other members, leading team meetings, and managing implementation of constructibility improvements.*	Constructibility Champion **(T205)**
2. Determine roles and responsibilities	☑	Assign constructibility roles and responsibilities to team members based on individual areas of expertise, experience, expected contribution, and cost to the team.	Constructibility Meetings **(T102)** Implementation Responsibility Matrix **(T111)**
	☑	Determine availability of team members so that their expertise can be sought when needed.	
	☑	Form subgroups, if necessary, with a leader assigned to each.	
3. Form constructibility team	☑	Organize the constructibility team for concept plan analysis.	Team Building **(T112)**
	☑	Initiate formal constructibility by having team members develop, agree to, and sign a formal commitment to constructibility objectives and procedures.	Project Constructibility Agreement **(T202)**

A1.15

FIGURE 8a
A Constructibility Function with Its Components

A114 CREATE CONSTRUCTIBILITY TEAM

Tool Applications

Constructibility Meetings (T102)

These meetings are critical when presenting overall project objectives. These meetings are also a key tool for conducting constructibility reviews. The agenda for each of these meetings should be predetermined yet not totally fixed. To facilitate the use of teams there needs to be periodic orientation of the team members at predetermined milestones within a project's duration.

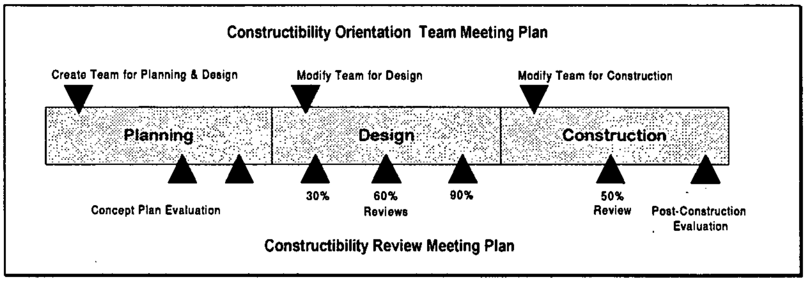

FIGURE A114.1
Typical Schedule for Constructibility Meetings during Project Development

Tips

Effective Meeting Guidelines

- Establish the **agenda** — The team leader should publish the agenda in advance.
- Establish an **issue board** for items that arise but are not on the agenda.
- Use the **plus/delta** technique to continue improving meetings — *pluses* are things that went well during the meeting and *deltas* are changes that will improve for the next meeting.
- Start **on time**.
- **Be prepared** — Bring required documents to meeting, read previous meeting minutes before meeting, and complete action items for the meeting.
- Invite the **right people** to the meeting.
- Use a **facilitator** at the meeting.
- During the meeting, appoint a **scribe,** a **timekeeper**, and a **minutes taker**.

A1.16

FIGURE 8b
A Constructibility Function with Its Components

Issues to Consider

Time Constraints

- Expected project timeframe
- Extent and duration of member commitment required

Project Complexity

- Level of expertise required of team members

Formality of Project Constructibility

- The structure and environment in which the team will operate

Key Players

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- Construction Expert (District Construction Engineer)
- City Planners, City Traffic Engineers
- Local Contractors/Associations

It is Important to:

- Select cooperative team players
- Minimize project team turnover
- Select experienced individuals

Examples

The Buffalo Gap Intersection

Due to the moderate size and simplicity of the project and lack of formality in the constructibility process, the constructibility team is formed with two persons — the Project Design Engineer, assisted by the Area Engineer. Final review will be performed by the District Engineer at 90% completion of design.

Constructibility Team Agreement is done informally because of the size of the team.

The Loop 322 Interchange

A multi-disciplinary constructibility team is chosen due to moderate complexity involved in the project.

The District Engineer is assigned champion of the constructibility team. Other team members are:

- Project Design Engineer
- District Construction Engineer (Constructibility Engineer)
- District Design Engineer
- Environmental Coordinator
- ROW Administrator
- District Maintenance Engineer
- Area Engineer/Project Engineer

This team will develop a constructibility team agreement outlining communication procedures, meetings schedule, and conflict resolution plan.

FIGURE 8c
A Constructibility Function with Its Components

PART III — HOW CAN AN AGENCY IMPLEMENT THE CONSTRUCTIBILITY REVIEW PROCESS?

Introduction

Integrating construction knowledge and experience into the PDP is a complex process. This integrating action often involves multiple disciplines in order to examine potential construction issues from different perspectives during planning and design. This workbook offers a formal CRP to assist STAs in implementing constructibility.

Implementation of the CRP should focus on small pilot projects, in a manner similar to that used in the Total Quality Management approach. Pilot projects — initiated under senior management directive — can give agencies valuable experience in applying the CRP. An agency-level constructibility program is not essential for these pilot projects; however, it is indispensable for continued implementation of the CRP.

Constructibility works best when it is simply an accepted way of doing business with self-evident benefits.

Long-term or complex bureaucracies are not needed to implement the CRP. Constructibility works best when it is simply an accepted way of doing business with self-evident benefits. Simply stated, initial implementation of constructibility requires neither hiring additional people nor creating additional departments. Implementation will require, however, awareness training of the agency personnel who will implement the CRP, beginning with senior management. This training must focus on basic objectives, methods, and concepts of constructibility. A team approach may be best for commencing a new effort, especially when considering the multi-disciplinary focus of constructibility. Several project-level strategies for implementation are recommended next. Each agency is encouraged to identify other innovative approaches to implementation.

Process Implementation on Projects

Three basic ways to implement the CRP at the project level are:

1. Start at the beginning of design on a small to moderately complex project, where design is performed in-house.
2. Start at the beginning of design on a small to moderately complex project, where design is performed by a consultant.
3. Start at project inception with planning and advance through the entire CRP on a small project, where all planning and design are performed in-house.

1. In-house design — Since most STAs perform constructibility informally during the design phase of project development, an excellent starting point is to apply a formalized constructibility process during preliminary design. The design process is well understood here so communication may be easier between project participants as far as constructibility is concerned. Although the full benefits of the CRP may not be realized, considerable cost savings can be achieved during design (a benefit to cost ratio of 25:1 — see part I). As successful implementation occurs, the CRP can eventually be integrated into the planning and construction phases of the PDP.

A moderately complex project, such as the Loop 322 project used in the guidelines, should be selected prior to start of the design phase. In the absence of a project constructibility plan formulated in the planning phase, one must be developed early in the design phase. As shown in Figure 9, this plan would entail both formation of a constructibility team and determination of project specific constructibility procedures. At this time, some additional effort is required to determine constructibility strategies, level of formality, and resources required. Decisions are made on frequency and timing of reviews, level of documentation desired, and roles and responsibilities of the constructibility team. Documentation of constructibility improvements should occur as the remaining constructibility functions of the CRP are applied during project design. This will help track results of the constructibility effort and provide input for future projects.

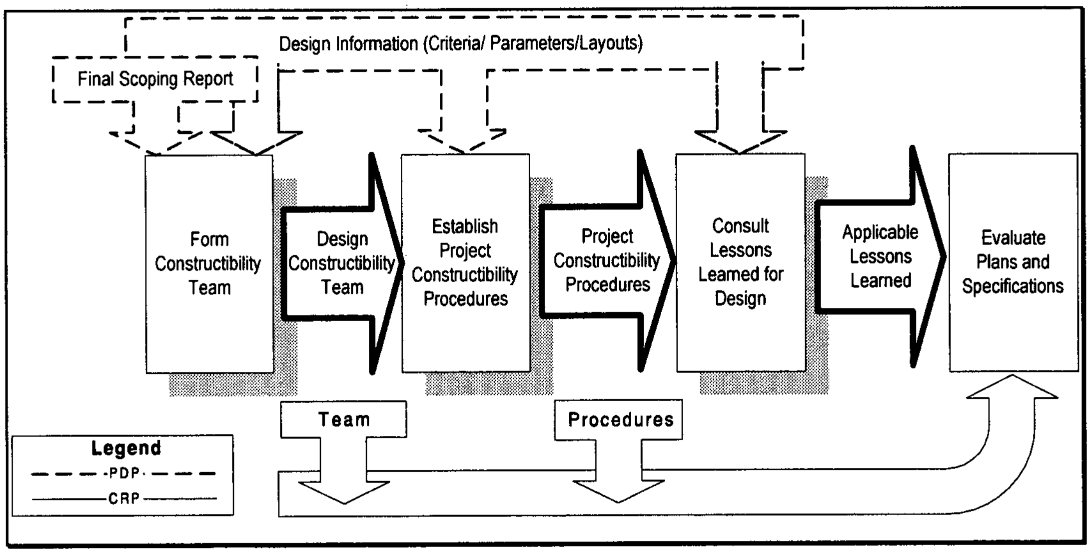

Figure 9
Implementation of the CRP during the Design Phase

2. Outsourced design — Another alternative for implementing the CRP is to start in the design phase of a project that is being designed by a consultant. Agency and consultant personnel would have to participate actively in the constructibility process. A project constructibility coordinator would be needed. This coordination effort could be outsourced to a construction management firm or supplied from within an agency.

Contract language may be required to ensure the application of the CRP during design. Additionally, clear specifications would be essential to determine the role and responsibility of the consulting organization, including the interface with the agency constructibility coordinator. Partnering may be a technique that would help develop a team approach to constructibility. The agency must accept the upfront planning effort and cost for implementing the CRP. It is recommended that results be documented and constructibility improvements generated to support future applications of the CRP.

3. In-house planning and design for small projects — A third approach to project implementation is to start with a small project using the full CRP. The process begins during planning and continues through to the end of construction. Planning and design should be performed in-house in order to obtain the full learning benefits of using the CRP. The project selected should be a standard project, similar to the *Buffalo Gap Intersection* project (see Section II), with minimum discontinuity between the planning and design phases. The process need not be highly formal and would require only a few key participants. All recommended constructibility functions outlined in the workbook should be performed. The CRP itself should be tracked to assess overall results. Documentation of constructibility improvements should be compiled during each project phase. As experiences are gained with constructibility, the CRP can then be applied over time to more complex projects.

Lessons Learned Implementation Strategies

The CRP is based on access to construction knowledge and experience which are primarily obtained through the experience of individuals. Another source may be those experiences captured on previous projects. Unfortunately, lessons learned are rarely documented for future use. Application of lessons learned in conjunction with constructibility analysis is a key concept leading to effective implementation. Lessons learned represent an organized collection of design and construction experiences, both successful and unsuccessful, gained from past projects.

A mechanism for collecting, storing, and retrieving lessons learned must be implemented by STAs to gain the full benefits from formalizing the CRP. Constructibility knowledge and experiences are accumulated in a lessons learned database. The process of building such a database takes time and effort. Senior agency management must be committed to establishing this database.

The CRP is structured to document constructibility improvements as they are identified. Functions are also included to capture knowledge and experience during construction. It is possible to start collecting constructibility improvements at various times in design, such as during 30%, 60%, and 90% design review sessions. The ultimate goal, however, should be continuous collection of constructibility improvements and ideas that could be used on future projects as depicted in Figure 10. With time, the agency will be able to build, expand, and use the lessons learned generated from the CRP, provided an agency-level database structure is established. Agency-level strategies for forming a lessons learned database are provided in the final report.

...start collecting constructibility improvements at various times in design, such as during 30%, 60%, and 90% design review sessions. The ultimate goal, however, should be continuous collection of constructibility improvements and ideas...

One readily available source of lessons learned data is a multimedia CD-ROM constructibility system developed at Purdue University for the Indiana DOT. This system incorporates a database of lessons learned. These lessons learned are accessed through different types of multimedia applications such as text, drawings, and videos. This system provides an easy way to access lessons learned during the design phase. It can be expanded for use during the planning phase. This system is described in more detail in Appendix B.1.

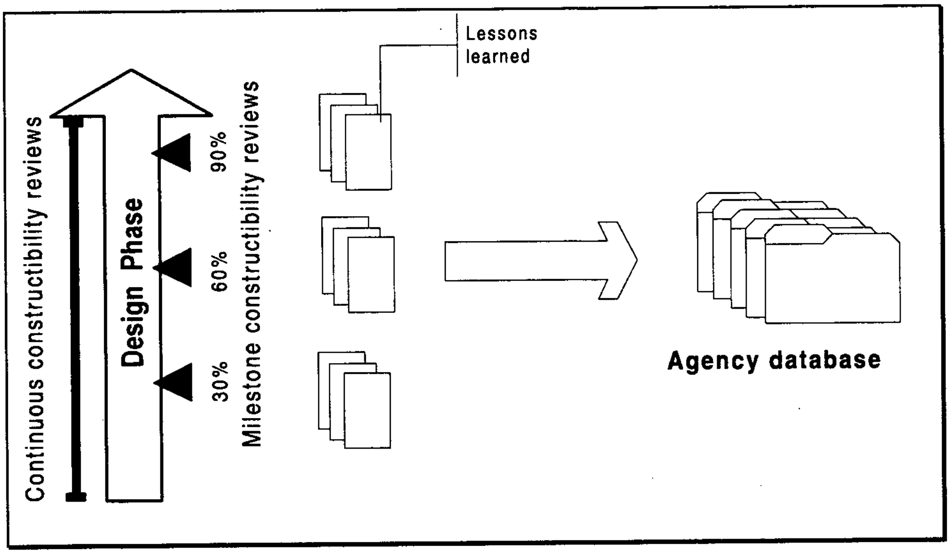

Figure 10
The Lessons Learned Process

Team Approach

A team approach is desirable for implementing constructibility. Due to its multidisciplinary nature, such a team can organize the appropriate expertise to address constructibility issues. Further, the collective experience of this team can often provide constructibility knowledge when this knowledge is not readily available through a single source. As shown in Table 3, a constructibility team can consist of core and ad hoc members. Core team members should include professionals from planning, design, and construction within the agency. Ad hoc members are specialists used as needed depending on project complexity and characteristics.

A project constructibility team could be one person with ad hoc assistance or a large group of experts representing several disciplines. The effort necessary on the part of the core team changes as the project moves from planning to the design phase and then construction. Ad hoc assistance can be sought as needed throughout the project duration. To ensure constructibility implementation, care should be taken to ensure continuity of the team as projects move through different phases. Formalization of the CRP would ensure such continuity.

The collective experience of this team can often provide constructibility knowledge when this knowledge is not readily available through a single source.

Table 3
Design Constructibility Team Composition

Constructibility Team	Possible Members
Core Team Members	o Design team representative o Construction experts o Planning and owner agency representative
Ad Hoc Members	o Structural consultants o Project management experts o Safety, environmental experts o Value engineering and cost experts o Right-of-way and property experts o Traffic, maintenance, and level-of-service experts o Specialized engineers and consultants o Contractor agency representative (AGC, ARTBA)

Agency Implementation

An agency-level constructibility infrastructure is needed to sustain implementation of the CRP. Some key ideas to form such an infrastructure are provided here. Suggested major actions in developing an agency-level program are:

- **Commitment to implementing constructibility.**
- **Establishment of formal constructibility program.**
- **Development of a learning organization culture.**

... the next major action is to establish an agency constructibility program. This starts with the identification of a senior agency management sponsor.

Agency-wide implementation of constructibility may result in paradigm shifts in the way projects are conceived and executed. A change in the organizational culture of an agency may be required. Such a change will not occur at once. An agency constructibility program necessitates basic changes in agency culture, which, in turn, needs an agency infrastructure to support a constructibility program. One way to facilitate change is to educate agency personnel on constructibility principles. A self-assessment of the present status of constructibility within the agency is also necessary. With a strong commitment to constructibility, the next major action is to establish an agency constructibility program. This starts with the identification of a senior agency management sponsor. As has already been emphasized, constructibility efforts will thrive only when senior agency management provides dedicated support. Finally, establishing a lessons learned database, nurturing a learning environment, and pro-viding valuable constructibility inputs for future projects all will be required to sustain constructibility and to achieve full benefits from this practice.

Section II

Implementation Guidelines

Apply Constructibility to Transportation Projects

What is Constructibility?

Constructibility is integrating construction knowledge and experience into planning, design, and construction to achieve overall project objectives.

Why Apply Constructibility?

Constructibility

- Reduces project cost and enhances schedule effectiveness
- Enhances quality
- Improves Project Development Process
- Pays for itself

When to Apply Constructibility?

Constructibility can be applied to each phase of the Project Development Process. Maximum benefits occur when people with construction knowledge and experience become involved from the very beginning of the project life cycle.

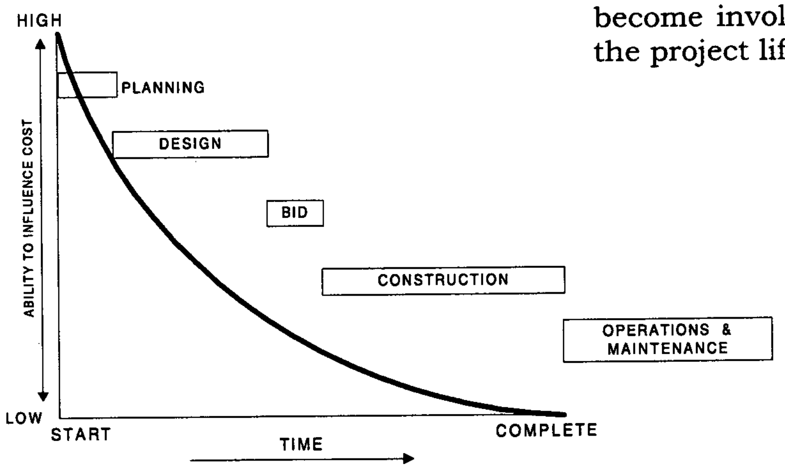

Figure AO.1
Ability to Influence Project Cost
Adapted from CII Publication 34-2, 1993

How to Apply Constructibility?

Constructibility can be applied through implementing a Constructibility Review Process (CRP) that integrates construction knowledge and experience into the Project Development Process (PDP). This process begins during planning and continues throughout design and construction. Integration occurs when information from the PDP becomes input to the CRP. The CRP acts on this input and returns suggested improvements to the PDP for incorporation into planning and design.

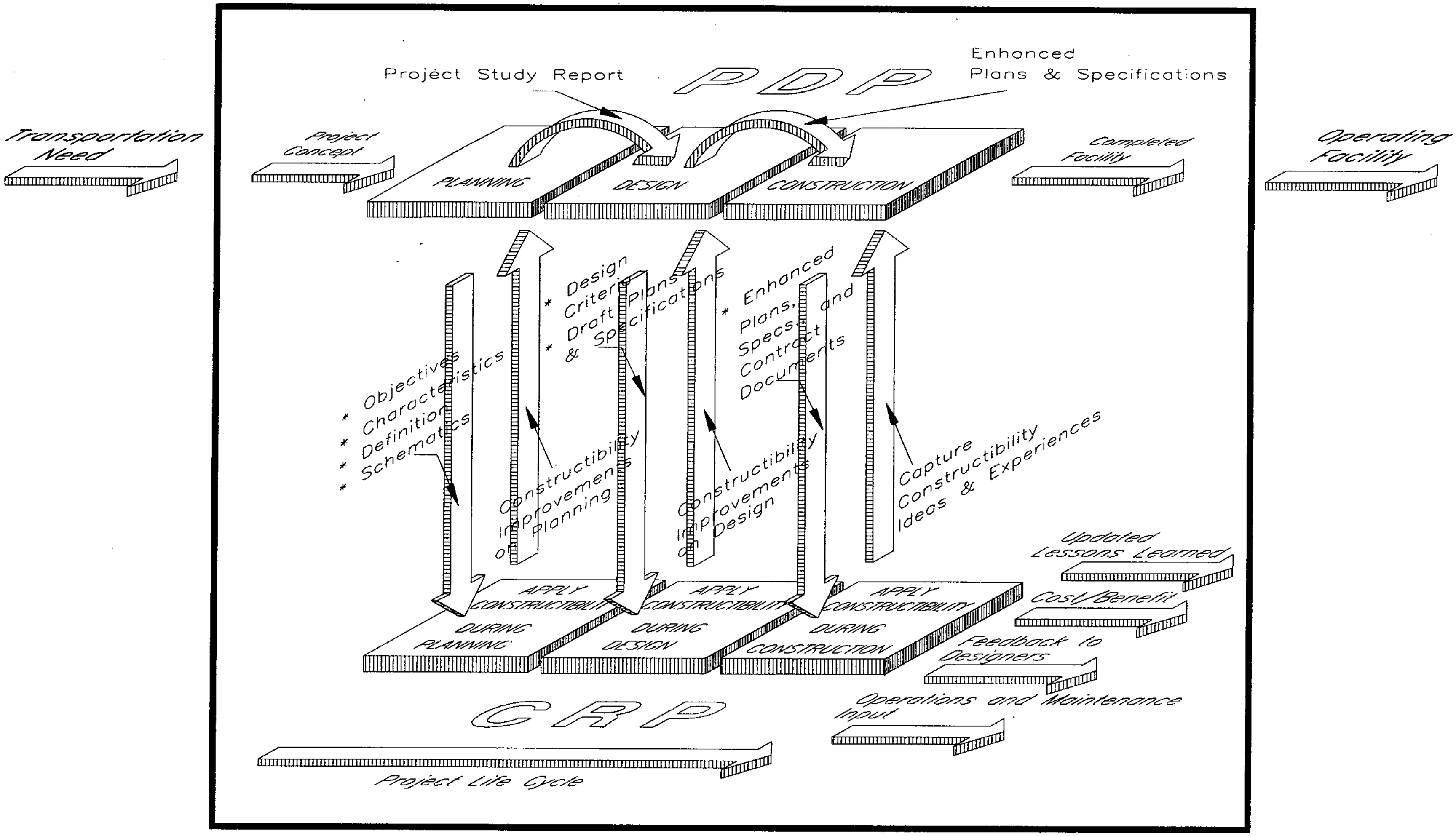

Figure A0.2
Integration of Constructibility Review Process with Project Development Process

Project Development Process (PDP) Framework

PDP typically consists of three main phases:

- Planning
- Design
- Construction

Each phase is further divided into an increasing level of detailed activities. These activities are considered generic and are typical of most project development processes. However, every state agency will have its own unique PDP. The PDP framework shown next is provided to orient users toward the types of activities and information required to apply constructibility during each phase.

Constructibility Review Process (CRP) Framework

CRP is applied during each phase of the Project Development Process — planning, design, and construction. Similar to the PDP, the CRP is divided into an increasing level of detailed constructibility functions. The CRP occurs concurrently with the PDP during each major project phase, where there is continuous feedback between the CRP and the PDP.

Timing of the Constructibility Review Process

A project develops in phases over time. During each phase, information exchange is initiated through PDP activities and is followed by specific applications of constructibility functions. This exchange of information between the PDP and CRP is cyclic and occurs throughout each project phase. This phase-time relationship is illustrated schmetically in Figure A0.6, which also identifies milestones critical to the project development phase. These milestones delineate transition points during the project life cycle. The CRP is structured to bridge the gap between phases, in order to sustain the constructibility process and to provide continuity over the project's life.

Within each phase, the contructibility process can be tailored to fit individual project characteristics and requirements. For example, constructiblity reviews can be continuous as implied in Figure A0.6 during Plans, Specifications, and Estimates (PS&E) Development or they can occur at prescribed points in time, such as at 30, 60, and 90 percent of design. Alternatively, as shown in Figure A0.6, constructibility reviews can begin during Preliminary Design. This is depicted by the open bar for the CRP under PS&E Development that starts toward the end of Preliminary Design. In this case, constructibility reviews could commence *as early as at 15% of design time.* Each STA will have to determine the appropriate level of effort for its constructibility process as well as the timing of the process in relation to its PDP approach.

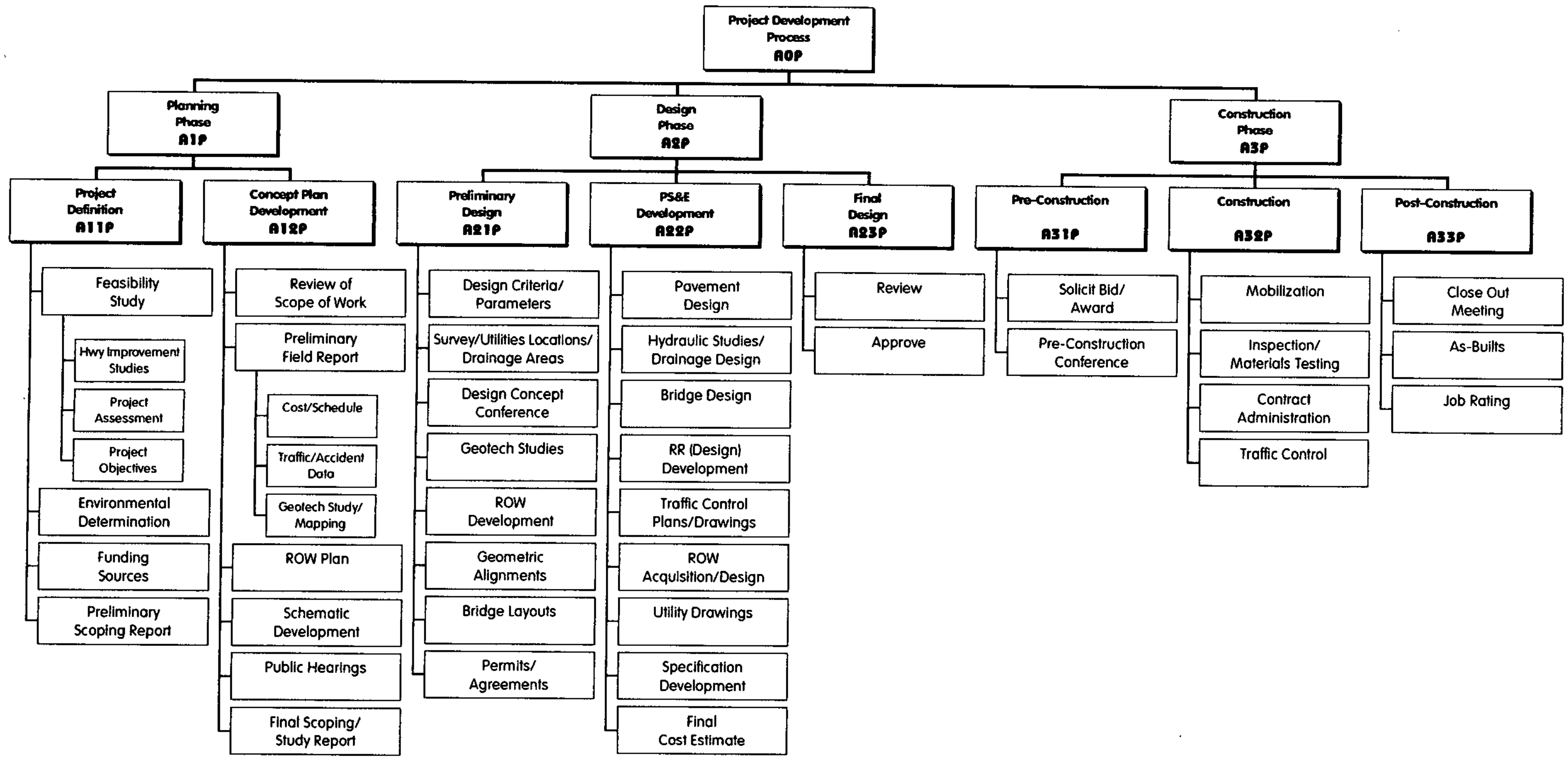

Figure A0.3
The Project Development Process Framework

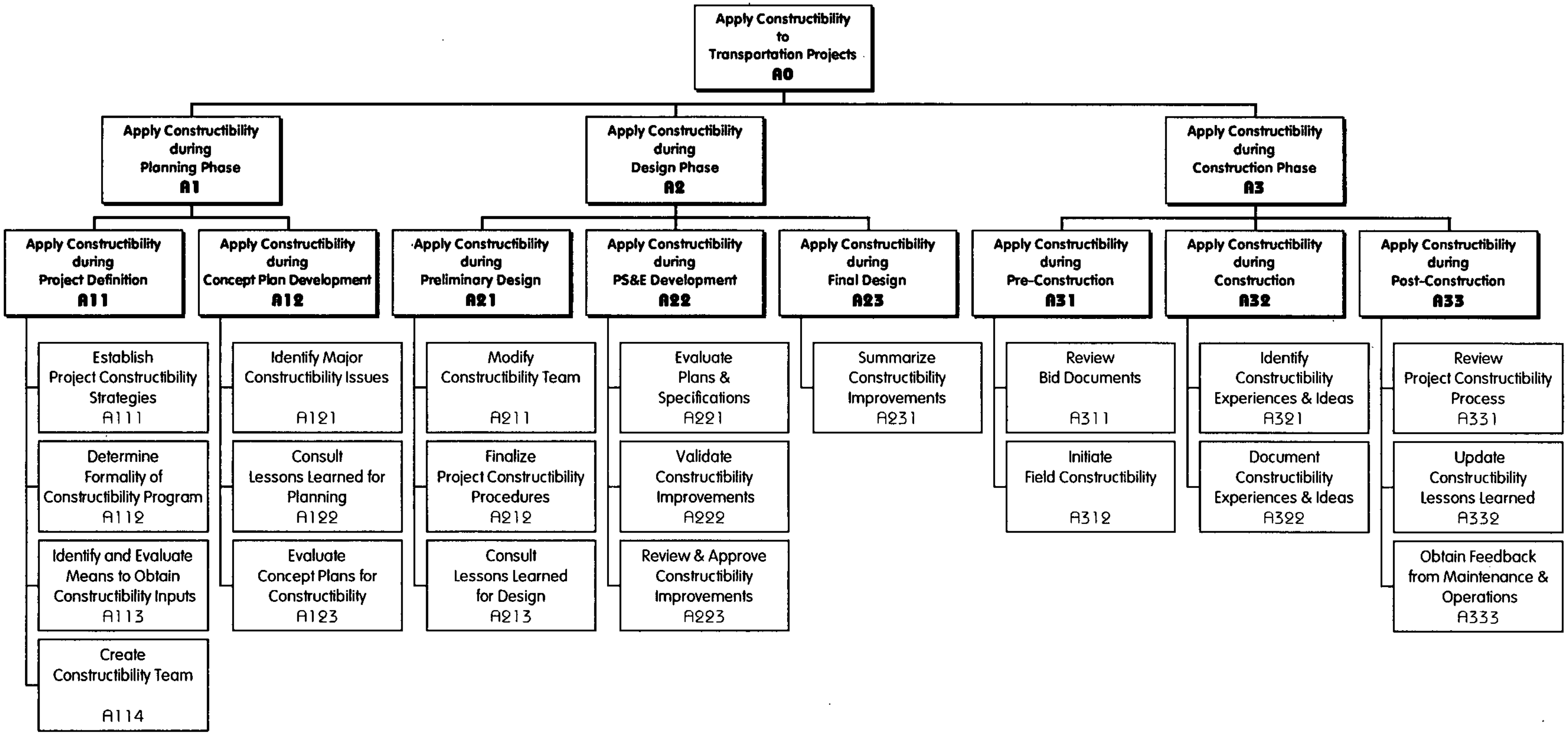

Figure A0.4

The Constructibility Review Framework

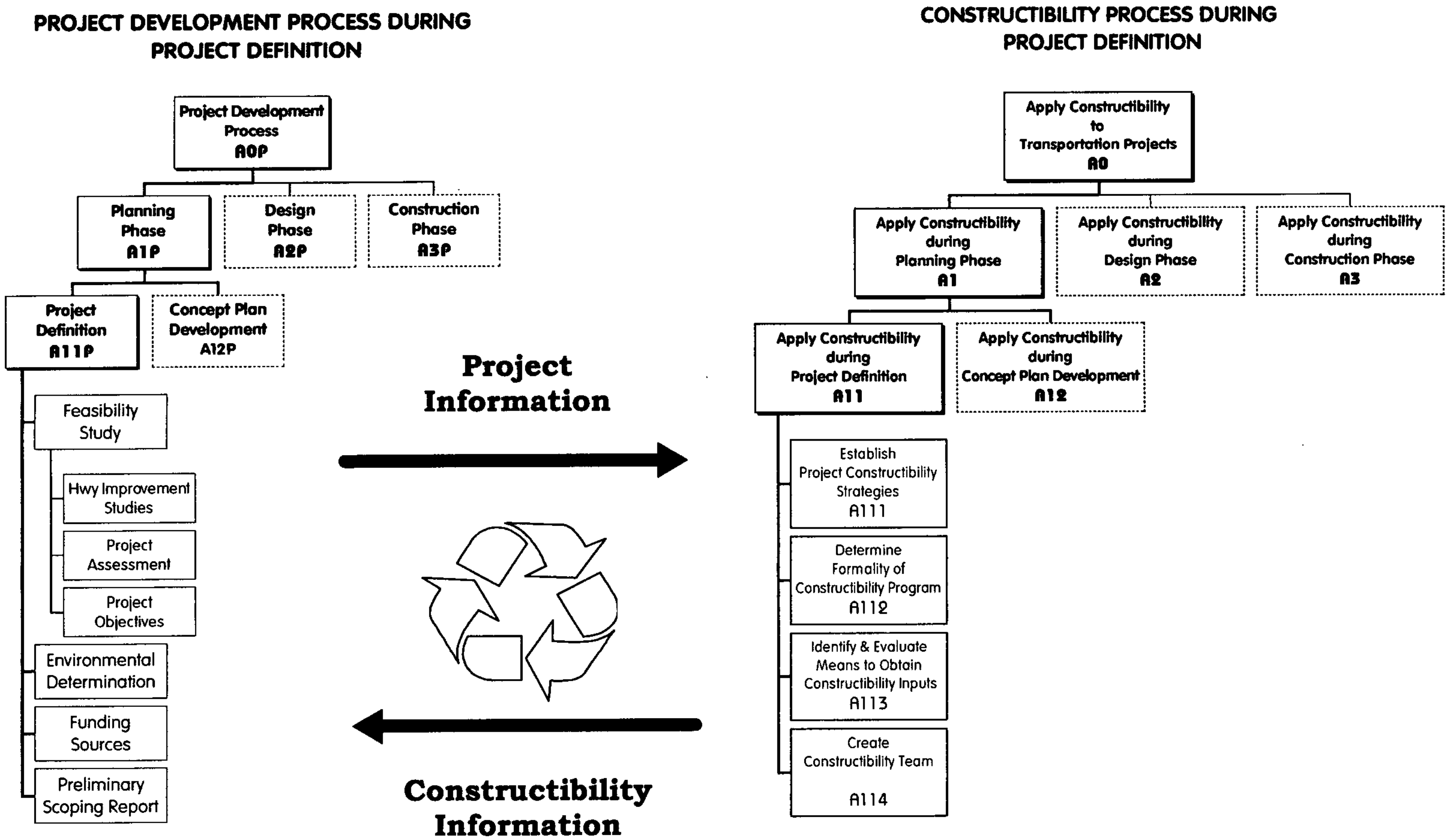

Figure A0.5

Exchange of Information between the PDP and the CRP

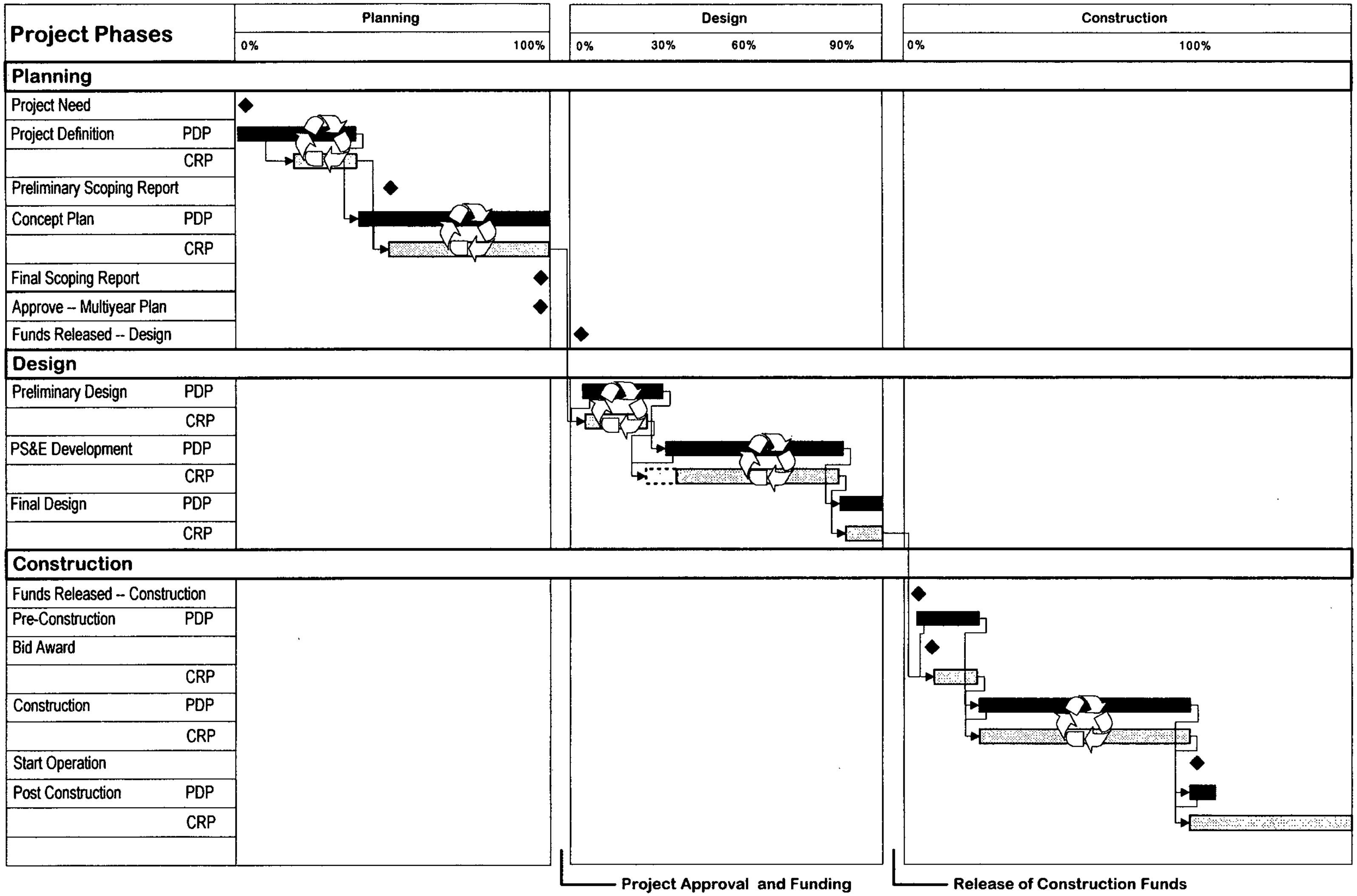

Figure A0.6

The Timing of the CRP with Respect to the PDP

How to Use the Guidelines

The Constructibility Review Process is performed during the three *major PDP phases*: **planning (A1), design (A2),** and **construction (A3)**. Each major phase is further divided into *subphases*. Thus, for example, planning (A1) is divided into two subphases: apply constructibility during project definition (A11) and apply constructibility during concept plan development (A12). A number of *constructibility functions* are performed during each subphase. A constructibility function is described by *steps* and *actions* supported by various *constructibility review tools.* Thus, for example, A12 is further divided into three constructibility functions: 1) Identify Major Constructibility Issues (A121); 2) Consult Lessons Learned for Planning (A122); and 3) Evaluate Concept Plans for Constructibility (A123). Tools are divided into three categories:

T100's — used to understand/communicate constructibility
T200's — used to implement/measure constructibility
T300's — cutting edge technology/computer tools.

The following icons are used throughout the workbook to provide complementary information. These symbols provide visual cues to the user to quickly identify key information.

Tool Applications: Describe the characteristics and the usage of tools recommended to perform individual actions for each constructibility function. Wherever applicable, tool formats are provided for better understanding and use. A complete list and description of the tools used in the workbook can be found in Appendix B1. Future tools, that is, those tools having potential applications in the future for an advanced CRP, are listed in Appendix B.2.

Issues to Consider: Point out the issues to be considered while performing a constructibility function. Only generic issues are given in the workbook. These issues can also serve as checklist items.

Tips: Give supplementary information on certain important constructibility tools, issues, or other topics.

Examples: Two example projects, the Buffalo Gap Intersection and the Loop 322 Interchange, illustrate how all the different tools, issues to consider, and actions tie together to provide the output of performing a constructibility function.

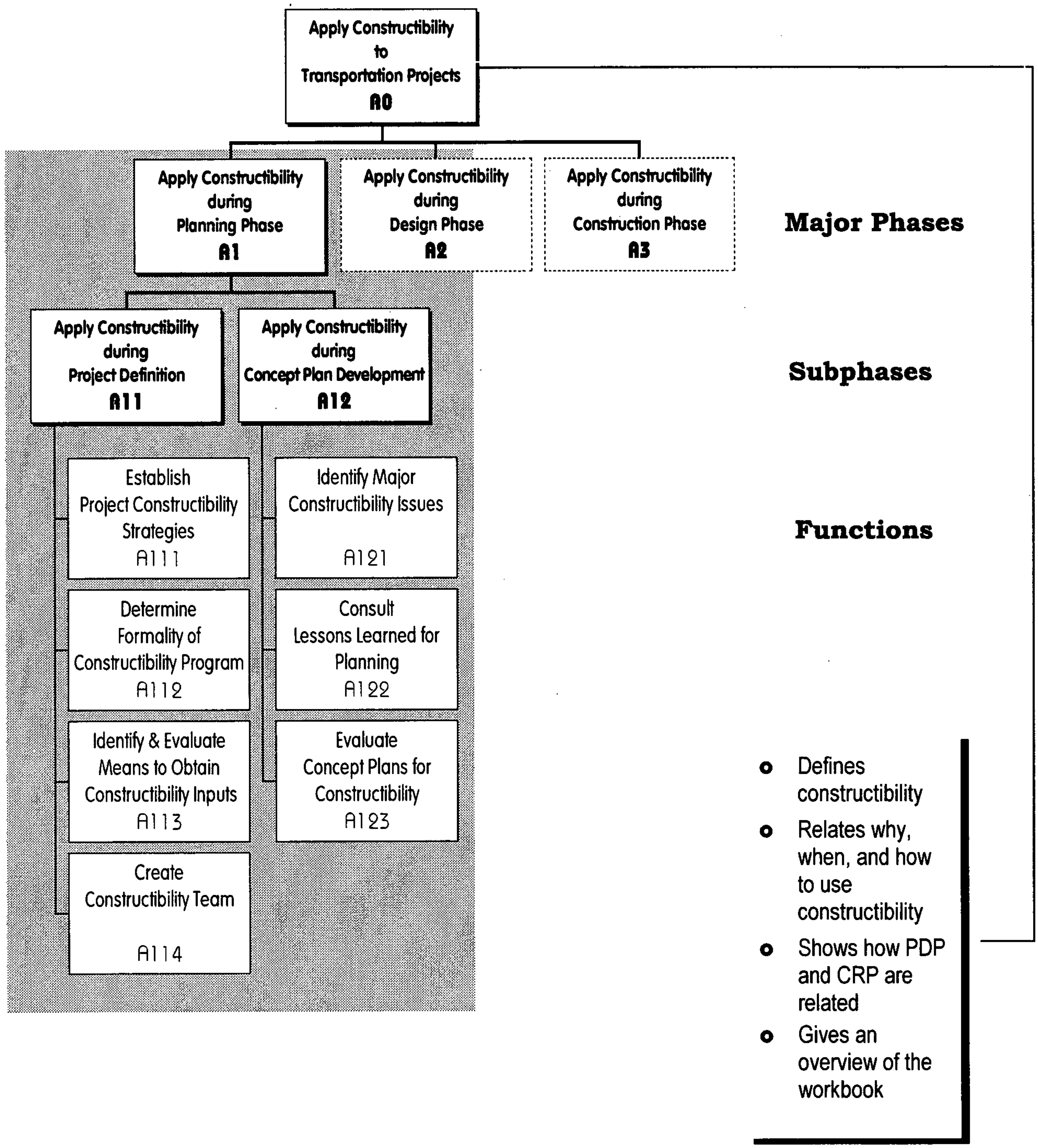

Figure A0.7a
Constructibility Review Framework

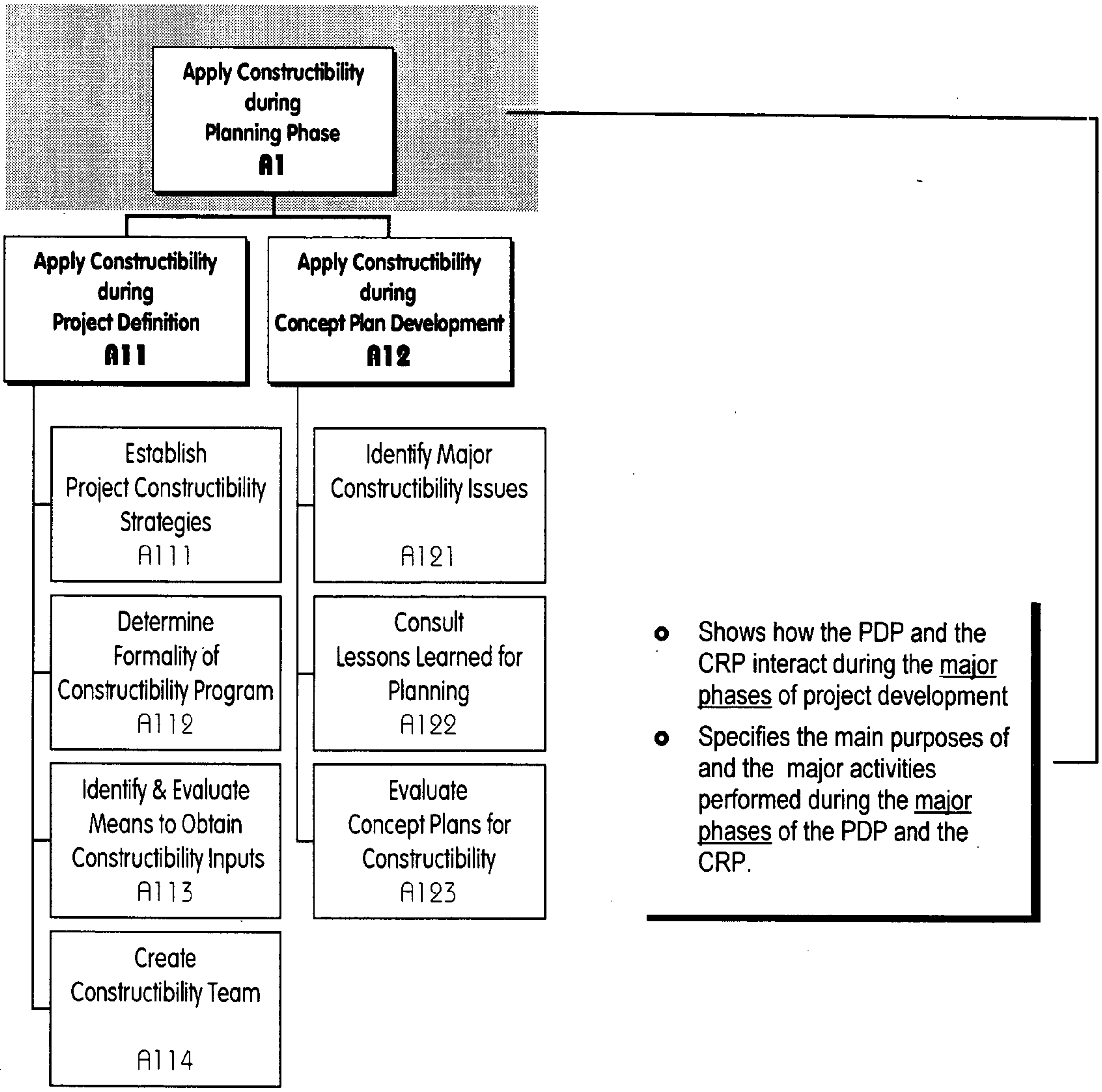

Figure A0.7b
A Major Phase of the CRP Framework

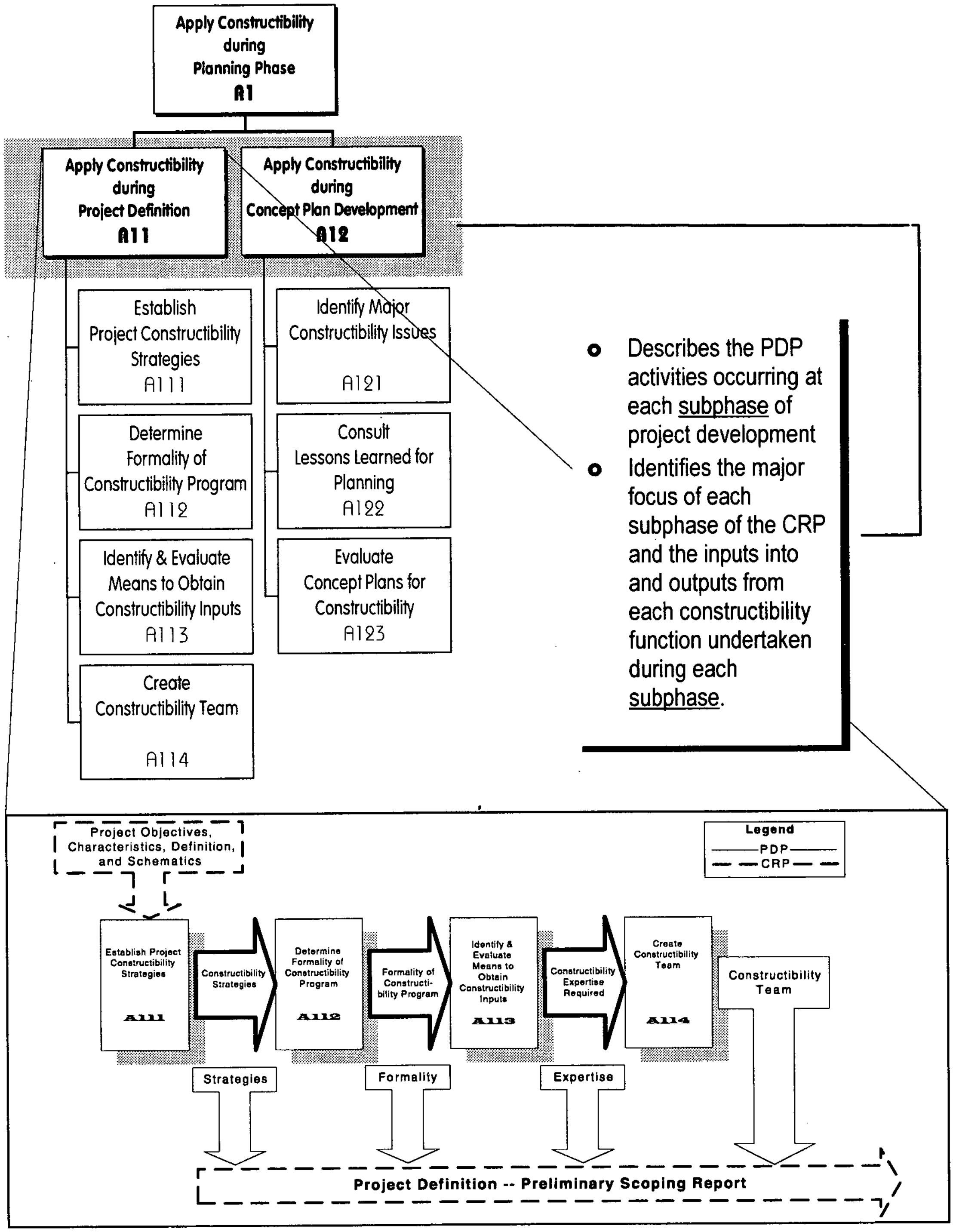

Figure A0.7c

Subphases in a Major Phase

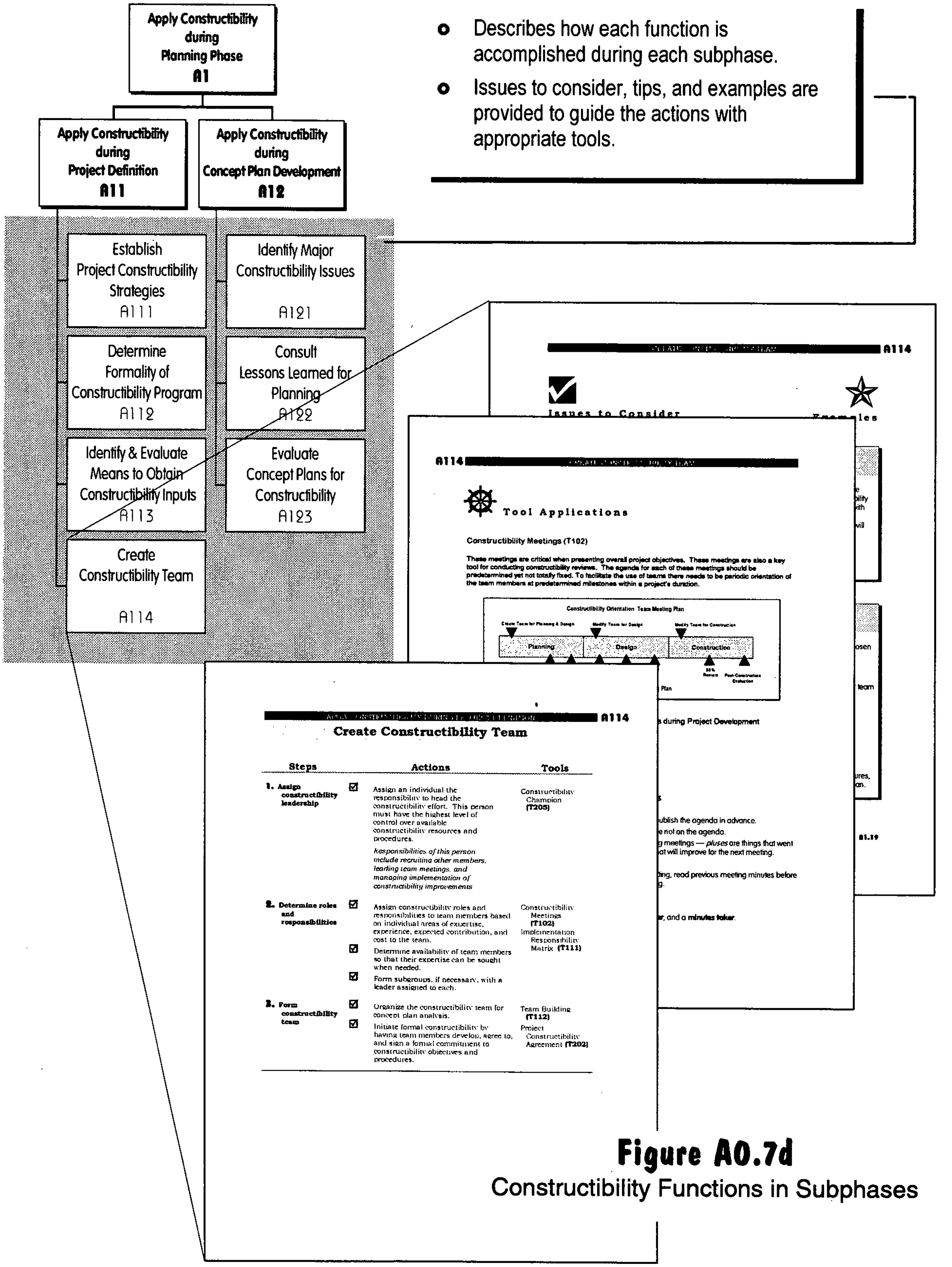

Figure A0.7d
Constructibility Functions in Subphases

Project Complexity Classification Scheme

The Constructibility Review Process is designed to be flexible so it can be adapted to fit a project's specific characteristics and requirements. Similarly, an agency can modify the CRP to be consistent with its approach to project development, policies, and resources available.

A key driver behind the flexible nature of the CRP is project complexity. Complexity can be described by many factors. Typically, project cost and work-hour (or duration) effort reflect a level of complexity. The type of project has a relationship to complexity. Projects located in an urban setting and those involving reconstruction and/or grade separation are often more complex. Projects that involve many interfaces with other government agencies, the public, consultants, designers, and contractors may indicate a higher level of complexity. For purposes of applying the CRP, the following classification of transportation projects reflects levels of project complexity. This classification is based on extensive inputs from experienced construction personnel involved with the research.

Standard or Smaller Projects

- Asphaltic concrete overlays
- Seal/flush coats
- Guard rail improvements
- Bridge widening less than 100 feet in length
- Intersection improvements
- Rural freeways/highways (new alignment — flat terrain)
- Rural traffic interchanges
- City street improvements (curb & gutter, resurfacing)
- Climbing lanes (without earthwork)
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- Generally smaller projects that do not get extensive review/attention

Moderate to Highly Complex or Larger Projects

- Urban freeways
- Depressed freeways
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- Urban traffic interchanges
- Rural widening or realignment (under traffic)
- Rural freeways/highways (new alignment — mountainous terrain)
- Retaining walls greater than 15 feet in height
- City street improvements (underground pipelines)

Example Projects

Standard Project

The Buffalo Gap Intersection

- Upgrading of a freeway facility, consisting of grading, flex base, one course of surface treatment, hot mix concrete paving, lighting, and striping; and
- Widening of a non-freeway facility, consisting of grading, asphalt stabilized base, concrete pavement, hot mix concrete pavement, curb and gutter, lighting, signals and striping.
- Average daily traffic — 20-year projection : 28,000
- Project cost $1.6 million
- Project life cycle 20 months
  - Planning — 4 months
  - Design — 6 months
  - Construction — 10 months
- Agency performed planning and design

Moderately Complex Project

The Loop 322 Interchange

- New interchange construction of grade-separated overpasses connecting three highways
- Average daily traffic — 20-year projection : 16,000
- Project cost $16 million
- Project life cycle 7 years
  - Planning — 2 years
  - Design — 2 years
  - Construction — 3 years
- Agency performed planning and design

See Appendix C for more information

Apply Constructibility during Planning Phase

●●●

The constructibility process begins once a project is given sufficient definition during the planning phase. Project planning has two major activities:

- **Project Definition** — determines the best course of action which would satisfy the perceived need for a project.
- **Concept Plan Development** — performs project concept cost, schedule, and benefit/cost analysis to test the economic viability of the project.

These activities prepare the project for agency approval and incorporation into a multi-year program. The major tasks performed during the project planning phase are:

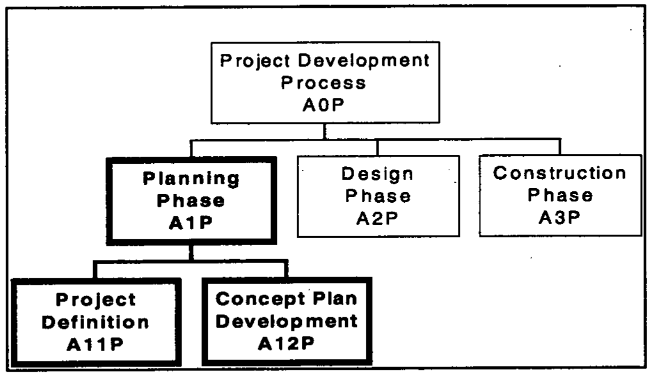


FIGURE A1.1
Project Development during Planning

- **Form Planning Team** — assemble best expertise to plan project.
- **Analyze Customer Need** — for a specific transportation service, a need may be detected through transportation system studies, identified as a result of deterioration of existing facilities, or proposed as part of infrastructure development programs; the planning team must determine how best to satisfy the specific customer need.
- **Develop a Project Study Report** — the planning team determines the type of facility to be built, establishes the scope for the project, and develops a project study report consisting of basic design parameters and requirements and economic viability of the facility.

Constructibility is performed concurrent with each major component of project planning. The purposes of the Constructibility Review Process during project planning are to:

- **Develop a Project Plan** for constructibility and to evaluate concept plans from a constructibility perspective
- **Integrate Construction Knowledge and Experience** into the planning process where there is the greatest flexibility to do so.

The project plan for constructibility establishes constructibility procedures and different resources required for constructibility efforts. Potential constructibility improvements are documented and forwarded to the project planning team throughout the planning phase.

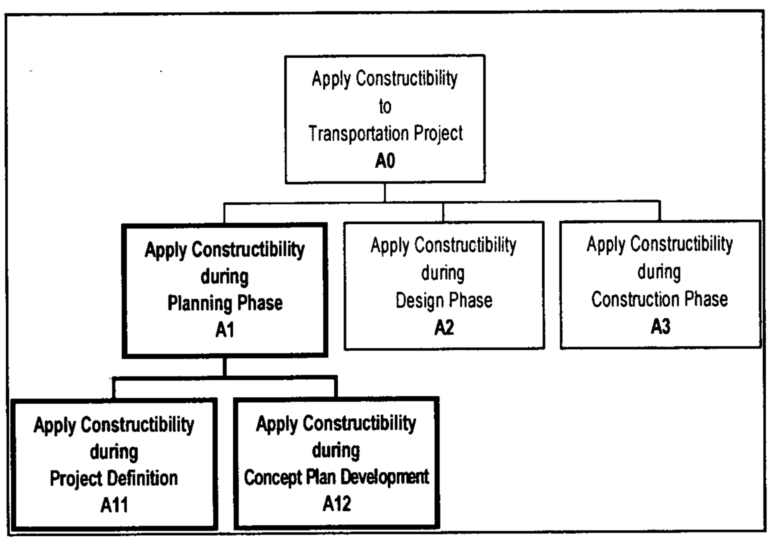


FIGURE A1.2
Constructibility during Planning

Apply Constructibility during Project Definition

As the scope of the project is defined during project definition a project plan for constructibility is developed by agency personnel. **Project Definition** provides the constructibility process with objectives, scopes and characteristics.

Project Definition consists primarily of:

- feasibility studies on the project,
- investigation of environmental factors impacting the project, and
- determination of funding sources to finance the project.

At the end of Project Definition, a **Preliminary Scoping Report**:

- captures findings of the Project Planning Team,
- defines the basic scope of work that must be accomplished to meet the project need, and
- identifies the quantity and quality of tasks that must be performed.

The Constructibility Review Process (CRP) begins once the project is sufficiently defined in terms of project scope, objectives, and characteristics. A major focus of the CRP during project definition is to develop a Constructibility Plan. This plan maps the strategies, procedures and resources for constructibility implementation. This process is illustrated below with the major inputs and outputs.

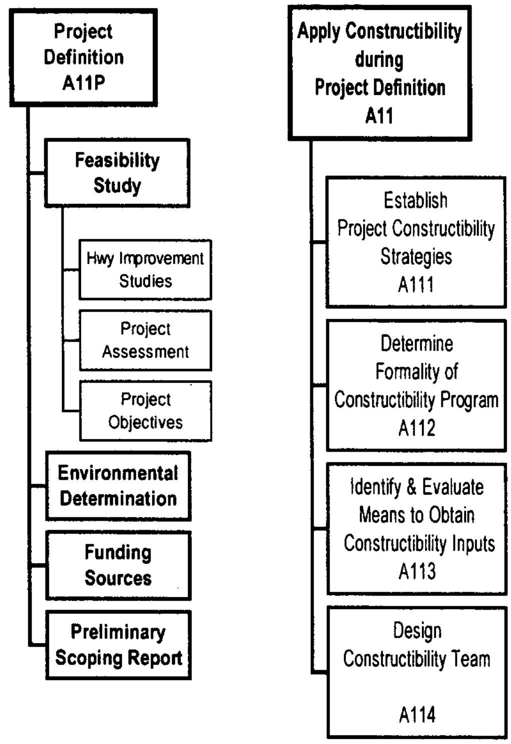


FIGURE A11.1
PDP and Corresponding CRP during Project Definition

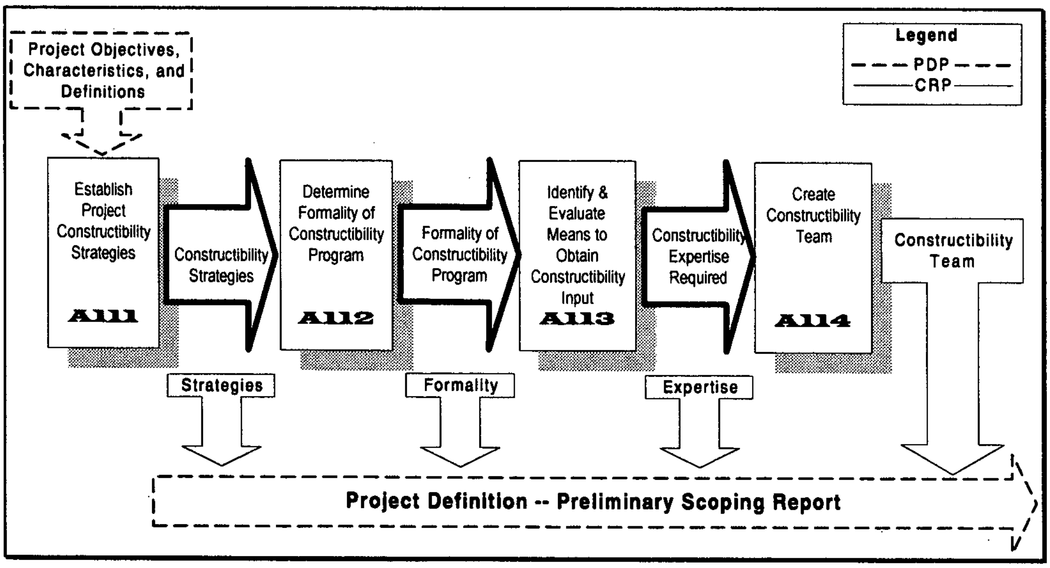


FIGURE A11.2
Integration of CRP with PDP during Project Definition

Establish Constructibility Strategies

Steps	Actions	Tools
1. Determine constructibility strategies	☑ Review project objectives and their priorities from a constructibility perspective. ☑ Based on project complexity and characteristics and guided by agency policy, determine possible constructibility strategies to help achieve project objectives.	Policy and Objective Statements **(T101)**
2. Record appropriate strategies selected	☑ Document constructibility directions (strategies) for current project. ☑ Capture strategies that are not used currently but may be applicable to future projects.	

Tool Applications

Constructibility Implementation Policy

Consistent with the National Quality Initiative (NQI), a Constructibility Review Process (CRP) is a major practice our agency is pursuing to continuously improve our project development process. Our agency has endorsed the cost savings potential of constructibility efforts. According to our definition, constructibility is "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives." Constructibility Review Process guidelines are available as a resource to promote project-level implementation.

In view of our continuing efforts to provide the highest degree of quality and cost effectiveness from our projects, it is our agency policy to implement constructibility to the fullest degree possible. This applies to all phases: project planning, design, and construction. We will ensure that we take full advantage of the high potential of constructibility to achieve savings during the earliest phases of project planning and prior to the start of PS&E development.

______________________is hereby designated as the Executive Sponsor for Constructibility, and will oversee the constructibility program, ensure consistency with other continuous improvement processes, implement changes, and regularly report to me on its effectiveness.

State Engineer____________________Date___________

FIGURE A111.1
A Sample Constructibility Implementation Policy

Policy and Objective Statements (T101):

A constructibility policy is a written and circulated document regarding the constructibility goals of the agency. This is the initial tool that an agency can use to implement a project constructibility program.

Project objectives need to be established to guide the implementation of constructibility on a project.

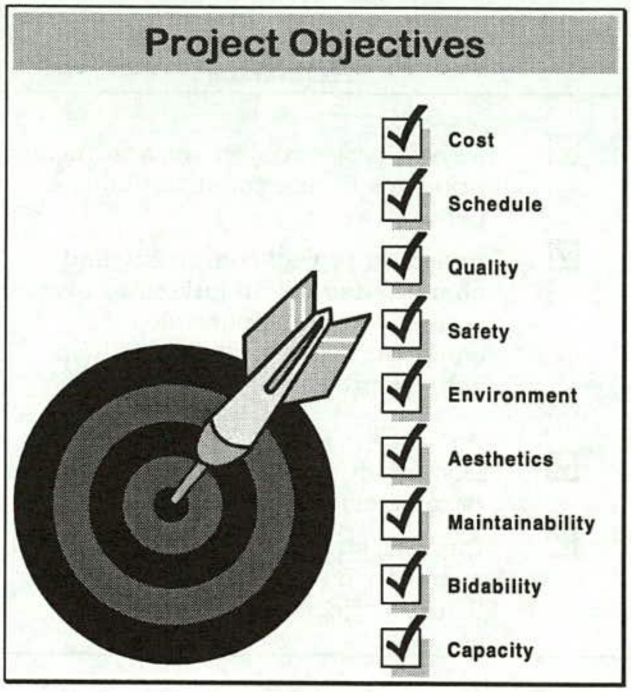


FIGURE A111.2
Major Project Objectives to Focus Constructibility Strategies

Issues to Consider

Agency Constructibility Policy

- Objectives for agency constructibility approach
- Requirements for project-level constructibility strategy

Project characteristics

- *Geographic location* — climate, soil type, local material supplies, etc.
- *Technical challenge* — projects with limited access, innovative construction materials, methods, and techniques, or new design strategies influence the nature of constructibility strategies to meet project objectives.
- *Project objectives* — a project with a short schedule may require a different constructibility strategy.

Key Players

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- Construction Expert (District Construction Engineer)
- Operations and Maintenance Personnel

Examples

The Buffalo Gap Intersection

Significant *project objectives* are:

Cost: Minimize cost so that the project is built within the limited funds available.

Schedule: Accelerate construction time because planned completion will occur near heavy traffic period (Thanksgiving and Christmas Holidays).

Capacity: Improve capacity to accommodate increased traffic from potential growth areas.

Significant *constructibility strategies* are:

- Sequence construction to minimize construction duration
- Modify existing intersection layout to incorporate unused right-of-ways (ROW) and provide access for construction
- Utilize existing overpass while widening and rebuilding intersection

The Loop 322 Interchange

This has been a problem intersection with high accident rates and low mobility at two stopping points. The significant project objectives, therefore, are:

Improved Safety: Remove at-grade intersections and reduce weaving distances.

Improved Mobility: Reduce heavy traffic build-up at two stopping conditions.

Cost: Minimize cost to stay within available funds.

Aesthetics: Make the intersection aesthetically pleasing so that it blends with the community fabric.

The following constructibility strategies are adopted to meet the foregoing objectives:

- Propose construction methods consistent with multi-level design.
- Utilize existing overpass during construction.
- Explore alternative intersection layouts for design and construction compatibility.
- Find methods, materials, and construction techniques to promote an aesthetically pleasing project.

Determine Formality of Constructibility Program

Steps		Actions	Tools
1. Evaluate criteria influencing level of formality of project constructibility program	☑	Identify different criteria to define potential levels of formality applicable to the project, considering project complexity and characteristics.	Level of Formality **(T204)**
2. Select the appropriate level of formality	☑	Select level of formality that most closely corresponds to the strategies of the constructibility program, constructibility knowledge and expertise required, and level of effort necessary.	Level of Formality **(T204)**

Tool Applications

Level of Formality (T204):

A constructibility process can be implemented with varying degrees of formality. Most agencies have some level of informal constructibility program. When the process is formalized, it ensures that constructibility issues will be addressed in a systematic manner, making maximum returns on investment possible.

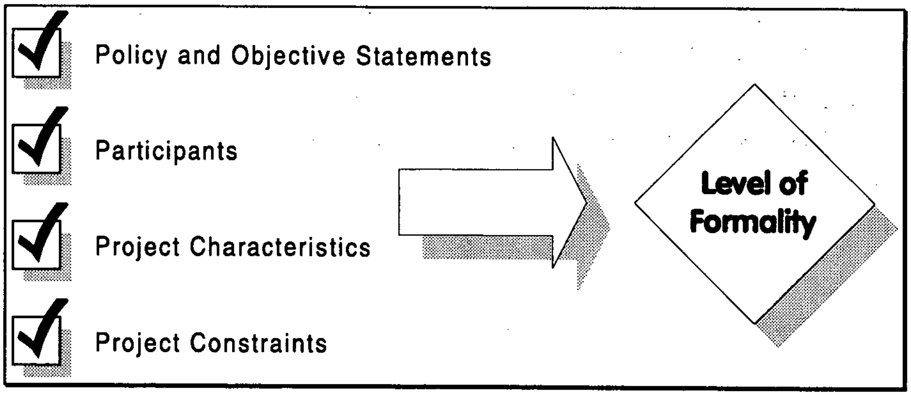


Figure A112
Determination of Level of Formality

TABLE A112: Level of Formality

Project Complexity	Standard/Small Projects	Moderate	High/Large Projects
CRP Attributes	Informal	Semiformal	Formal
Resources	1 Person w/Ad Hoc Assistance As Needed	Multi-Discipline	Team Structure w/ Core and Ad Hoc Members
Frequency of Reviews	Periodic Milestone Reviews	Periodic Reviews w/ Scheduled Reviews at 30/60/90%	Continuous w/ Scheduled Reviews at 30/60/90%
Time/Commitment Required	10% Project Team Time in Constructibility Role	Assigned by Constructibility Coordinator; Part-Time Constructibility Coordinator/Engineer	Full-Time Project Constructibility Coordinator and/or Constructibility Engineer
Leadership	Project Leader	Constructibility Champion	Constructibility Champion
Sources of Constructibility Information	File Cabinet/ Personal Experiences	File Cabinet/ PC/ Personal Experiences	Networked PC/ Databases/ Personal Experiences
Procedural Approach	CRP As Is — No Specific Project Documentation	Modified CRP to fit Project w/Limited Project Documentation	Develop Project Specific CRP and Document Approach

Issues to Consider

Project Complexity

- Standard, moderately complex, or highly complex

Project characteristics

- *Geographic location* — climate, soil type, local material supplies, etc.
- *Technical challenge* — projects with limited access, innovative construction materials, methods, and techniques, or new design strategies influence the nature of constructibility strategies to meet project objectives.
- *Project objectives* — a more formal constructibility effort may be necessary for a project with a short schedule.

Constructibility knowledge and experience required: projects with informal programs may only consult lessons learned, e.g., past experience of knowledgeable individuals or project files; more formal programs may involve in-house construction personnel, a construction manager, experienced contractors, or databases.

Levels of effort necessary: formal programs require more effort than informal ones — consider written policies and contract documents referencing constructibility; require more personnel with constructibility responsibilities; involve frequent constructibility meetings, more review and documentation of lessons learned, and tracking of savings generated due to the program implementation.

Key Players

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- Construction Expert (District Construction Engineer)
- Operations and Maintenance Personnel
- City Planners and/or City Traffic Engineers

Examples

The Buffalo Gap Intersection

This is a **standard** project because:

- no right-of-way acquisitions are required
- construction of a new overpass is not required
- utilities are already relocated

Standard project complexity warrants implementation of an informal constructibility program. One person, with ad hoc assistance, will be assigned the responsibility to oversee the constructibility process.

Constructibility reviews will be performed on a periodic basis, to be determined prior to start of PS&E development. Past project experiences will be the primary mechanism to obtain constructibility inputs.

The Loop 322 Interchange

This is a **moderately complex project** because of:

- at grade intersection with railroad
- grade separate interchange with multiple structures
- requirement of additional ROW
- environmental issues involved with purchase of adjacent park land for ROW
- utility adjustments involving a major gas line and major overhead utilities
- limitations of ROW due to a dam bordering the project
- proximity to a hospital
- hospital helipad affecting placement of utility poles
- existence within the site of an old borrow pit containing unknown materials
- a wide variety of geological formations
- restricted drainage capabilities
- a projected high future traffic volume

Project complexity warrants the implementation of a constructibility program with a moderate level of formality including:

- *Resources* — a multi-disciplinary team
- *Frequency* — monthly meetings with constructibility reviews during 30%/60%/90% completion
- *Resource availability* — a constructibility manager will be assigned to ensure resource availability
- *Historical information* — looking into lessons learned from past projects
- *Procedures* — standard but modified to fit this project

Identify and Evaluate Means to Obtain Constructibility Inputs

Steps		Actions	Tools
1. Identify possible constructibility resources	☑	Identify possible resources to constructibility information. *Possible resources come from either external or internal sources. Considerations should be given to creation of the position and/or role of Constructibility Engineer.*	Constructibility Resources **(T210)** Constructibility Engineers **(T113)**
2. Evaluate constructibility resources	☑	Evaluate usefulness of resources based on expected quality and quantity of information, cost, time, and any other considerations pertinent to acquisition of the information.	
	☑	Select best potential constructibility resources consistent with project resource constraints, complexity, formality of constructibility program, and contracting strategy.	
	☑	Confirm availability of the resources selected.	
3. Select organization to manage constructibility implementation	☑	Determine responsibility for coordinating the constructibility effort. This may be assigned to individuals within the agency or to an external organization (insourcing vs. outsourcing).	

Tool Applications

Constructibility Resources (T210)

Constructibility resources are organizations or people that are brought into a project with the experience that is needed. These sources of construction knowledge come in the form of construction management services, value engineering firms, retirees, or other agencies. The use of an outside source allows owners to obtain knowledge on constructibility issues that is not available within their own agencies. This knowledge should include a thorough understanding of the design and broad experience in construction, with the ability to convey constructibility issues and ideas in sometimes unreceptive conditions.

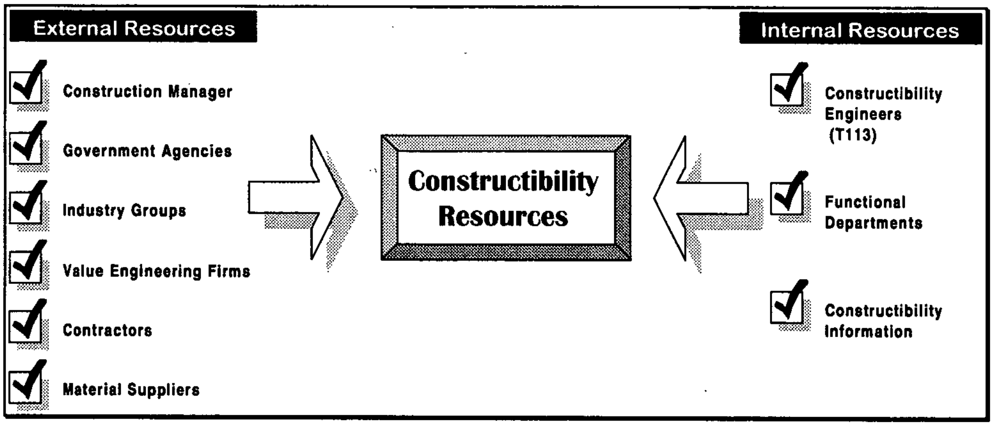


Figure A113
Constructibility Resources

Constructibility Engineers (T113)

This position/role requires an experienced and knowledgeable individual who provides guidance and specific analysis of project constructibility issues and suggested improvements. This person must be someone who has both the perspective of the agency and the contractor. An understanding of the design process is also essential. This individual can be provided through any constructibility resource, such as a construction manager. A qualified project team member can perform this role for a project. Finally, hiring a full time agency Constructibility Engineer is another recommended approach.

Tips

Skills of the Constructibility Engineer

- Knowledge of design process
- Construction knowledge
- Communication
- Leadership
- Planning
- Conflict management
- Technical knowledge and managerial experience

Issues to Consider

Formality of Project Constructibility

- Level of coordination required
- Sources of constructibility information

Project Complexity

- Need for different sources with information covering unrelated areas
- Type of expertise required

Resource Constraints

- Budgets and schedules available to obtain the information
- Availability of needed resources

Contract Strategies

- Project delivery approach to acquire design services (in-house vs. outsource)
- Specific contractual requirements for acquiring constructibility inputs (e.g., constructibility consultants, construction management approach, etc.)

Potential Sources of Information

- Contractors — can be invited through a local contractor organization (AGC, for example)
- Pre-bid addenda (past projects)
- Post-contract award value engineering proposals (past projects)
- In-house construction representative
- Surrogate construction contractor or construction manager — may come from owner, design organization, constructor, construction manager, or consultant

Key Players

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- Construction Expertise (District Construction Engineer, construction manager, consultant)
- Operations and Maintenance Personnel
- City Planners, and/or City Traffic Engineers

Examples

The Buffalo Gap Intersection

The constructibility resources available are:

- District Maintenance Office
- District Design Office
- District Construction Office
- City Traffic Engineer
- Local contractors

The decision is made to coordinate constructibility in-house using resources identified.

This decision is made based on the following project characteristics:

- standard project
- small budget
- short time-frame
- design performed in-house

The Loop 322 Interchange

The constructibility resources available are:

- District Maintenance Office
- District Design Office
- Local contractors
- City Traffic Engineer
- District Construction Engineer (Constructibility Engineer)
- Design Division (Bridges and Retaining Walls)

The decision is made to utilize in-house personnel based on the following:

- resources are available in-house
- not highly complex project
- agency has limited experience with outsourcing
- agency wants to exercise a higher degree of control

Create Constructibility Team

Steps		Actions	Tools
1. Assign constructibility leadership	☑	Assign an individual the responsibility to head the constructibility effort. This person must have the highest level of control over available constructibility resources and procedures. *Responsibility of this person includes recruiting other members, leading team meetings, and managing implementation of constructibility improvements.*	Constructibility Champion **(T205)**
2. Determine roles and responsibilities	☑	Assign constructibility roles and responsibilities to team members based on individual areas of expertise, experience, expected contribution, and cost to the team.	Constructibility Meetings **(T102)** Implementation Responsibility Matrix **(T111)**
	☑	Determine availability of team members so that their expertise can be sought when needed.	
	☑	Form subgroups, if necessary, with a leader assigned to each.	
3. Form constructibility team	☑	Organize the constructibility team for concept plan analysis.	Team Building **(T112)**
	☑	Initiate formal constructibility by having team members develop, agree to, and sign a formal commitment to constructibility objectives and procedures.	Project Constructibility Agreement **(T202)**

Tool Applications

Constructibility Meetings (T102)

These meetings are critical when presenting overall project objectives. These meetings are also a key tool for conducting constructibility reviews. The agenda for each of these meetings should be predetermined yet not totally fixed. To facilitate the use of teams there needs to be periodic orientation of the team members at predetermined milestones within a project's duration.

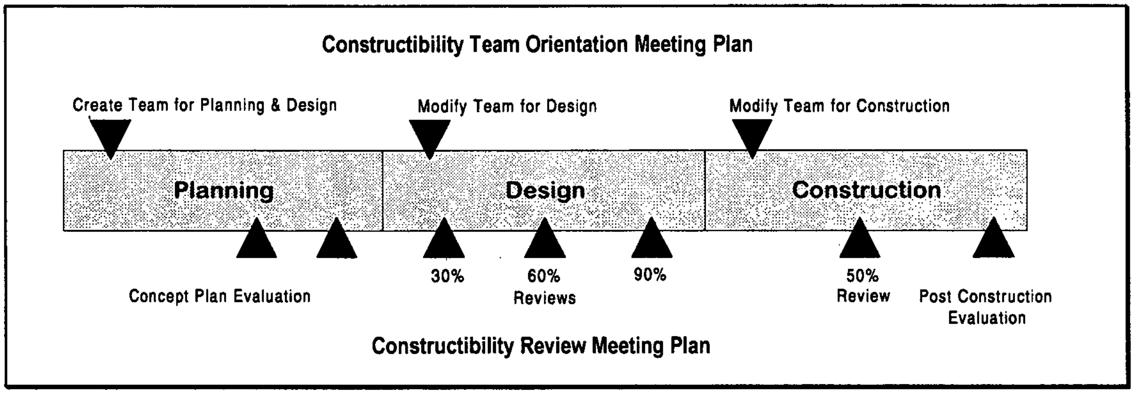


FIGURE A114.1
Typical Schedule for Constructibility Meetings during Project Development

Tips

Effective Meeting Guidelines

- Establish the **agenda** — The team leader should publish the agenda in advance.
- Establish an **issue board** for items that arise but are not on the agenda.
- Use the **plus/delta** technique to continue improving meetings — *pluses* are things that went well during the meeting and *deltas* are things that will improve the next meeting.
- Start **on time**.
- **Be prepared** — Bring required documents to meeting, read previous meeting minutes before meeting, and complete action items for the meeting.
- Invite the **right people** to the meeting.
- Use a **facilitator** at the meeting.
- During the meeting, appoint a **scribe,** a **timekeeper**, and a **minutes taker**.

Implementation Responsibility Matrix (T111)

An implementation responsibility matrix is a graphical description of functions that need to be performed and the key players or functional divisions responsible for performing the functions. The matrix is a result of placing the responsible entities on one axis and the functions performed on the other axis. Key players and functional division responsible for each function are related to the appropriate functions by placing a mark at the intersection of each within this matrix.

Constructibility Review Process Functions \ Functional Key Players	Program Manager	Project Design Engineer	District Construction Engineers	Contructibility Engineer	District Maintenance Engineer	Local Contractor Association
Identify Major Constructibility Issues	☑	☑	☑	☑		
Consult Lessons Learned for Planning		☑		☑	☑	☑
Evaluate Concept Plans for Constructibility	☑	☑	☑	☑	☑	

FIGURE A114.2
An Example Implementation Responsibility Matrix

Team Building (T112)

This is an optional tool for projects with diverse groups who have never worked together. Each time a new constructibility team is formed, team building can be used to orient the team in preparation for conducting constructibility reviews. Team building creates an environment where different disciplines can work together and, as a consequence, operate more effectively. A facilitator is used in the team building process. The facilitator can be an in-house employee or a consultant.

Constructibility Champion (T205)

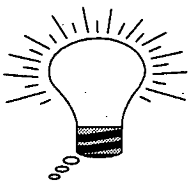
A constructibility champion is an individual who has the authority and responsibility for implementation of and adherence to the constructibility program within each individual project. The champion must be available to projects throughout all phases. The champion's responsibilities are to focus attention on constructibility issues and to ensure that lessons learned are documented. For a constructibility program to have an impact, the champion must have access to the resources necessary for the task to be performed effectively. These resources will require a financial commitment to be implemented up front.

Project Constructibility Agreement (T202)

The project constructibility agreement is a document or an agreement stating specific objectives in regards to performance, communication, and a conflict resolution plan. All members of the project agree to the terms stipulated and sign the document.

> The (design/project) constructibility team members believe proactive efforts to promote optimal constructibility and bidability in its project designs have considerable potential for cost and schedule savings, increased safety to workers and the public, and improved quality of the completed transportation facility.
>
> Our team will issue a Statement of Project/Constructibility Objectives including the following:
>
> - Performance Objectives
> - Communication Objectives
> - Conflict Resolution Plan
> - Constructibility Documentation
>
> We the undersigned agree to make a good faith effort to undertake and implement the above as applicable to each of us.
>
> ______________________________
>
> Signatures

FIGURE A114.3
An Example Project Constructibility Agreement



Tips

Planning Constructibility Team Composition

Constructibility Team	Possible Members
Core Team Members	• Design team representative • Construction experts • Planning and owner agency representative
Ad Hoc Members	• Project management experts • Safety, environmental, budget experts • Right-of-way and property experts • Traffic, maintenance, and level-of-service experts • Contractor agency representative (AGC, ARTBA)

Issues to Consider

Time Constraints

- Expected project timeframe
- Extent and duration of member commitment required

Project Complexity

- Level of expertise required of team members

Formality of Project Constructibility

- The structure and environment in which the team will operate

Key Players

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- Construction Expert (District Construction Engineer)
- City Planners, City Traffic Engineers
- Local Contractors/Associations

It is Important to:

- Select cooperative team players
- Minimize project team turnover
- Select experienced individuals

Examples

The Buffalo Gap Intersection

Due to the moderate size and simplicity of the project and lack of formality in the constructibility process, the constructibility team is formed with two persons — the Project Design Engineer, assisted by the Area Engineer. Final review will be performed by the District Engineer at 90% completion of design.

Constructibility Team Agreement is done informally because of the size of the team.

The Loop 322 Interchange

A multi-disciplinary constructibility team is chosen due to moderate complexity involved in the project.

The District Engineer is assigned champion of the constructibility team. Other team members are:

- Project Design Engineer
- District Construction Engineer (Constructibility Engineer)
- District Design Engineer
- Environmental Coordinator
- ROW Administrator
- District Maintenance Engineer
- Area Engineer/Project Engineer

This team will develop a constructibility team agreement outlining communication procedures, meetings schedule, and conflict resolution plan.

Apply Constructibility during Concept Plan Development

During concept plan development, basic design decisions are made. The best alternative is selected, locations of major structures are defined and dominant site conditions are identified. The planning team prepares rough design parameters to serve as guidelines for the design team to follow when preparing the detailed design.

The main purpose of concept development is to develop a schematic plan based on the identified scope of the project, available field data, and ROW plan.

At the end of Concept Plan Development phase, a **Final Scoping Report** is prepared that:

- captures such project information as the physical description of the facility, environmental issues, ROW requirements and orientation of structures,
- confirms project economic viability, and
- identifies basic design parameters.

This document provides the basis for project approval and inclusion of the project in a multi-year budgeting plan.

The focus of the CRP during concept plan development is to evaluate schematic plans and other conceptual information and to provide constructibility inputs. These evaluations and inputs are driven by major project constructibility issues and experiences of knowledgeable experts.

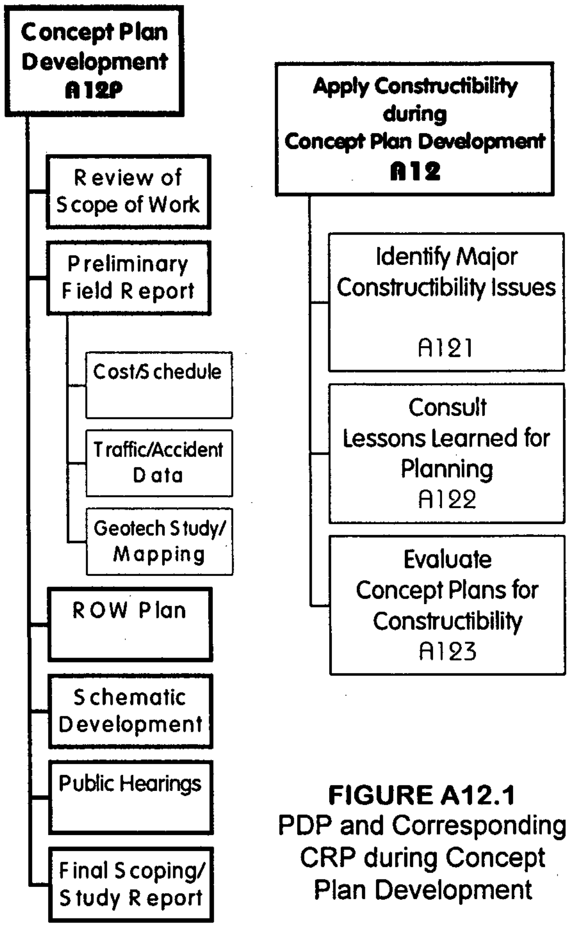


FIGURE A12.1
PDP and Corresponding CRP during Concept Plan Development

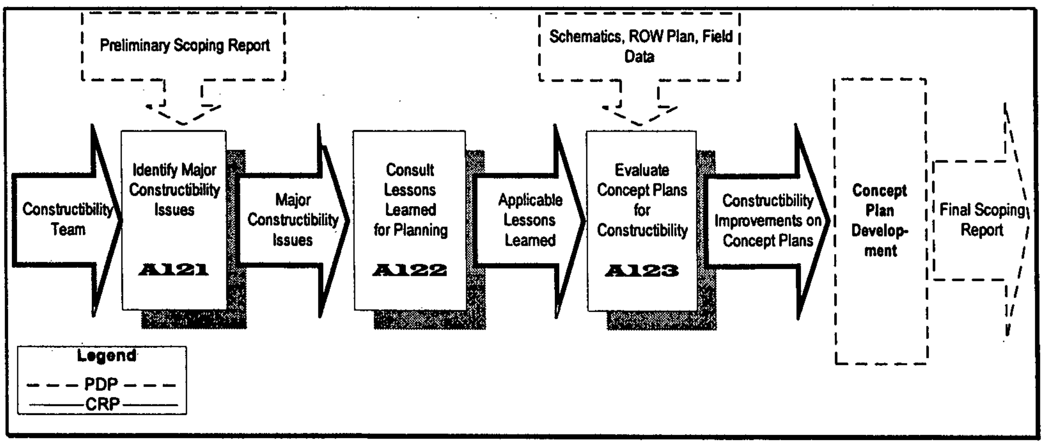


FIGURE A12.2
Integration of CRP with PDP during Concept Plan Development

Identify Major Constructibility Issues

Steps		Action	Tools
1. Familiarize team with project characteristics, concept design data, alternative concepts, and environmental considerations	☑	Constructibility team becomes acquainted with different aspects of the project — location, site conditions, environmental impact, ROW, resources available, project objectives, and constructibility strategies.	Policy and Objective Statements **(T101)**
2. Identify major constructibility issues	☑	Based on constructibility strategies, analyze project concept information to identify major issues relevant to constructibility.	
3. Document major constructibility issues	☑	List major constructibility issues so that they may be revisited when identifying and evaluating potential areas for improvement during consultation of lessons learned.	

Tool Applications

Policy and Objective Statements (T101)

See Tool Application T210, page A1.12

Issues to Consider

Project Characteristics

- *Geographic Location* — climate, soil type, local material supplies
- *Site Plan* — existing structures, geometrics, alignment, access, right-of-way, traffic flow, location of utilities
- *Project Size* — approximate volumes of materials, number of elevated structures, traffic capacity

Project Complexity

- Standard, moderate, or high (Identifies if coordination of resources is a problem area)

Constructibility Concepts

- Concepts related to, for example, earthwork and grading, bases and pavements, traffic control plans, etc.

Key Players

The constructibility team

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- City Engineers
- Local contractors/associations
- Maintenance Engineer
- District Construction Engineer

Examples

The Buffalo Gap Intersection

Primary constructibility issues identified are:

- How to fit extra lanes within the restricted area
- How to maintain safe column clearances
- How to maintain acceptable vertical clearances, which affects pavement structure
- Early completion, which affects schedule
- Detour plan, which affects traffic control plan

The Loop 322 Interchange

Primary constructibility issues identified are:

- How to continue carrying traffic volumes during construction
- How to limit the use of detours
- How to maintain safety clearances within a restricted ROW
- How to adjust the horizontal alignment at the park land in order to minimize adverse environmental impact
- Determination of any required construction easements
- Drainage restrictions
- Utility locations affecting structure placement
- Drainage of construction work area
- Sourcing of acceptable fill materials

Consult Lessons Learned for Planning

Steps	Actions	Tools
1. Access sources of lessons learned	☑ Access constructibility information searching for lessons or experiences related to the identified major constructibility issues.	Constructibility Engineers **(T113)** Post-Construction Reviews **(T201)** Constructibility Resources **(T210)** Databases **(T302)** CD-ROM/ Multimedia/ Hypermedia **(T303)**
2. Identify and organize applicable lessons learned	☑ Identify and select best procedures and/or techniques applied on projects with similar conditions as the project is being reviewed. ☑ Lessons learned should not only deal with what issues need to be addressed, but also when during planning they should be addressed.	
3. Document specific lessons learned applicable to the project	☑ List applicable lessons learned and prepare them for use as a basis for formulating constructibility improvements.	

Tool Applications

- Constructibility Engineers and Constructibility Resources are vehicles for personal experience.
- CD-ROM and databases are vehicles for documenting experience.
- Post-construction reviews from past similar projects can be consulted for reviewing constructibility lessons learned.

CD ROM/ Multimedia/ Hypermedia (T303)

One readily available source of lessons learned is a multimedia CD-ROM constructibility system developed at Purdue University for the Indiana DOT. This system incorporates a database of lessons learned. These lessons learned are accessed through different types of multimedia applications such as text, drawings and video. This system provides an easy way to access lessons learned during the design phase. This is described in more detail in Appendix B-1 of this workbook. The following graphic shows the user interface of this CD-ROM that can be used for accessing lessons learned during planning.

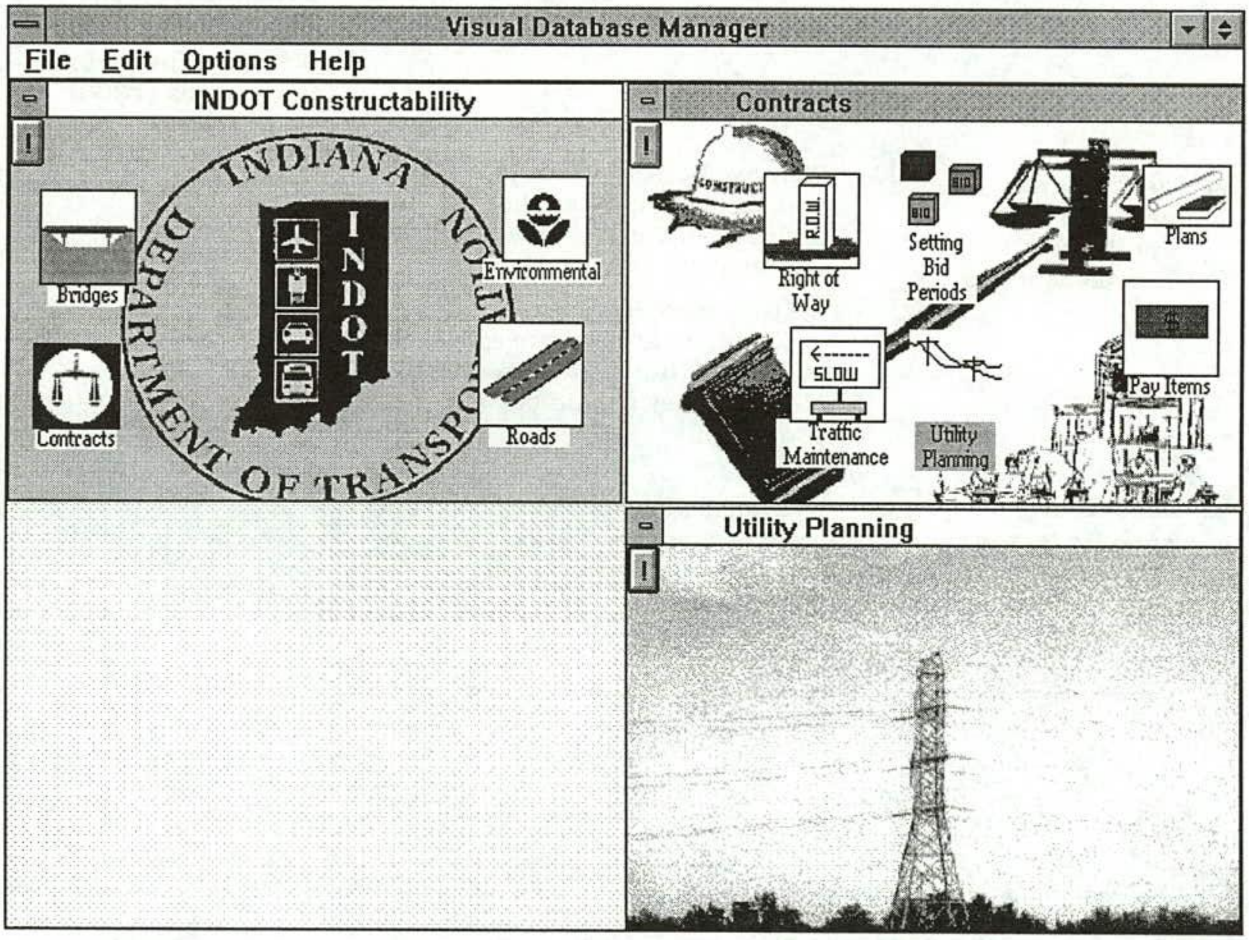


FIGURE A122
The User Interface of the Lessons Learned CD-ROM Developed for the INDOT

Issues to Consider

Availability of Lessons Learned

- Past experiences of project personnel
- Past experiences of other non-project personnel (agency, consultant, etc.)
- Project history files
- Databases (manual or electronic)
- Past experiences of local contractors, associates, material suppliers

Format of Lessons Learned

- Ease of use
- Ease in retrieval

Key Players

The constructibility team

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Project Programmer
- City Engineers
- Local Contractors/Associations
- Maintenance Engineer
- District Construction Engineer

Examples

The Buffalo Gap Intersection

Based on the major constructibility issues identified, the constructibility team starts researching the potential use of fast-track concrete and Critical Path Method (CPM) scheduling. The lessons learned being consulted relate to:

- fast-track concrete specifications
- CPM scheduling specifications
- Linear scheduling

The Loop 322 Interchange

Based on the identified major constructibility issues involved, lessons learned are sought in the following areas:

- Historical review of interchange designs in terms of
  - spacing (affected by ROW restrictions)
  - alignments (affected by ROW)
  - layouts (levels)
  - traffic control plans
- Materials logistics on other similar projects
- Review of similar interchanges

Evaluate Concept Plans for Constructibility

Steps	Actions	Tools
1. Identify possible areas for improvement	☑ Evaluate schematic drawings and other concept plan data for potential constructibility improvements guided by lessons learned previously documented. ☑ Select constructibility improvement that will help meet project objectives.	Suggestion Form **(T105)** Benefit/Cost Analysis **(T209)** Constructibility Meetings **(T102)**
2. Document suggested constructibility improvements	☑ Review and approve those comments that will have a net positive effect on the project. ☑ Document the approved improvements and release them to the project planning team for incorporation into project schematic drawings and other concept plan documents.	Idea/Lessons Learned Log **(T207)** CPM **(T208)** CAD/GCCA **(T301)**

Tool Applications

- CAD can be used during the conceptual phase of a project to study layout configurations and ROW accessibility.
- Constructibility meetings are a mechanism to review and approve suggestions.
- CPM is a tool to analyze fast tracking as a constructibility issue or to coordinate complex interactions of activities. Although CPM is used for overall schedule control, at this stage it is used to investigate the feasibility of a contractor-driven schedule.

At this stage of the project, the forms (Suggestion Form, Benefit/Cost Forms, and Idea/Lessons Learned Log) may only be partially completed or may have only order of magnitude estimates. These forms will be documented in greater detail in the design phase. These are available in Appendix B.1. The kind of information needed is:

- an idea described
- impact (cost/schedule)
- benefit/cost

Issues to Consider

Project Constraints

- Cost
- Schedule
- Site conditions
- Horizontal and vertical alignments

Right-of-way

- Utility easements
- Limited ROW width
- Type of ROW

Environmental Constraints

- Surrounding land use
- Existing wetlands
- Wildlife and plants
- Aesthetic considerations

Key Players

The constructibility team

- Project Champion (Project Manager)
- Project Designer (Design Engineer)
- Representative from city
- Local Contractors/Associations
- Project Programmer
- Maintenance Engineer
- District Construction Engineer

Examples

The Buffalo Gap Intersection

The constructibility team recommends that the designer pursue fast-track concrete in more detail to control pavement depth, including related construction schedule and sequencing approaches.

The CPM scheduling will not be pursued due to limited in-house expertise.

The Loop 322 Interchange

The constructibility team makes the following recommendations after reviewing the concept plans:

- Pursue drainage layout (include special graded ditches) to handle water during construction
- Create ad hoc constructibility team to analyze all possible interchange alternatives
- Look at existing alignments for construction traffic sequencing
- Identify work zone hauling of materials to improve project schedule
- Ensure availability of equipment to accommodate multi-level interchange construction (for pumping concrete, building long spans, etc.)

The concept plan proposes a three-level interchange to improve traffic mobility. The plan was reduced to two levels to meet cost restrictions.

Apply Constructibility during Design Phase

During the planning phase of the PDP, the scope, objectives, and goals of the project are established by the planning team. Before design can begin, the project must be approved by the owner agency. The design phase has three main activities:

- **Preliminary Design** — concept plans are finalized and design criteria and site features are documented.
- **Plans, Specifications, & Estimates (PS&E) Development** — detailed facility design is completed; structures, pavements, and other aspects of the project are engineered; and plans and specifications are developed including contract documents and cost estimates.
- **Final Design** — Consists of the review and approval of plans, specifications, and estimates generated during PS&E development.

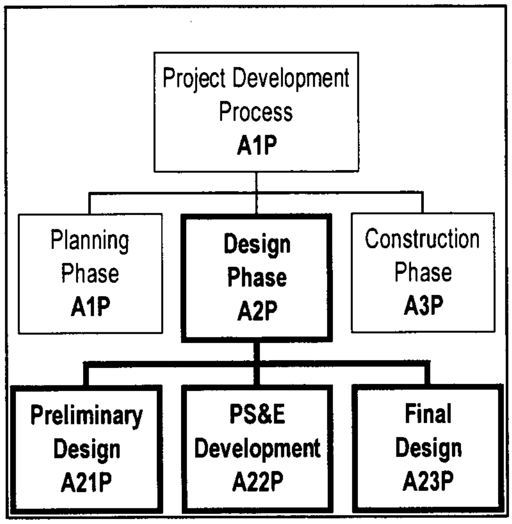


FIGURE A2.1
PDP during Design Phase

Constructibility is performed during each design activity. The overall purposes of constructibility during project design are to:

- **Mobilize and direct** constructibility resources for involvement in design
- **Integrate construction knowledge and experience** into the design process to enhance plans and specifications
- **Improve cost effectiveness**
- **Improve benefit/cost ratio** of funds expended
- **Provide lessons learned experiences** for future projects

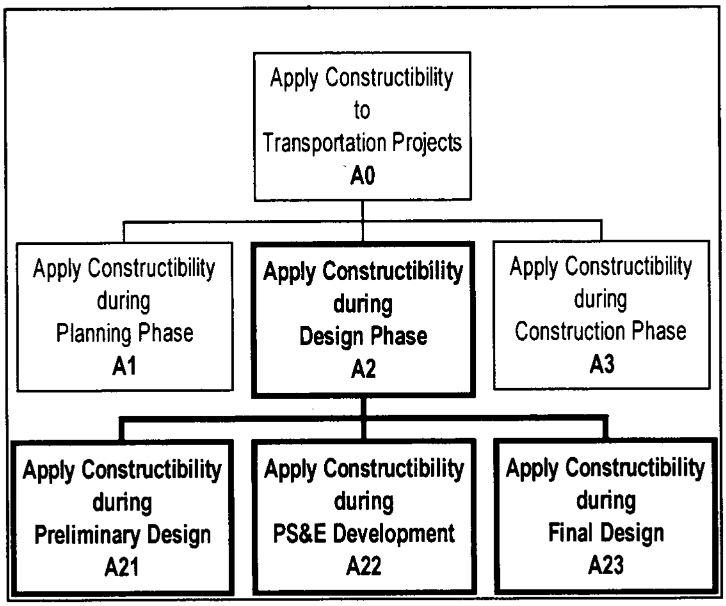


FIGURE A2.2
CRP during Design Phase

Apply Constructibility during Preliminary Design

Preliminary design consists of preparation of data and resources needed to support PS&E development. Some typical activities performed are:

- preparing environmental impact statements
- securing permits
- conducting detailed survey of the site
- developing pavement geometrics and bridge layouts
- collecting other information and data necessary for detailed design

A key input that initiates the constructibility process at this time is the final **Scoping Report** from the planning phase. This report establishes the **constructibility plan** for the project, including constructibility strategies, level of program formality, constructibility expertise and resources required, and proposed constructibility team structure.

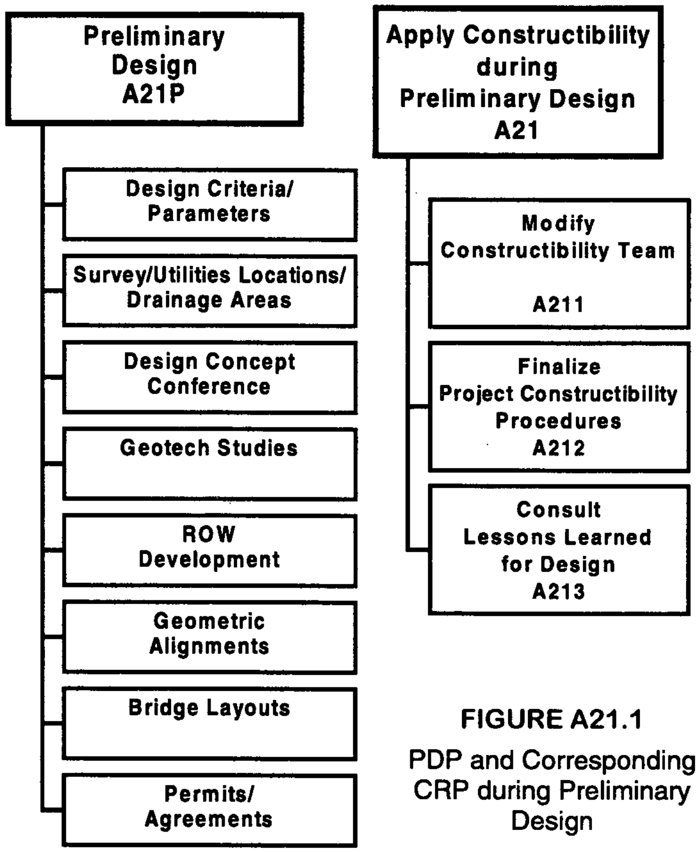


FIGURE A21.1
PDP and Corresponding CRP during Preliminary Design

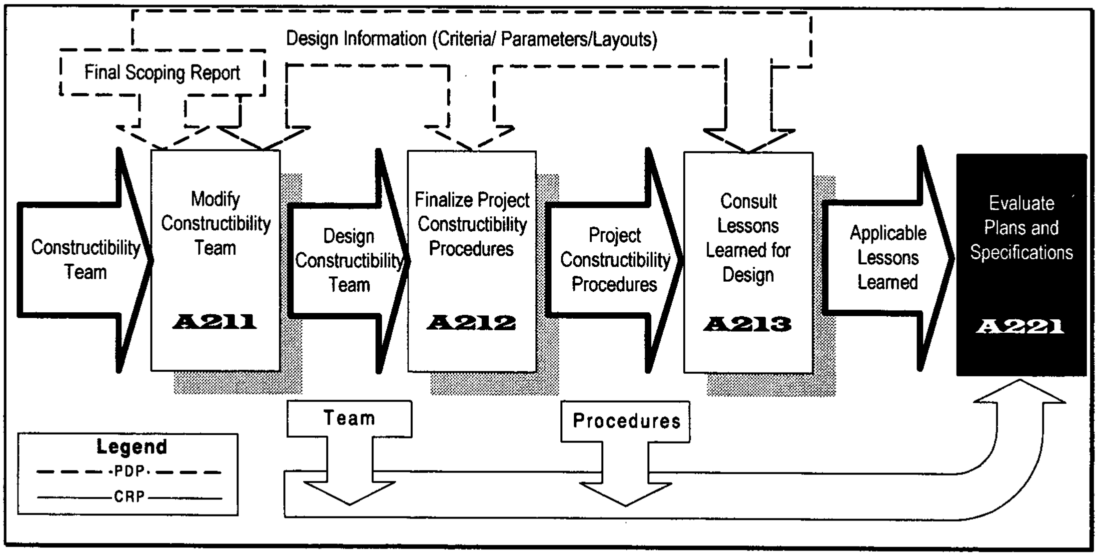


FIGURE A21.2
Integration of the CRP with the PDP during Preliminary Design

Modify Constructibility Team

Steps		Actions	Tools
1. Review project study report and proposed composition of constructibility team	☑	Analyze the technical requirements of the proposed design alternatives.	Constructibility Resources **(T210)** Constructibility Engineers **(T113)** Value Engineering **(T206)**
	☑	Search for areas where specialized knowledge and input may result in improvements to the design or avoidance of problems.	
	☑	Analyze the proposed constructibility team to determine if appropriate areas of expertise and knowledge are covered.	
2. Determine modifications required to the size and composition of the team	☑	Evaluate areas of expertise that may be beneficial to the project, but are under-represented on the proposed constructibility team.	
	☑	Identify the level of expertise required in each area and recommend modifications of the team to satisfy project needs.	
	☑	Confirm availability of possible team members.	
3. Modify the team	☑	Assemble key members of the constructibility team that are capable of providing necessary constructibility analysis and input for the project during the design phase. *The team will be a dynamic entity, with people resources acquired as needed to address constructibility issues, perform detailed reviews, and help solve specific construction related problems.*	Partnering **(T109)** Team Building **(T112)**

Tool Applications

- Decide among resources — who goes on and off the team.
- Reorient new constructibility team members through team building techniques — there are now new and different team players.
- At this point, a value engineering firm may be considered as a member of the modified team.
- If design is being outsourced, the concept of partnering may be utilized at this stage.
- Use partnering to look for "rocks in the road" or constructibility issues.
- Use value engineering as a tool to determine not just those functions that have cost savings associated with them, but also constructibility aspects to them.

Issues to Consider

Agency Constructibility Policy

- Team composition and leadership through CRP Workbook Guidelines
- Use of constructibility consultants or coordinators

Contract Strategy

- Level of involvement of constructibility consultant or design engineers, or construction manager
- Agency involvement in design process
- Type of expertise required

Project Complexity

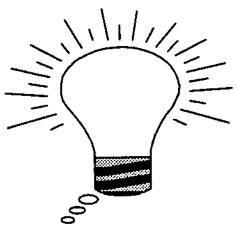
- Potential size of constructibility team
- Type of expertise required

Resource Constraints

- Budget allocated for constructibility effort
- Availability of potential team members

Formality of Project Constructibility Process

- Frequency of constructibility reviews
- Assignment of responsibilities and duties



Tips

Design Constructibility Team Composition

Constructibility Team	Possible Members
Core Team Members	o Design team representative o Construction experts o Planning and owner agency representative
Ad Hoc Members	o Structural consultants o Project management experts o Safety, environmental, budget experts o Value engineering and budget experts o Right-of-way and property experts o Traffic, maintenance, and level-of-service experts o Specialized engineers and consultants o Contractor agency representative (AGC, ARTBA)

Examples

The Buffalo Gap Intersection

Core players on the constructibility team during planning were:

- the Project Design Engineer
- the Area Engineer

As preliminary design is started, the team is modified to add the following people on an ad hoc basis:

- City Engineers (traffic signalization),
- District Maintenance Engineer, and
- District Construction Engineer.

It is determined that a value engineering study would benefit this project. The Project Design Engineer requests a value engineering team to be assembled, which will include:

- an outside value engineering consultant
- a Project Development Engineer from the State Design Division
- a Design Engineer from another urban district who has expertise in fast-track concrete.

The Loop 322 Interchange

The following core players were included in the constructibility team during planning:

- Project Design Engineer
- Field Area Engineer
- District Construction Engineer (Constructibility Engineer)
- District Design Engineer

The team is modified to include the following players on an ad hoc basis:

- Traffic Engineer
- Experienced Project Inspectors (in-house)
- City Planners
- Maintenance Engineer
- Local contractors

Finalize Project Constructibility Procedures

Steps		Actions	Tools
1. Review project objectives and proposed level of program formality and team composition	☑	Examine project objectives and constructibility strategies including mechanisms to be used to help attain project objectives through constructibility.	Policy and Objective Statements **(T101)** Level of Formality **(T204)**
	☑	Review pertinent issues that determined formality of constructibility process and processes required to achieve proposed level of formality.	
2. Determine desired team organization and functions	☑	Review expertise available within and outside the constructibility team.	
	☑	Decide the most appropriate team organization that will promote successful project constructibility reviews.	Constructibility Organization Structure **(T104)**
	☑	Establish responsibilities, procedures, priorities, and communication channels for constructibility process.	Constructibility Meetings **(T102)**
	☑	Familiarize key team members with individual roles and duties.	
3. Document finalized procedures and responsibilities	☑	Record assigned responsibilities, establish channels of communication, and group structure and sources of lessons learned experiences.	Implementation Responsibility Matrix **(T111)** Project Constructibility Agreement **(T202)**

Tool Applications

- Based on the level of formality, determine the frequency of reviews or constructibility meetings.
- The constructibility project agreement is used to create team buy-in and commitment to responsibilities and procedures (see Tips).

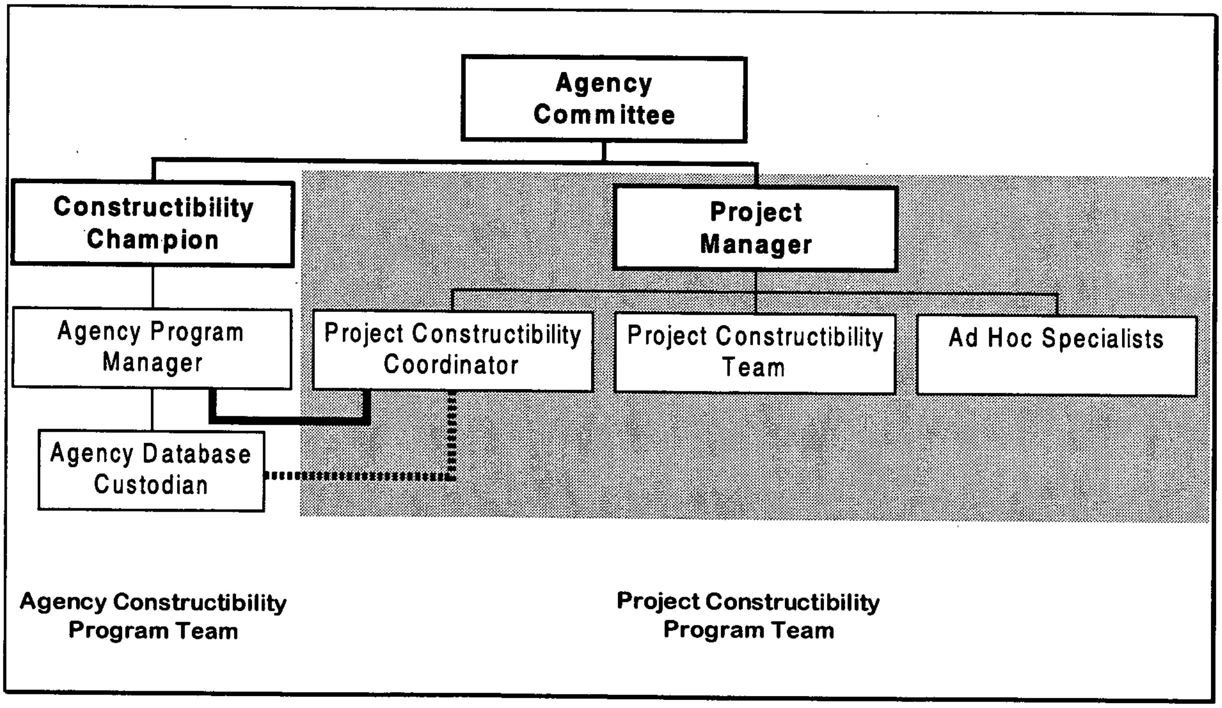


FIGURE A212
A Typical Constructibility Organization Structure

Tips

Project Constructibility Procedures Should Include:

WHO	Team Size and Make-Up
WHAT	Team Rules and Responsibilities
WHEN	Frequency, Timing, and Requirements for Constructibility Analysis
HOW	Methods for Capturing Constructibility Suggestions, Ideas, and Comments and for Incorporating Them into Design Documents

Issues to Consider

Agency Constructibility Policy

- Requirements for project constructibility reviews
- Standard structure and content of project constructibility procedures

Formality of Constructibility Process

- Level of documentation required of project constructibility procedures
- Contract language to support use of constructibility process
- Frequency and timing of constructibility reviews

Resource Constraints

- Budget allocated for constructibility

Key Players: The Modified Constructibility Team

- Project Manager
- Designers
- Constructibility Engineers
- Maintenance Engineers
- Traffic Engineers
- Consultants/Construction Managers
- Inspectors
- Contractors

Examples

The Buffalo Gap Intersection

Team Responsibilities

The Project Design Engineer and the Area Field Engineer will have responsibility for constructibility analysis and reviews.

Project Constructibility Procedures

During the design phase two formal meetings are planned to discuss constructibility issues. One meeting will incorporate value engineering and allow three days to produce recommendations for design improvement. The second meeting will include all other ad hoc members to discuss construction, maintenance, and traffic issues related to design. Both meetings will produce written reports for future reference.

The Loop 322 Interchange

The constructibility team is broken down into special areas of construction. Monthly reviews will be held with the traffic safety team. The traffic safety review committee will meet monthly to review traffic control plans in terms of existing routes, proposed routes, and detours. Public inputs will be accepted.

Three division team meetings will ocurr at 30/60/90% of design completion to examine:

- bridge spans
- retaining walls
- equipment needs
- materials
- construction techniques
- adjustments in traffic control plans
- work sequencing

Value engineering meeting will ocurr at 30% completion of design.

All suggestions and ideas will be documented in hard copy format and added to project files.

Consult Lessons Learned for Design

Steps		Actions	Tools
1. Access sources of lessons learned	☑	Access available constructibility information, searching for lessons related to major constructibility issues.	Operations and Maintenance Inputs **(T103)** Constructibility Engineers **(T113)** Post-Construction Reviews **(T201)** Constructibility Resources **(T210)** Databases **(T302)** CD-ROM/ Multimedia/ Hypermedia **(T303)**
2. Identify and organize applicable lessons learned	☑	Identify and select best ideas, procedures, and/or techniques applied on projects with conditions similar to the project being developed. *Lessons learned should deal with not only what issues need to be addressed, but also when during detailed design they should be addressed.*	
3. Document specific lessons learned applicable to the project design	☑	List applicable lessons learned as a basis for formulating constructibility suggestions.	

Tool Applications

- Constructibility engineers and resources are vehicles for personal experiences.
- CD-ROM and databases are vehicles for documented experiences.
- Post-construction reviews from past similar projects can be consulted for reviewing constructibility lessons learned.

CD ROM/ Multimedia/ Hypermedia (T303)

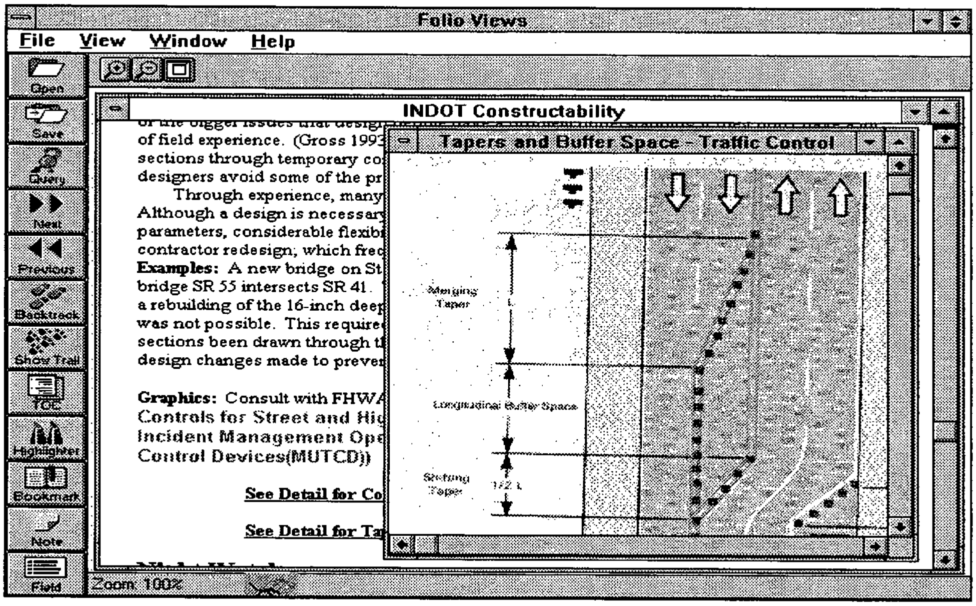


FIGURE A213 The User Interface of The Multimedia CD-ROM Constructibility System Developed for The Indiana DOT

Issues to Consider

Constructibility Concepts (see Tips)

- Specific lessons learned that facilitate application of concepts

Project Complexity

- Types of projects providing lessons learned in similar circumstances

Project Constructibility Procedures

- Sources of lessons learned
- Approach to use lessons learned

Existing Lessons Learned Sources

- Past experiences of project personnel
- Past experiences of non-project personnel (agency, consultants, and other resources)
- Project history files
- Databases (manual and electronic)
- Past experiences of local contractors, contractor associations, and material suppliers

Level of Preliminary Design Detail

- Design criteria and parameters available?
- Survey of utility location and drainage areas complete?
- ROW requirements identified?
- Geometric alignments developed?
- Bridge layouts available?

Key Players

- Constructibility Team
  - Project Champion (Project Manager)
  - Project Designer (Design Engineer)
  - Constructibility Engineer
  - Representative from city
  - Local Contractors/Associations
- Project Programmer
- Field (Area) Engineers
- Project Manager/Engineer

Tips

Some Constructibility Concepts

- Is there sufficient space on the project for temporary stockpiling?
- Are relocated utilities shown in their new location on the plans or referenced documents?
- Is it possible to allow access through the ROW fence with temporary cattle guards on interstate highways to reduce haul lengths to materials sources?
- Are there restrictions on access to site or other sensitive environmental issues?
- Are soil conditions conducive for trenching?
- Has offsite drainage been considered?
- Does the site have any overhead utilities that will conflict with operation of cranes?
- Has access for affected local business or residents been considered while the detour is in use?
- Can traffic conflicts be avoided by constructing temporary over/under passes for hauling equipment in high volume areas?

Examples

The Buffalo Gap Intersection

Approach

- The Project Design Engineer and Area Engineer reviews the sequence of work to determine if the schedule can be accelerated.
- Field documents are reviewed on fast-track concrete to identify optimum pavement depth, and realistic construction schedules.
- Past intersection projects are reviewed to capture cost data for fast-track concrete.

The Loop 322 Interchange

Approach

The constructibility team reviews bridge designs in terms of:

- aesthetics — use of single columns as opposed to multiple columns, and placement of landscape pavers
- alternative retaining wall designs

Constructibility comments from local contractors will be solicited, especially in the areas of equipment mobilization and material handling.

Apply Constructibility during PS&E Development

During PS&E development project plans and specifications are prepared, and supporting engineering analysis is prepared. The major tasks performed are as follows:

- Completion of construction drawings for structures, pavements, drainage, construction phasing, and traffic control.
- Acquisition of necessary ROW and determination of utility adjustments.
- Preparation of contract documents and final project cost estimates.

The constructibility team reviews the plans, specifications, and estimates as they are developed. This team searches for areas where constructibility can enhance design documents through recommended improvements. Approved improvements are forwarded to the design team.

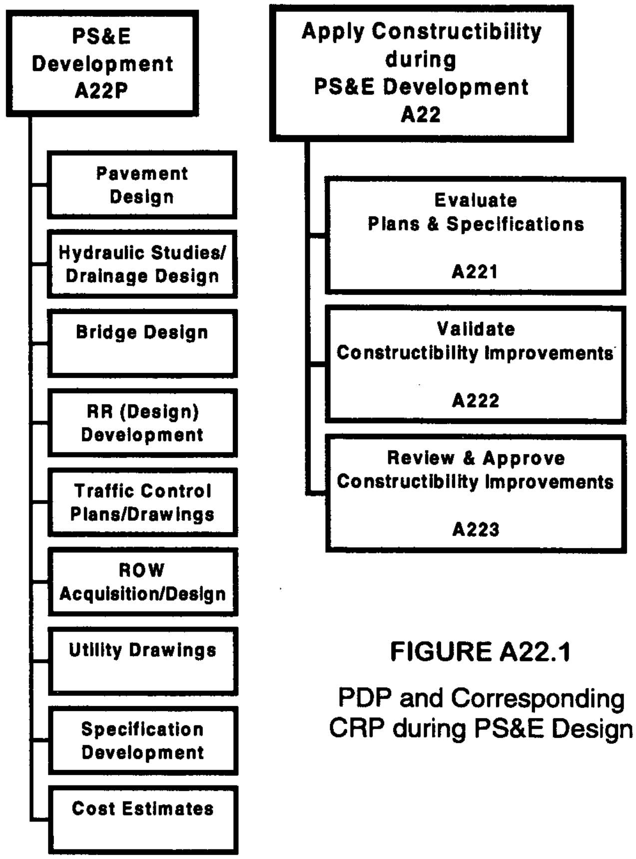


FIGURE A22.1

PDP and Corresponding CRP during PS&E Design

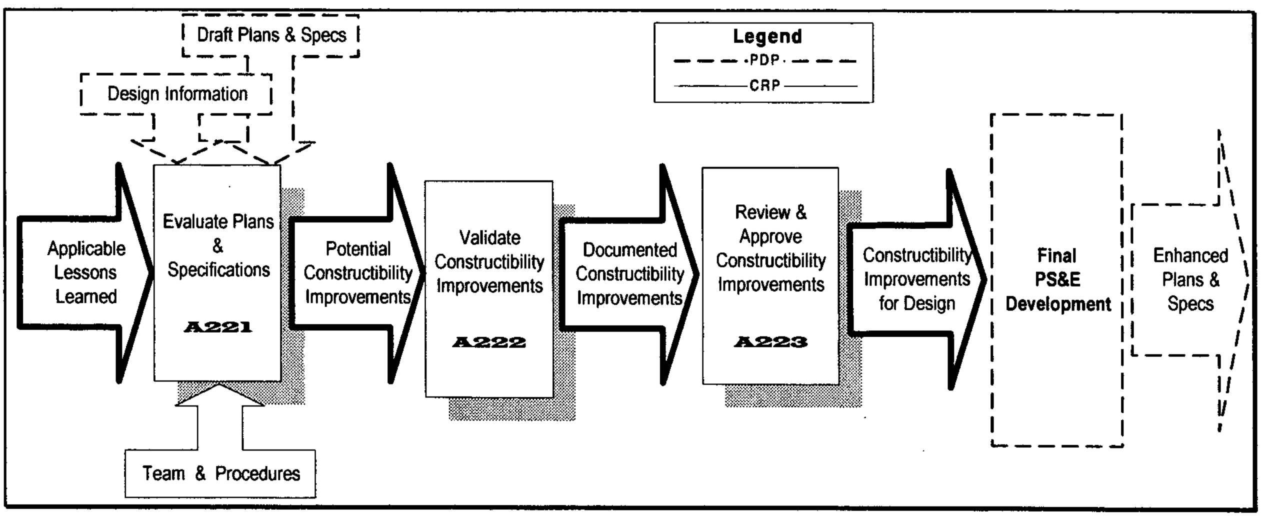


FIGURE A22.2
Integration of the PDP with the CRP during PS&E Development

Evaluate Plans and Specifications

Steps		Actions	Tools
1. Test applicable lessons learned against design	☑	Identify similarities and differences between the current project and those from which the lessons learned have been extracted.	Agency Constructibility Checklist **(T203)** Critical Path Method **(T208)**
	☑	Determine the impact of the differences on the project and the mechanisms through which these impacts act.	
2. Identify areas of congruency	☑	Distinguish those lessons learned that demonstrate similar constructibility patterns to current project under review.	
3. Generate potential constructibility comments	☑	Use lessons learned that are valid for the project to generate constructibility suggestions for draft plans and specifications.	Suggestion Form **(T105)** Constructibility Meetings **(T102)** CAD/GCCA **(T301)** CD-ROM/ Multimedia/ Hypermedia **(T301)**
	☑	Formulate new ideas and suggestions for improvement by evaluating draft plans and specifications being developed.	

Tool Applications

- CPM helps determine schedule impact. It needs to be reviewed, based on anticipated rates, to see if a construction-driven schedule is realistic.
- CAD can be used for detailed graphical constructibility analysis to generate potential improvements.
- CD-ROM may be used to access design details which then become potential improvements.

Suggestion Form (T105)

Constructibility Suggestion Form

Suggestion:__________
Discipline/Craft Affected:__________
Description & Illustration:__________
Originated By:__________ Date:__________
Project:__________
Assessment of Impact to Project: (to be completed by the Constructibility Coordinator)
Cost:__________
Schedule:__________
Quality:__________
Safety:__________
Engineering:__________
Need to change/update corporate standard specs?__________
Other:__________
Approvals:__________
Comments:__________

FIGURE A221.1
An Example Constructibility Suggestion Form

Agency Constructibility Checklist (T203)

A checklist identifies potential areas in the project design where constructibility may be an issue. A standardized agency checklist will ensure that these issues (or features) are considered from a constructibility perspective. This checklist can be general, such as a set of questions concerning various aspects of the project scope, or specific to certain types of tasks such as clearing/grubbing/excavation.

1. CLEARING/GRUBBING/EXCAVATION				
Item No.	**Feature to be Checked**	**OK**	**Not OK**	**N/A**
1-1	Delineation of limits of grubbing, clearing, and landscaping.			
1-2	Sites for temporary fill and top soil storage. Laydown area on same side of road as fill area. Indication of dump sites.			
1-3	Provisions (such as phasing of work) to minimize borrow and use of excavated material for fill.			

Suggested Changes (to be completed for items checked "Not OK")	
Item No.	**Description of Changes**
Designer's Comments:	

FIGURE A221.2
An Example Agency Constructibility Checklist

Issues to Consider

Resource Constraints

- Time available to make changes or alterations
- Dollars available for constructibility reviews

Project Constructibility Procedures for Design

- Level of documentation required
- Frequency and mechanisms for constructibility analysis

Constructibility Concepts

- Specific areas for constructibility analysis

Key Players

- The Design Constructibility Team
- Value Engineers
- Estimators
- Transportation Planners

Tips

Possible Areas for Constructibility Improvements

Area	Potential Improvement
Construction Contract Language	• Eliminate duplicate contract requirements • Eliminate conflicts among various contract documents • Redistribute risks
Project Staging	• Enhance site access and available work areas • Improve traffic flow patterns during construction • Balance earth movements • Minimize number of stages
Contract Conditions	• Establish realistic bidding schedule • Establish realistic construction schedule • Change construction methods
Project Specifications	• Standardize specifications • Develop QA/QC specifications

Tips
Detailed Constructibility Review

- Understand design intent
- Reference applicable lessons learned
- Review plans with emphasis on roadway plan sheets and location/type of structure
- Perform rough takeoff calculations on major work items
- Review construction staging plan or develop alternative approach
- Check overall traffic control plan
- Review cross-sections for project and compare with intended construction sequence, then ask: "Will earthwork needs be met within each stage?"
- Visit project site. Ask: "Has anything been overlooked? Are there any access problems?"
- Determine availability of materials, type of roadway excavation or borrow
- Re-analyze construction strategy, based on plan review and familiarity with typical construction methods/operations
- Determine critical path activities
- Review schedule based on anticipated production
- Review checklist for completeness

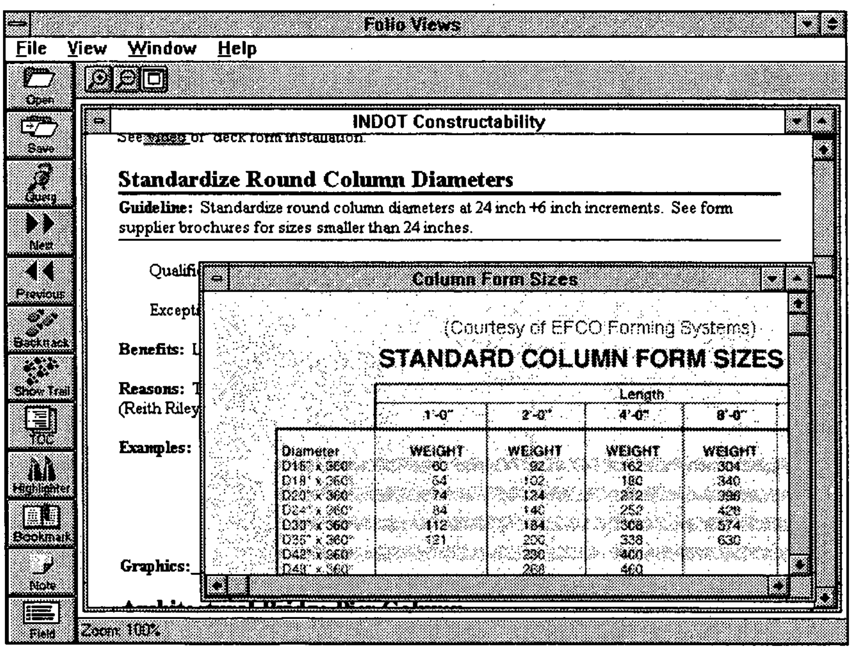


FIGURE A221.3
The User Interface of the Multimedia CD-ROM Constructibility System Developed for the Indiana DOT

Examples

The Buffalo Gap Intersection

Review of Lessons Learned

The constructibility team has discovered that the use of CPM on similar transportation projects was limited. There was insufficient information available and expertise is lacking. There are very few contractors available who have effectively used CPM scheduling.

Potential Constructibility Improvements

- Fast-track concrete still remains valid and a suggestion has been forwarded for detailed review.
- Reducing lane widths has surfaced as a potential idea to accommodate restricted right-of-way.
- Project can avoid cost by eliminating retaining walls that would otherwise be required.
- Change of construction detour has been suggested to use existing pavement turnarounds. This will create a larger construction work area, prevent major detour construction, and maintain adequate capacity.

The Loop 322 Interchange

Through a review of lessons learned the constructibility team has made the following *constructibility suggestions:*

- At the beginning, move traffic to the perimeter of the project to have adequate construction work area.
- The height of the retaining wall is too great for cast-in-place construction, the unit cost for a mechanically stabilized earth-type wall is less than that for cast-in-place construction, mechanically stabilized earth prevents erosion, and also material is locally available; therefore, use mechanically stabilized earth construction.
- Use prestressed concrete panels for bridge construction because these create larger work area, reduce labor, increase safety, and allow for faster construction.
- Instead of multiple columns use single columns that would enhance the appearance of the bridge, allow for standardized size of the column and, as such, facilitate the reuse of formwork.

Validate Constructibility Improvements

Steps		Actions	Tools
1. Perform detailed benefit/cost analysis and prioritize according to project objectives	☑	Perform benefit/cost analysis for each constructibility improvement idea.	Benefit/Cost Analysis **(T209)**
	☑	Prioritize suggested improvements according to the significance of their impact on the project constructibility effort.	
2. Document constructibility improvements	☑	Document those constructibility improvements offering the greatest potential benefit to the project while still satisfying the project design basis and objectives.	Idea/Lessons Learned Log **(T207)**

Tool Applications

Idea/Lessons Learned Log (T207)

An Idea/Lessons Learned Log provides a format for documenting ideas and lessons learned throughout a project. This matrix allows for all the lessons to be stored centrally and have their areas of application denoted. It also allows for the status of each lesson learned to be monitored. Lessons may apply to more than one area, and areas may be affected by more than one lesson.

Issue Code	Lessons Learned	Phase	Function	B/C	Approval		
					Project	Database	Checklist
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐

FIGURE A222.1
An Example Idea/Lessons Learned Log

Benefit/Cost Analysis (T209)

Information needed:

- described constructibility idea/suggestion
- impact (cost/schedule)
- benefit/cost
- hard/perceived benefits

Estimates are developed for the final cost of implementing each constructibility suggestion. These costs are then compared to the expected benefits that will be derived from the proposed change.

Constructibility Suggestion Benefit/Cost Form

Project Name:

Existing Design Description:
Alternate Design Description:

Assessment of Cost Impact:

Redesign Cost:
- Labor________________
- Material________________
- •
- •
- Total________________

Original Cost:
- Labor________________
- Material________________
- •
- •
- Total________________

Assessment of Benefit Impact to Project:

Cost Savings

Actual (Hard $)
- Labor________________
- Material________________
- •
- •

Perceived (Soft $)
- Schedule ____________
- User Savings___________
- •
- •

Total Benefit__________

Existing Design Description A	% Complete of Total Project at Proposed Change	Alternate Design Description B	Cost Difference Between A and B	Benefit		% Accuracy of Cost Data
				Actual (Hard$)	Perceived (Soft$)	
			Redesign: Labor: Material: Equipment:	Labor: Material: Equipment:	Schedule: User:	
			Total:	Total:	Total:	

FIGURES A222.2 & A222.3
Example Constructibility Suggestion Benefit/Cost Forms

Issues to Consider

Budget Limitations

- Total project cost
- Life cycle cost of project

Schedule Limitations

- Impact on construction schedule
- Impact on design schedule

Resources Limitations

- Personnel
- Materials
- Equipment

Project Constructibility Procedures

- Types of information documented
- Form in which information is documented

Key Players

- Constructibility team
- Designers
- Value Engineers
- Estimators
- Transportation Planners

Examples

The Buffalo Gap Intersection

Pavement reviews indicate that fast-track concrete would yield a higher cost — about $7,000 more in equivalent uniform annual cost. However, it would also provide the shortest construction period, saving almost three months.

Due to the requirement to finish the project before Thanksgiving, the constructibility team concludes that the schedule was the primary project objective.

Suggestions are made to use existing turnarounds for detours, which would provide an improved work area while maintaining adequate traffic capacity.

The Loop 322 Interchange

The constructibility team performs benefit/cost analysis on the constructibility suggestions it made.

- **Traffic Control** — move traffic to the perimeter; this would provide adequate construction work area, increase concurrent construction, and improve time but would require frontage road upgrade.
- **Retaining Wall Design** — The cost for reinforced gravity wall construction is estimated to be $27/sq. ft. compared to $35/sq.ft. for cast-in-place construction. Constructing embankment while building mechanically stabilized earth retaining wall will eliminate form work for concrete placement; such concurrent operations will save 5-6 months in schedule. With mechanically stabilized earth, work can be done in inclement weather.
- **Prestressed Concrete Panels for Bridge Design** — These create a larger and safer work area, which facilitates faster operation, saving a total of 7 months during construction. Although the material cost is higher, significant savings occur in labor cost.

Review and Approve Constructibility Improvements

Steps		Actions	Tools
1. Review constructibility improvements	☑	Compare benefit/cost analyses already developed for constructibility improvements.	
	☑	Analyze scope of each comment to make sure there are no conflicting improvements.	
	☑	Compare improvements that address the same situation to determine the best option.	
	☑	Determine effects of individual improvements on the performance of other improvements.	
	☑	Modify and adjust benefit/cost analyses.	
2. Approve constructibility improvements for implementation	☑	Determine net effect of implementing the constructibility improvements.	
	☑	Select set of improvements with largest net benefit for project.	

Issues to Consider

Budget Limitations

- Total project cost
- Life cycle cost of project

Schedule Limitations

- Timing of review process
- Impact on design schedule
- Impact on construction schedule

Approval Requirements

- Agency policy determines approval by dollar magnitude of change
- Agency policy dictates review and approval process

Key Players

- Constructibility Team
- District Engineer
- Chief Design Engineer

Project Constructibility Procedures

- Dictate mechanisms for review
- Dictate frequency and timing of reviews
- Dictate who is involved with reviews
- Dictate approval responsibility and authority

Examples

The Buffalo Gap Intersection

Review — Cost: Fast-track Jointed Concrete Pavement (JCP) Equivalent Uniform Annual Cost (EUAC) is $29,000 versus an EUAC of $22,000 for Asphaltic Concrete Pavement (ACP).

Review — Schedule: Fast-track JCP can be completed three months earlier than ACP.

Review — Construction Access: Use existing turnarounds for detours to maintain capacity versus a one-lane reduction proposed in initial design of detours. This will reduce user cost.

Approval: District Engineer has approved both recommendations based on accelerated completion and maintaining existing traffic capacity, although conceding higher construction costs for achieving these two objectives.

The Loop 322 Interchange

Review — Traffic Control: The perimeter detour decreases traffic mobility and increases cost in temporary detours, but improves work area and speeds up operations.
Review — Gravity Wall: At $27/sq.ft., mechanically stabilized earth is cheaper and faster for construction than the cast-in-place option.
Review — Single Column Design: Single columns are costlier, but more appealing aesthetically.
Review — Prestressed Concrete Panels: Prestressed concrete panels require higher material cost, lower labor cost, and speed up construction, but are difficult for maintenance operations.

Approval: Approval is given to use mechanically stabilized earth retaining walls. The contractor is given the option to use prestressed concrete panels or metal deck forms. Because of aesthetic requirements, single columns are approved in spite of higher cost. The perimeter traffic detour plan is rejected due to expected reduction in mobility and the cost of temporary detours that cannot be recovered. Also, the benefit of the improved work area would not speed up operations significantly.

Apply Constructibility during Final Design

During this phase, final review and approval of the PS&E is performed. After this the project is released for construction.

During final design, the constructibility team summarizes all constructibility improvements incorporated into PS&E documents. The main purpose is to capture enhancements in PS&Es from constructibility improvements so that these enhancements can be conveyed to the contractor and referred to during construction as necessary.

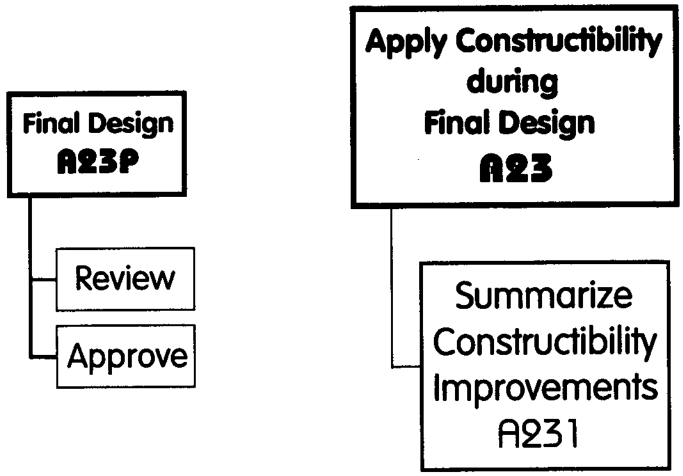


FIGURE A23.1
PDP and corresponding CRP during final design

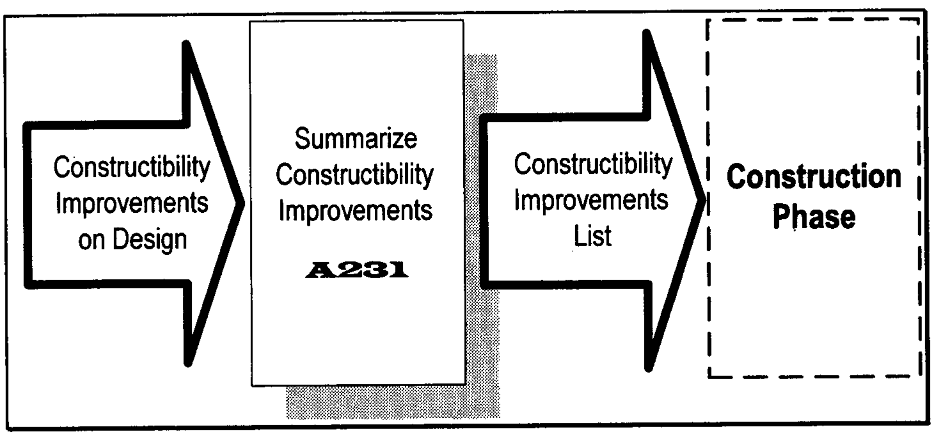


FIGURE A23.2
The CRP during final design

Summarize Constructibility Improvements

Steps		Actions	Tools
1. Compile constructibility improvements	☑	Compile all constructibility improvements that have been approved for implementation.	Idea/Lessons Learned Log **(T207)**
	☑	Verify that all constructibility improvements affecting individual areas of expertise of each team member are included. This prevents overlooking those comments that do not fall clearly within one area of expertise, but are common to several areas.	
	☑	List improvements according to a predetermined structure established in the project constructibility procedures.	
2. Compile potential constructibility improvements not selected	☑	Compile improvements not selected for potential incorporation into a lessons learned database for future projects. *Improvements not used should be documented to include reasons why they were not selected and the benefit/cost analysis related to these.*	

Issues to Consider

Key Players

- Constructibility Engineer
- Constructibility Team

Project Constructibility Procedures

- Format for compiling lessons learned
- Required parameters
- Lessons learned database requirements, such as data format
- Compilation requirements, such as inclusion of areas of expertise or improvements not used

Benefit/Cost Information of the Improvements

- Level of benefit/cost
- Sensitivity of benefit/cost ratios to external factors

Examples

The Buffalo Gap Intersection

Constructibility improvements are captured in a final written document and added to the project files.

Constructibility Improvements Incorporated into Design

- Use fast-track concrete pavement
- Use existing turnarounds for traffic detours
- Shorten schedule three months

Constructibility Improvements Not Used

Use of CPM has potential to aid in analysis of construction schedule when project is schedule driven and access constitutes a problem. Use of CPM on future project should be considered if expertise can be developed.

The Loop 322 Interchange

Constructibility improvements are captured in a final written document and added to the project files.

Constructibility Incorporated into Design

- Use mechanically stabilized earth retaining wall construction
- Use single column design for bridge
- Use prestressed concrete deck panels for bridge design

Constructibility Improvements Not Used

The traffic control plan to carry traffic around the perimeter of the project during construction is discarded due to the need for improved traffic mobility.

Apply Constructibility during Construction Phase

▲▲▲

The construction phase of the Project Development Process begins after PS&E's are approved and the project bidding process has commenced. By then, project plans and specifications have been developed with input from the constructibility team and reflect approved enhancements. The construction phase incorporates three major activities:

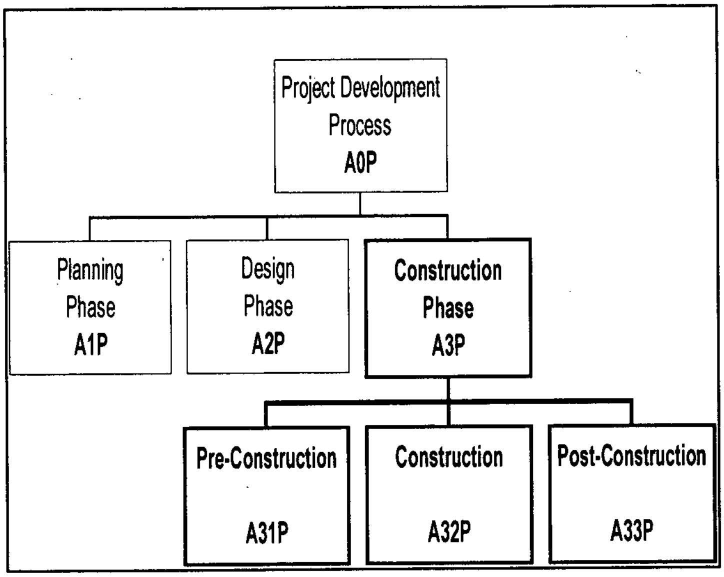


FIGURE A3.1
PDP during Construction Phase

- **Pre-Construction** — bids are solicited, contracts are awarded, and project participants plan and organize for the construction effort.
- **Construction** — the facility is physically built.
- **Post-Construction** — final documentation of construction activities is performed, the constructed facility is accepted by the agency, and operation and maintenance of the facility begins.

The major emphasis of constructibility analysis during construction is twofold:

- to **help solve** construction problems
- to **capture and document** constructibility information for future use

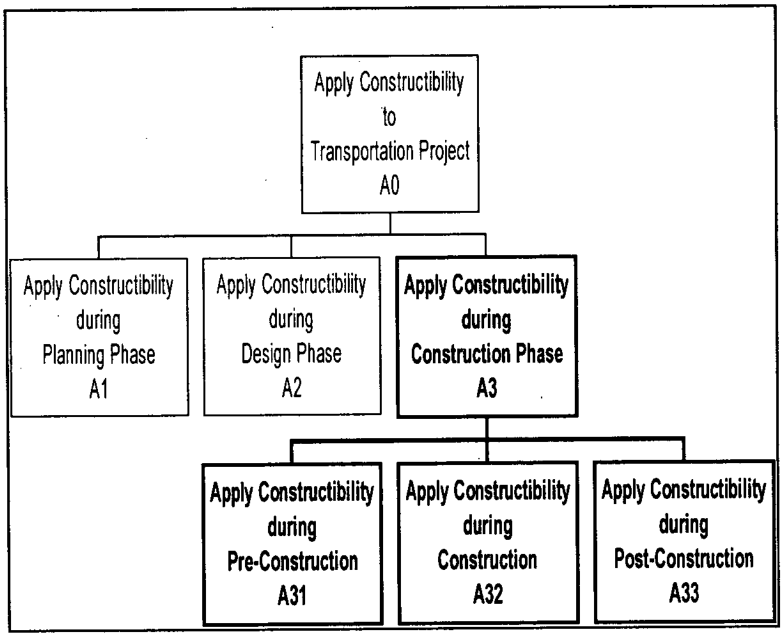


FIGURE A3.2
CRP during Construction Phase

Apply Constructibility during Pre-Construction

During pre-construction the contract is awarded to the lowest responsible bidder. This phase has the following major steps:

- Bid packages are distributed according to agency procedures and potential bidders are given access to the design documents.
- A **pre-bid conference** is scheduled to address questions or issues raised, or for addenda to be fully explained and understood by all parties. Interested bidders may ask questions for clarification.
- After all issues are clarified, bids are received, and the traditional bid evaluation process is performed.
- Contract is awarded to the lowest responsive
and responsible bidder and the pre-construction conference is held with the contractor.

The focus of the CRP during construction is:

- to ensure understanding of design and contract requirements
- to modify the constructibility team and procedures for field implementation

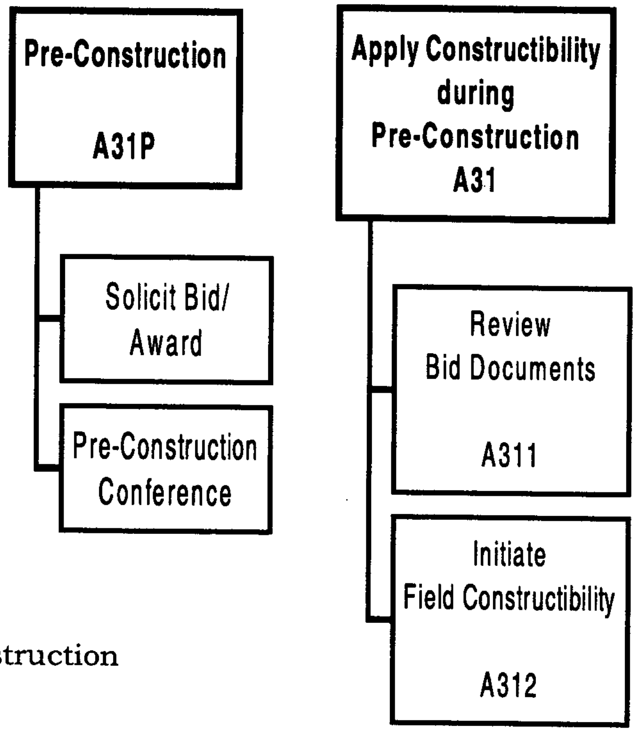


FIGURE A31.1
PDP and Corresponding CRP during Construction Phase

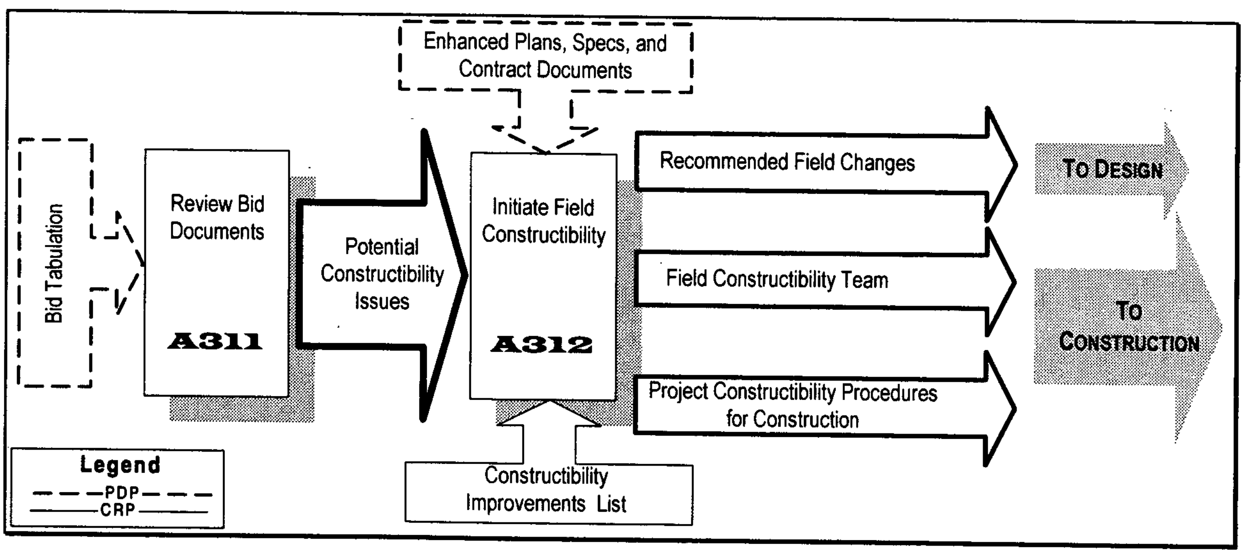


FIGURE A31.2
Integration of CRP with PDP during Pre-Construction Phase

Review Bid Documents

Steps		Actions	Tools
1. Review bidder's queries	☑	Address all questions in an open forum to prevent issuance of different conditions to different parties.	Pre-Bid Conference **(T106)** Contract Clauses/Incentives **(T108)**
	☑	Interpret these questions and comments for potential improvements to be made to the design or contract documents.	
2. Review bid tabulation sheets	☑	Scrutinize bid tabulation sheets to ascertain if bidders are interpreting available documents differently, indicating possible lack of clarity, conflicting information, and missing constructibility information, and to uncover contractual deficiencies.	
3. Develop list of potential constructibility issues	☑	Collect information for future use.	

Tool Applications

- The pre-bid conference provides a forum to ensure that the parties know and understand the constructibility improvements that are compiled and adapted for the project.
- The pre-bid conference is also an opportunity to develop and obtain additional constructibility issues from the various participants.
- A use of contract incentives may be CPM as a requirement in the contract, or shared savings from constructibility improvements generated by the contractor.

Issues to Consider

Contract Strategy

- Compliance with requirements of low bid contracting system
- Compliance with contract language relevant to constructibility
- Involvement of outside participants (consultants, construction manager, etc.)

Project Constructibility Procedures

- Reviews of contract bids from constructibility perspective

Technology

- Available technology or technology required for the project may affect bids

Geographic Location

- Topography, access, and proximity to labor and material sources are some of the location variables that may influence bids

Key Players

- Construction Engineer
- Project Design Engineer
- Estimator
- Area (Field) Engineer
- Project Manager
- Construction Manager

Examples

The Buffalo Gap Intersection

Bid tabulations show all bidders above the original estimate.

The critical factors influencing bids are presumably traffic control and fast-track concrete.

Follow-up with contractors reveals inflated prices due to the use of fast-track concrete.

The Loop 322 Interchange

Fractured fin design of the retaining wall has been found to drive up cost. The cost is, however, still within acceptable range. Bids, on an average, are $500,000 below engineers' estimate.

Pre-bid conference with participating contractors has addressed the issue of materials quality. It has been decided that the earth to be used for reinforcement must be below 20PI. This requirement is supposed to affect material source.

Use of fractured fin design and material source for fill are placed on the list of potential constructibility issues.

Initiate Field Constructibility

Steps		Actions	Tools
1. Reorganize and initiate constructibility team	☑	Determine expertise that will be required during construction phase.	Constructibility Engineers **(T113)** Constructibility Resources **(T210)**
	☑	Modify team makeup and size to match expertise required.	Constructibility Organization Structure **(T104)**
	☑	Orient new team to procedures, schedules, working conditions, constructibility strategies, and constructibility developments included in PS&E.	Pre-Construction Meeting **(T107)** Partnering **(T109)** Contractor Determined Schedule **(T110)**
2. Review and modify constructibility procedures for construction	☑	Establish constructibility procedures for construction based on contract requirements, constructibility procedures used during design, and expected constructibility issues.	Constructibility Meetings **(T102)** Implementation Responsibility Matrix **(T111)** Project Constructibility Agreement **(T202)**
3. Review plans and specifications	☑	Analyze contract plans, specifications, estimates, and list of constructibility improvements to orient team toward constructibility and convey design intent/objectives to construction.	Value Engineering **(T206)**

Initiate Field Constructibility

4. Recommend field changes from preconstruction review	☑	Evaluate any proposed changes that may occur from reviewing the PS&E in terms of economic impact, impact on the schedule, and final performance of the facility.	Suggestion Form **(T105)** Benefit/Cost Analysis **(T209)**
	☑	Utilize benefit/cost analysis or other techniques to compare different alternatives.	
	☑	Recommend those changes that have the greatest net positive impact on the project and that can be accomplished within approved resources.	

Tool Applications

- The pre-construction meeting provides a forum to ensure that the contractor knows and understands the constructibility issues relevant to the project.
- The pre-construction meeting is also an opportunity to develop and obtain contractor input to the constructibility issues.
- The contractor should also understand any contractual obligations required such as CPM, resources to help collect constructibility lessons learned, and frequency of reviews.
- Use partnering to look for *rocks in the road*.
- Use value engineering as a tool to determine functions that facilitate cost savings as well as constructibility.

Contractor-Determined Schedules (T110)

The contractor is responsible for meeting the milestones of a project. These milestones are decided upon by having a desired project completion date, and the time to complete each required activity. Working backwards, one can find when each activity must begin in order to meet the completion date. These schedules are more accurate if they are determined by the contractor. The contractor has a better knowledge of the production rates and duration required to perform each task. These schedules are determined by the methods used by the contractor and the specific equipment available. This allows the contractor to prepare performable schedules with available resources, thus optimizing the work schedule and satisfying the established requirements.

Issues to Consider

Contract Strategy

- Contract requirements with respect to changes
- Contract language for specific constructibility responsibilities of contractor
- Involvement of outside participants (consultants, construction managers, etc.)

Formality of Process

- Approach to capturing construction experience, new ideas, and suggestions
- Level of documentation required
- Formality of post-construction review of project constructibility process

Resource Constraints

- Budget available determines level of constructibility effort for agency and contractor personnel during construction

Schedule Limitations

- Impact of recommended field changes requiring design modifications on construction sequence and timing

Agency Constructibility Policy

- Importance of and requirements for project-level constructibility during construction

Project Constructibility Procedures for Design

- Basis for developing constructibility procedures for construction

Key Players

- Constructibility Team
- Project Engineer
- Contractor (Construction Manager, Superintendent, Field Engineer, etc.)
- Specialty Consultants and Contractor (Construction Manager, Superintendent, Field Engineer, etc.)
- Project Inspector
- Constructibility Engineer
- Construction Engineer

Examples

The Buffalo Gap Intersection

The constructibility team is modified to include the prime contractor and several specialty consultants and contractors.

In-house personnel added include the Project Inspector. Members leaving the team include the Design Engineer.

A partnering workshop is conducted by the modified constructibility team to address possible *rocks in the road* identified during pre-construction phase.

From this workshop the contractor identifies improvements to the traffic control plan, signal timing, and sequence of work.

The Loop 322 Interchange

The constructibility team is modified to remove City Planners and District Design Engineer and to add the following members:

- Chief Project Inspector (core)
- Prime Contractor (core)
- Subcontractors (ad hoc)
- District Construction Engineer (ad hoc)
- Laboratory Engineers (ad hoc)

Weekly meetings are scheduled with the core team throughout the duration of the project. Meetings are also scheduled before each of the 6 phases of construction, phases being defined in terms of changes in traffic flow pattern.

A bridge construction prework meeting is also scheduled. Construction Management of the Division is called in to interpret survey specifications. Prestressed panel approach for bridge construction is selected.

Apply Constructibility during Construction

During this phase the facility is constructed. Activities performed include the following:

- the **contractor** mobilizes site offices, prepares for construction, defines the schedule, secures specialty contractors and material suppliers, and identifies the equipment necessary, and
- the **owner** agency mobilizes for contract administration, finalizes outstanding ROW and construction access issues, and prepares for construction inspection.

Purpose of the CRP during construction is to:

- **capture** constructibility related experiences and ideas,
- **document** constructibility experiences and ideas for future project use, and
- **administer** contract, inspect and test materials, and facilitate traffic control.

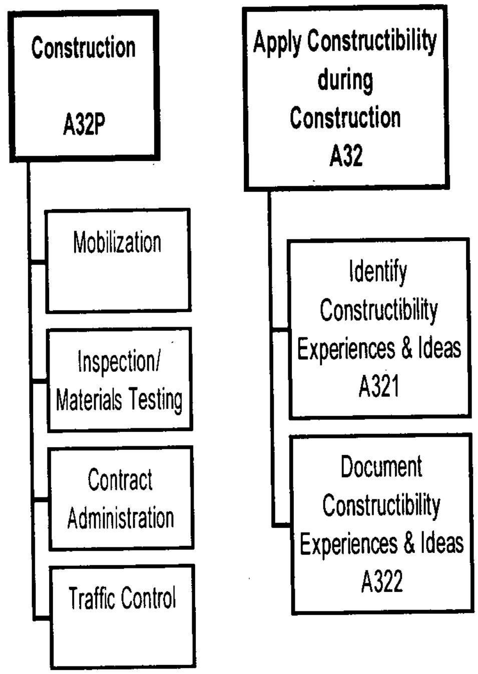


FIGURE A32.1
PDP and Corresponding CRP during Construction Subphase

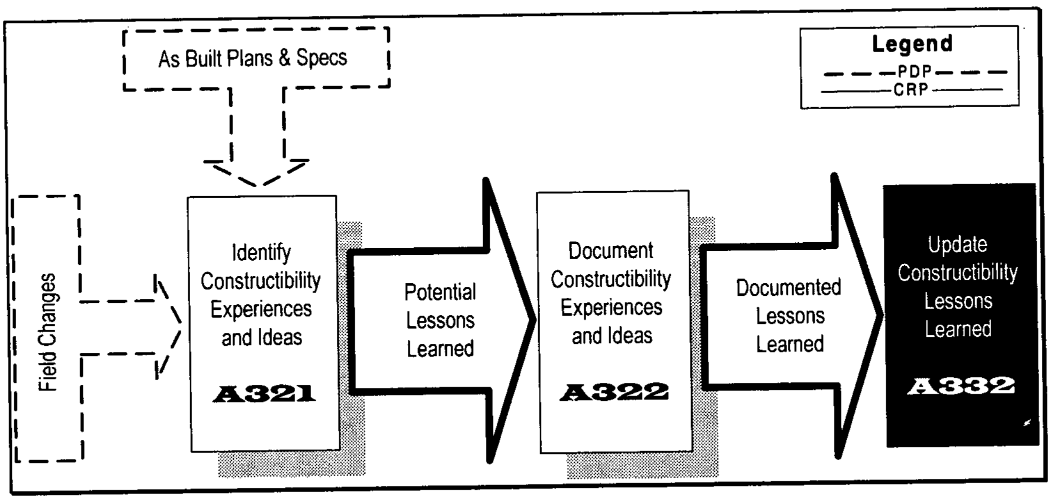


FIGURE A32.2
Integration of CPR with PDP during Construction Subphase

Identify Constructibility Experiences and Ideas

Steps		Actions	Tool
1. Review field change orders during construction	☑	Review field changes and analyze for patterns, tendencies, and reasons for changes that may be related to constructibility.	
2. Review deviations from construction plans	☑	Compare "as built" diagrams to design drawings and analyze, from constructibility perspective, major differences and deviations.	
	☑	Develop explanations for differences and determine if they are constructibility issues.	
3. Interview key personnel	☑	Interview key field personnel — engineers, superintendents, inspectors, and others — to gain insight into project operations in terms of reasons for deviations, possible improvements, unnecessary alterations, and inappropriate efforts to improve the process.	
4. Identify constructibility experiences and ideas	☑	From the data collected, identify ideas and experiences; separate opinions from facts.	

Issues to Consider

Performance Constraints

- Standardization of data collection and documentation
- Accessibility to key personnel for input
- Objective interview instrument
- Criteria for identifying best constructibility experiences and ideas

Resource Limitations

- Sufficient time available
- Right player available

Project Constructibility Procedure for Construction

- Approach to capturing construction experiences and ideas

Agency Policy

- Directives and support for capturing construction knowledge and experience
- Funds to support capture of construction knowledge and experience

Key Players

- Constructibility Coordinator
- Constructibility Team
  - Project Engineer
  - Contractor/Owner
  - District Construction Engineer
  - Area Engineer
  - Specialty consultants and subcontractors
- Database Custodian

Examples

Agency policy would drive the implementation of this construction review. An assigned individual would have responsibility to review field changes and deviations, conduct interviews, and identify best ideas. This will involve time, money, and personnel. On a standard project it may be one person, on a complex project it may be a team. The output would be a list of constructibility ideas to be considered for incorporation into a database.

The Buffalo Gap Intersection

All field changes are captured in the project files. The Project Engineer has discussed project operations with the contractor and this information is captured in job diaries.

One important experience was the use of fast-track concrete, which actually improved work area mobility by allowing construction into otherwise restricted areas. This resulted in faster completion of the project, which is a project objective.

The Loop 322 Interchange

The following change orders are noted on the project file:

- Upgrade roadway surface course to accommodate traffic volume and increased time on the project.
- Remove auto grading specification on the final base course to improve construction sequence, thereby reducing cost.
- Remove emulsion required from base to improve construction schedule.

One review deviation is noted:

- Utilize cement stabilized backfill to improve stability of retaining wall.

Project Design Engineer suggests that borrow sources should be restricted within project limits to improve drainage, even if it means higher hauling costs. Change in survey techniques is also recommended.

Document Constructibility Experiences and Ideas

Steps		Actions	Tools
1. Sort and categorize constructibility experiences and ideas	☑	Categorize desirable ideas by general considerations, such as utility, access, weather, and materials, and by specific considerations, such as earthwork and grading, bases and pavements, pipelines and drainage, structures, traffic control plans, maintenance, and incidentals. Include benefit/cost ratio by project, and by phasing.	Idea/Lessons Learned Log **(T207)**
2. Formally document constructibility experiences and ideas	☑	List the constructibility experiences and ideas for future application. Each one will have a specific format, subject, area of concentration, and cost associated with it.	EDI/Bar-Coding/Pen-Based Technology **(T304)**
	☑	Submit these documents in the proper format and to appropriate custodian.	

Tool Applications

Categorize lessons learned on the idea/lessons learned log by:

- phase (when) and
- function (who)

New technology is replacing paper forms and workbooks and making the collection of knowledge faster and easier via automated diaries to collect, store, and retrieve data.

Issues to Consider

Performance Constraints

- Standardization of data collection and documentation
- Accessibility to key personnel for input
- Criteria for identifying best constructibility experiences and ideas
- Complexity of implementation

Resource Limitations

- Availability of sufficient time
- Availability of right players

Project Constructibility Procedure for Construction

- Approach to capturing construction experiences and ideas

Agency Policy

- Directives and support for capturing construction knowledge and experience
- Funds to support capture of construction knowledge and experience

Key Players

- Constructibility Coordinator
- Constructibility Team
  - Project Engineer
  - Contractor/Owner
  - District Construction Engineer
  - Area Engineer
  - Specialty consultants and contractors
- Database Custodian

Examples

Agency policy would generate the development of a constructibility lessons learned database. A constructibility coordinator or team would be responsible for sorting and categorizing constructibility experiences and ideas to be captured and documented. This will occur towards project completion. Possible documentation formats include hard copy files, microcomputer files, mainframe, and network. The constructibility coordinator would be responsible for managing the database at agency organization level.

The Buffalo Gap Intersection

The project files including constructibility ideas are retained by the construction office. All improvements and constructibility experiences are divided into major categories of work:

- Traffic control
- Concrete pavement — use of fast-track concrete improved construction sequence and completion time
- Traffic signals — manned controllers improved traffic mobility
- Earthwork — embankment and excavation

A constructibility file with each major division of work is retained in the construction office for future reference. The design office will provide the construction office with both a hard and a soft copy of the files including project records, diaries, constructibility ideas, and drawings.

The Loop 322 Interchange

The project files capture all the change order information on:

- Base material
- Roadway surface
- Auto grading specification
- Survey requirements

Experiences in the following areas are also captured:

- Drainage restrictions affecting work sequence
- Use of cement stabilized backfill for reinforced earth retaining wall
- Use of prestressed concrete panels for bridge construction, which sped up the process

Apply Constructibility during Post-Construction

Post-construction activities start after construction operations are completed and routine operations and maintenance procedures have begun. During this phase:

- punch lists, final project evaluation, and as builts are completed and verified;
- cleaning crews, pavement marker crews, signilization crews, traffic control personnel, and users have access to the facility; and
- agency personnel assess the efficiency of design and construction.

The Constructibility Review Process focuses on:

- evaluating the CRP itself,
- compiling lessons learned throughout the PDP and incorporating the best ones into the appropriate agency databases, and
- obtaining inputs from operations and maintenance personnel regarding the performance of the facility.

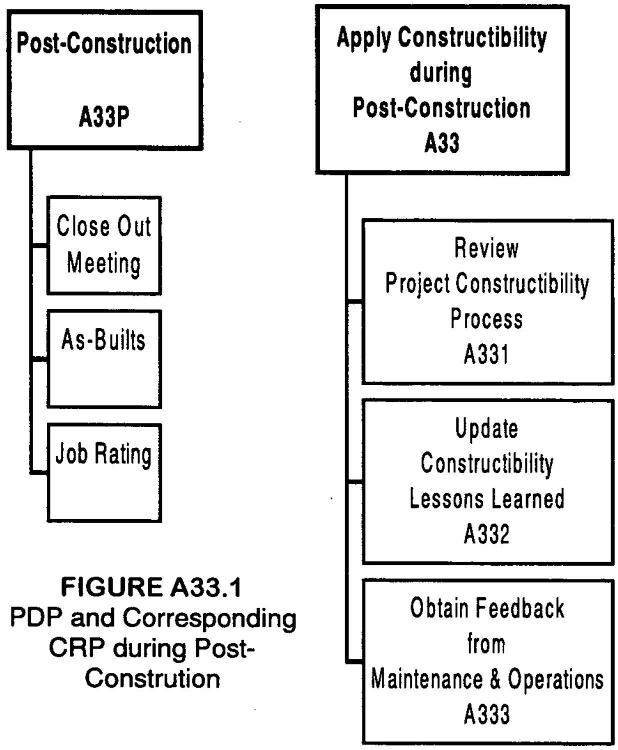


FIGURE A33.1
PDP and Corresponding CRP during Post-Constrution

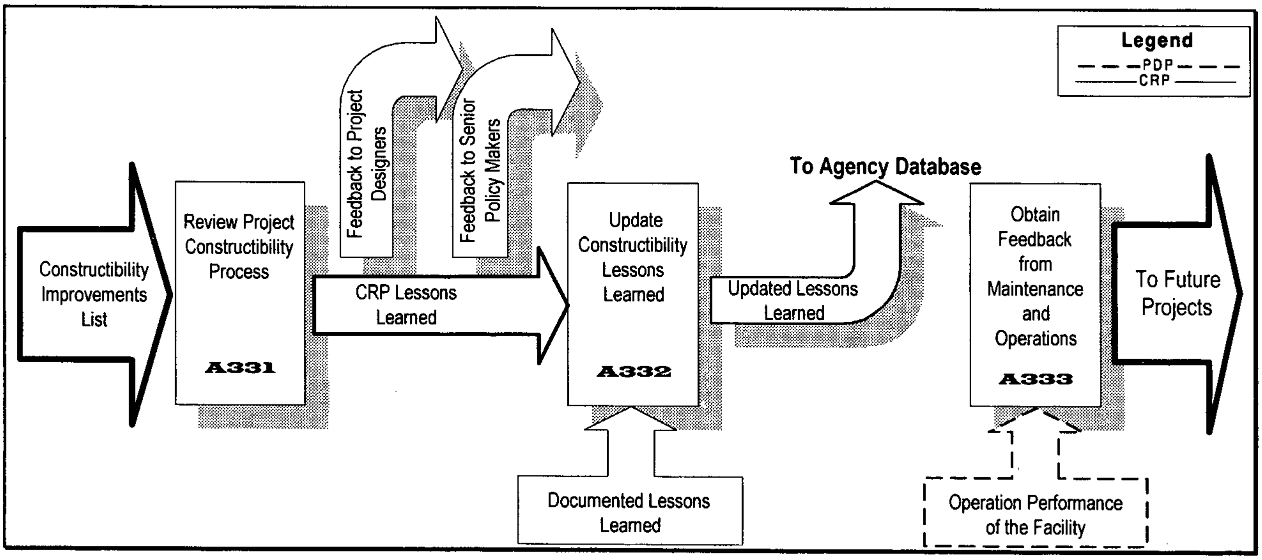


FIGURE A33.2
Integration of CRP with PDP during Post-Construction

Review Project Constructibility Process

Steps		Actions	Tools
1. Evaluate costs and benefits of project constructibility process	☑	Compile cost savings and benefit data generated throughout the project and compare these to the cumulative cost of the constructibility effort.	
2. Solicit comments from project participants	☑	Obtain information from key project participants through questionnaires, personal interviews, and telephone calls to evaluate the constructibility team's performance and to aid future teams to better meet needs and situations they will face.	Post-Construction Review **(T201)**
3. Organize and document results of application of constructibility on the project	☑	Document conclusions and supporting evidence regarding constructibility effort. Distribute results to design personnel on this project, to those attempting to use the Constructibility Review Process on other projects, and to senior agency management to substantiate support for constructibility efforts.	Idea/Lessons Learned Log **(T207)**

Tool Applications

- Add process lessons learned to the Idea/Lessons Learned Log.

Project Name________________________________ Project ID______________
Design Supervisor____
Construction Project Manager____________________________________
Reviewers____

Right of Way

Post-Construction Rating	Very Good	Good	Fair	Poor
	4	3	2	1

Discussion:____
____

Horizontal Fit

Post-Construction Rating	Very Good	Good	Fair	Poor
	4	3	2	1

Discussion:____
____

FIGURE A331.1
Post-Construction Review (T201)

Project Name________________________________Project ID__________
Design Supervisor____
Construction Project Manager_____________________________________
Reviewers____

Project was: Roadway Bridge
Intersection Signalization

Were the plans clear with sufficient detail and free from error?
Yes No
If no, what details were lacking, omitted, or in error?

____
____
____

FIGURE A331.2
Post-Construction Review (T201)

Even though past construction reviews are conducted on many projects, a formalized, focused effort helps to document constructibility lessons learned.

Issues to Consider

Project Constructibility Procedures

- Requirements for review of overall effectiveness of project Constructibility Review Process

Resource Limitations

- Sufficient time available
- Right players available
- Funds available to perform review

Agency Policy

- Requires comprehensive analysis of effectiveness of project Contructibility Review Process

Key Players

- Constructibility Coordinator
- Constructibility Team
  - Project Engineer
  - Contractor/Owner
  - District Construction Engineer
  - Area Engineer
  - Subcontractors
- Database Custodian

The constructibility coordinator will review the compiled benefit/cost data to determine an overall B/C rating. This could include documenting any unusual experiences that would create different outcomes in the future. The constructibility coordinator should solicit comments from all players starting with the planning phase and progressing through construction. Any potential constructibility solutions should be captured into the lessons learned database.

Examples

The Buffalo Gap Intersection

The project constructibility process is evaluated mainly on the basis of the benefit/cost ratio of *partnering* and *value engineering* applied to the overall project.

Value engineering generated fast-track concrete and alternate detours. Partnering generated manned traffic controllers at the traffic signals to improve mobility. Each key player is interviewed by the Project Engineer as to the success of these constructibility activities.

The Loop 322 Interchange

The Project Constructibility Review Process is reviewed on this project to determine:

- if the review schedules were adequate
- if partnering agreements prior to construction would have improved the constructibility process

It is suggested that team composition should include utility personnel in the planning phase.

An executive summary of the review is submitted to key management, design, and planning personnel. Comments and ideas concerning the review process are forwarded to the lessons learned database.

Update Constructibility Lessons Learned

Steps		Actions	Tools
1. Compile and organize all constructibility experiences and ideas	☑	Collect and organize all the constructibility experiences and ideas that have been documented throughout the constructibility process to facilitate their future use.	
2. Document in appropriate lessons learned format	☑	Submit to appropriate custodian experiences and ideas for incorporation into lessons learned database; the constructibility coordinator and agency constructibility procedures will identify databases for storing new knowledge, where this knowledge will be stored, and in what form.	Agency Constructibility Checklists **(T203)** Databases **(T302)** Hypermedia/Multi-media/CD-ROM **(T303)**

Issues to Consider

Database Constraints

- Standardization of lessons learned
- Selection of lessons learned to be incorporated
- Software and hardware requirements

Agency Policy

- Support development and maintenance of lessons learned database
- Directives on development of lessons learned database to project personnel

Resource Constraints

- Funds available to develop and maintain database
- Expertise required to implement lessons learned database system

Who are Key Players

- Constructibility Coordinator
- Database Custodian

Tools for Capturing Information

- Project files (hard copy)
- Computerized database
- Hypertexed database
- Multimedia

How to Store Information

- *Storage*
  - Type of lessons learned
  - Discipline involved
  - Type of project
  - Media used
- *Access*
  - Keywords
  - Cost

Examples

The Buffalo Gap Intersection

The constructibility file is updated to include the interviews and outputs from the value engineering and partnering efforts. This file is given to the District Construction Office, the custodian for project files.

The value engineering and partnering outputs include the overall rating of the constructibility process given by the key players and the actual constructibility issues throughout the planning, design, and construction of this project. Some examples are:

- **Planning** — traffic planning in a restricted area
- **Design** — use of fast-track concrete
- **Construction** — use of manned traffic signal controllers to improve traffic mobility

The Loop 322 Interchange

Constructibility experiences and ideas occurring during planning, design, and construction phases of the project are collected and documented. Examples include:

- **Planning** — Availability of equipment for multilevel construction.
- **Design** — Use of reinforced earth for high retaining wall.
- **Construction** — Removal of auto grade specification on the final base course.

Process improvement ideas and experiences are also collected and documented. One such idea is to include partnering on complex projects.

Obtain Feedback from Maintenance and Operations

Steps		Actions	Tools
1. Establish roles and responsibility in feedback process	☑	As the facility begins operation, assign individuals to collect data from maintenance and operations personnel and make those available to planning and design teams.	Constructibility Organization Structure **(T104)** Implementation Responsibility Matrix **(T111)**
2. Establish methodology for gathering feedback	☑	Consult field personnel from maintenance and operations divisions by means of questionnaires, interviews, study of reports, etc., regarding possible constructibility comments.	Operations and Maintenance Input **(T103)** EDI/BarCoding/Pen-Based Technology **(T304)**
	☑	Methods used must be tailored to both the type of information being sought and the expertise of those being consulted.	
3. Organize comments, ideas, and suggestions	☑	Organize information being collected in a manner that will allow for easy interpretation by those who can use it to improve future facilities.	
	☑	Present the information as an "ideal" design, table, narrative, diagram, or any other method as deemed appropriate.	
4. Document constructibility issues	☑	Organize feedback from maintenance and operations personnel into easily referenced packages and document them for future use.	Agency Constructibility Checklists **(T203)** Idea/Lessons Learned Log **(T207)** Databases **(T302)**
	☑	The final output of this stage is an input into a lessons learned database containing the comments of the maintenance and operations personnel.	

Tool Applications

- Feedback from operations and maintenance (O&M) will be more likely if data collection is automated.
- Sort/categorize the lessons learned matrix by who and when before entering data into database.
- High technology tools, such as EDI, bar coding, and pen-based technology are already being used for communication, inspection, and material management. These tools can be configured to facilitate constructibility.

Operations and Maintenance Input (T103)

Operation and maintenance personnel inherit the finished product. They benefit from well-conceived designs and constructed facilities, but in turn must deal with shortcomings of design and construction deficiencies that might occur. A finished construction project remains operational for a long time. It is, therefore, necessary to design for ease of operation and maintenance. The O & M personnel should be involved in the earliest stages of planning and design and have the opportunity to review and comment on the concepts and designs in order to eliminate problems with the finished facility throughout its lifetime. Once a project is completed, there needs to be feedback to the designer from operations and maintenance. This continuation of input from the operations and maintenance personnel regarding the long-term performance of the constructed facility, is extremely important when the agency has similarly designed facilities.

YEARLY MAINTENANCE AND OPERATIONS QUESTIONNAIRE

Name____________________ Date____________________
Project Name______________________________
Project Description ______________________________

Are there problems or potential problems with material selection? Yes No

Comments

Are there traffic control problems? Yes No
Comments:

Are there interference problems? Yes No
Comments:

FIGURE A333
An Example of a Yearly Maintenance and Operations Questionnaire

Issues to Consider

Agency Policy

- Directives and support for capturing and documenting operations and maintenance feedback

Resource Constraints

- Time available for operations and maintenance personnel to provide feedback
- Funds available to develop and maintain database
- Expertise required to implement lessons learned database system

Performance Constraints

- Criteria for standardization of lessons learned database
- Criteria for maintenance and operations experiences to be incorporated into lessons learned database
- Software and hardware requirements for capturing maintenance and operations experiences

Key Players

- Operations personnel
- Maintenance personnel

Examples

The Buffalo Gap Intersection

The Maintenance Engineer solicits comments from maintenance personnel concerning the serviceability of the intersection. All ideas suggested are filed in the constructibility folder and forwarded to the design office for enhancement of future designs.

According to the maintenance personnel, concrete pavement has effectively eliminated patchwork and base failures at the intersection, as a result of which maintenance costs have already been reduced.

The Loop 322 Interchange

Maintenance cost during winter is much higher because of the many skews in the overpass. It is suggested that skews should be reduced if enough space is available.

Appendices

Appendix A

GLOSSARY

"As Built" Drawings. Drawings of a facility as it has been built, incorporating changes made during construction.

Agency Constructibility Checklist. A checklist is a review guide to ensure that design features are considered for specific constructibility issues during project evaluation of plans and specifications.

Agency Constructibility Program. A constructibility program at the agency level which, sponsored by a senior policy maker, would provide support in the form of procedures, policies, and resources for project-level implementation of constructibility.

Agency Constructibility Sponsor. A top-level senior policy maker whose primary role is to maintain a high level of awareness and visibility of the constructibility program. This sponsor works also as a catalyst for change by supporting pilot projects and implementation efforts at lower levels within the organization.

Agency Database Custodian. A member of the Agency Constructibility Program core team. Mainly responsible for documentation, tracking, and distribution of constructibility ideas and lessons learned.

Agency Program Manager. A member of the Agency Constructibility Program core team. Responsible for day-to-day coordination of agency-wide constructibility efforts.

Benefit/Cost Analysis. Focuses on the costs of a particular action and the comparison of these costs with the measured gain or benefit resulting from such actions.

Concept Plan Development. The second part of the planning phase, when the planning team develops rough design parameters, captured in the Final Scoping Report, to serve as guidelines for the design team to follow when preparing the detailed design.

Constructibility Champion. See Agency Constructibility Sponsor.

Constructibility Concepts. Constructibility concepts are representative of good practices that will enable practitioners in any organization to take advantage of the lessons learned by others and apply these lessons learned in their organization and on their projects.

Constructibility Consultant. Professional Constructibility expert who helps with organizing for constructibility and provides construction knowledge and expertise.

Constructibility Coordinator. Usually a member of the project team, the Constructibility Coordinator mainly facilitates coordination of constructibility programs between the agency and the project.

Constructibility Engineer. A project team member who is responsible for providing guidance on project constructibility issues. This person must represent the perspective of the agency, designer, and contractor.

Constructibility Function. Breakdown of subphases of the Constructibility Review Process into distinct elements that are further defined by steps and actions and are supported by specific tools. Constructibility functions are essential for conducting formal, project-level constructibility reviews.

Constructibility Implementation Policy. A formal document that specifies constructibility purpose, goals, and objectives of the agency.

Constructibility Improvements. Improved plans and designs resulting from constructibility suggestions, ideas, or solutions relevant to concept plans and design documents.

Constructibility Meetings. Meetings of the Constructibility Team at given intervals during different project phases to perform constructibility reviews.

Constructibility Organization Structure. Infrastructure for both Agency and Project Constructibility Program Teams, supporting constructibility efforts both at agency and project levels.

Constructibility Plan. A constructibility plan describes the strategies, level of formal procedures used, mechanisms for obtaining construction expertise, and the size and makeup of the constructibility team needed to implement a project constructibility process.

Constructibility Procedures. A series of steps followed in definite order to implement a project constructibility process.

Constructibility Resources. Sources of constructibility knowledge and experiences such as district construction engineers, construction management services, value engineering firms, retired construction professionals, or local contractor associations.

Constructibility Review Process (CRP). A process, integrated with the Project Development Process, to review projects for constructibility and collect lessons learned from previous constructibility efforts.

Constructibility Review Tools. Tools used to perform constructibility functions.

Constructibility Strategy. Directives for the constructibility effort that will support achieving project objectives.

Constructibility Team. A multidisciplinary team of in-house and possibly outside experts assembled for conducting constructibility analysis and evaluation on a given project.

Constructibility. Integration of construction knowledge and experience into planning, design, and construction to achieve overall project objectives in terms of cost, schedule, quality, and safety.

Contractor Agency Representative. Representatives of agencies such as Associated General Contractors (AGC), whose expertise is sought as ad hoc members to the Constructibility Team.

Contractor-Determined Schedules. Schedules determined by contractors and designed to be performable within resources available to the them, thus optimizing their work schedule and satisfying the established requirements.

Critical Path Method (CPM). The Critical Path Method is the most commonly used network analysis system. This technique of defining and coordinating work by a graphical diagram that shows work activities and the interdependence of activities.

Databases. A collection of various information which has been organized into related areas and structured in a manner so as to provide easy access and quick retrieval.

Electronic Data Interchange (EDI). Technology allowing multiple access communication delivered exclusively on and between computer networks.

Executive Sponsor. See Agency Constructibility Sponsor.

Idea/Lessons Learned Log. A format for documentation of lessons learned throughout a project.

Implementation Responsibility Matrix. A graphical description of constructibility functions that are to be performed and key players responsible for performing these functions.

In-house Construction Representative. An agency construction expert, such as the District Construction Engineer, who is a member of the Constructibility Team.

Lessons Learned. Constructibility ideas and experiences, positive or negative, obtained from past projects.

Level of Complexity. Degree of project complexity as indicated by total project cost, work hour effort, type of project, urban or rural location, grade separation, and interface with other project participants.

Level of Formality. Degree that project constructibility process is documented through formal written procedures. Formality is based on level of complexity.

Milestone-Driven. Pre-specified points on the project schedule. Used to indicate when constructibility reviews are performed based on certain percentages of completion of project design or other project completion criteria.

National Quality Initiative (NQI). The NQI is a result of the "partnerships in quality," a concept formed in 1990 at a Federal Highway Administration (FHWA) sponsored workshop attended broadly by representatives from state highway administrations, the construction industry, construction associations, academia and the Federal Highway Administration. An NQI Steering Committee was formed by AASHTO in 1991, with memberships from the FHWA and six other national industry organizations. The mission of the Steering Committee is to solidify this partnership and the commitment to quality through policy development, training, and technical support.

Operations and Maintenance Input. Feedback to project programmers/designers from operation and maintenance personnel regarding the long term performance of similar projects which are presently in use.

Paradigm Shift. A complete rethinking of and change in existing methods and approaches to project development.

Partnering. A program through which owners and contractors focus on developing a relationship that creates a project team united by a common project mission and objectives.

Phases of CRP. The major phases of the Constructibility Review Process as they relate to the Project Development Process — planning, design, and construction.

Phases of PDP. The major phases of project development — planning, design, and construction.

Pilot Project. A project used for testing the Constructibility Review Process before proceeding to full-scale implementation.

Policy and Objective Statement. See Constructibility Implementation Policy.

Post-Construction Review. Review at the end of construction when all responsible project participants meet together to discuss the actual performance of the project.

Pre-Bid Conference. A meeting of potential bidders for a particular project prior to the submission of bids. The idea is to exchange project information between the agency and contractors.

Pre-Construction Conference. A meeting between contractor and owner held after the bid is awarded. The idea is to decide on any unresolved concerns of both the owner and contractor.

Project Constructibility Agreement. An agreement formed between all personnel and organizations involved in the constructibility process to ensure complete understanding of the project constructibility objectives as well as objectives of the team, regarding communication and responsibilities.

Project Definition. Determination of the best course of action which would satisfy the perceived need of a project.

Project Development Process (PDP). Process through which a project is developed from planning, through design, to construction.

Project Study Report. A Project Study Report captures such project information as the physical description of the facility, environmental issues, ROW requirements and orientation of structures; confirms project economic viability; and identifies basic design parameters.

Scoping Report. See Project Study Report.

Subphases of CRP. Breakdown of major phases of the CRP as they relate to those of the PDP. These subphases are: Project Definition and Concept Plan Development; Preliminary Design, PS&E Design, and Final Design; Pre-Construction, Construction, and Post-Construction.

Subphases of PDP. Breakdown of major PDP phases. These subphases are: Project Definition and Concept Plan Development; Preliminary Design, PS&E Design, and Final Design; Pre-Construction, Construction, and Post-Construction.

Suggestion Forms. Forms used in conjunction with some form of solicitation for suggestions, such as a constructibility meeting to review plans and specifications, to capture possible constructibility ideas, comments or solutions.

Surrogate Construction Contractor. A contractor whose expertise is sought for constructibility reviews.

Team Building. An organizational process to project management that emphasizes the pooling of individual skills towards achieving a project's mission and objectives.

Value Engineering. A process by which a project is analyzed to determine the most basic approach to achieve functional performance requirements. Once this base is determined, all improvements are analyzed on the basis of the additional cost over the base, compared with the value of the improvements.

Appendix B.I

WORKBOOK CRP TOOLS

This appendix contains 27 tools that can be used by an organization that is initiating a constructibility review program (CRP). The purpose of this appendix is to give more detailed information about the tools that are used in conjunction with the functions in the workbook. It contains generic descriptions of each tool and citations on where to find more information about each tool. It also has full size forms that can be extracted and used immediately in an agency's CRP.

Each constructibility function is implemented by using an associated tool. The tools are divided into three categories:

T100's — used to understand/communicate constructibility
T200's — used to implement/measure constructibility
T300's — cutting edge technology/computer tools.

Another way of viewing or breaking down tools is by tools presented in the workbook strictly for constructibility purposes (specific) and tools presented in the workbook that are used for many purposes, but can be refocused from a constructibility perspective (generic) to aid or assist in constructibility implementation. Please note that some tools are people, some relate to processes, and some are a product of the CRP.

Table 1 is a matrix that links each of the functions to a tool. For example, T101 (Policy and Objective Statement) is used in functions A111, A121, and A212. In function A111, the form for T101 (Figure T101.1) is used to communicate the policy and objective of the CRP. This form can be copied and used immediately when establishing project constructibility strategies (A111). In function A121, Figure T101.2 can be used to familiarize the team with the project characteristics and constructibility strategies in order to determine the major constructibility issues involved in the project. During the design phase in function A212, Figure T101.2 can again be used to examine the project objectives and constructibility strategies when finalizing the project constructibility procedures. Application tips describing how to utilize these tools on all of the CRP functions are contained in the main body of the workbook,

Section II. The third column of Table 1 indicates whether or not a tool is strictly used for constructibility purposes (specific = S) or a tool that has many functions on a project, but can be refocused to aid or assist constructibility (generic = G). The fourth column of Table 1 identifies whether a tool is related to a process (PROC), if it is a person (PEOP), or a product (PROD).

TABLE 1
Matrix Linking Functions* to Tools

Name of Tool		A111	A112	A113	A114	A121	A122	A123	A211	A212	A213	A221	A222	A223	A231	A311	A312	A321	A322	A331	A332	A333		
		Constructibility Functions																						
Policy & Objective Statements	T101	X				X				X													S	PROD
Constructibility Meetings	T102				X			X		X		X					X						S	PROC
Operations & Maintenance Input	T103							X														X	S	PROD
Constructibility Organization Structure	T104									X							X					X	S	PROD
Suggestion Forms	T105							X				X					X						S	PROD
Pre-Bid Conference	T106															X							G	PROC
Pre-Construction Conference	T107																X						G	PROC
Contract Clauses/Incentives	T108															X							G	PROD
Partnering	T109								X								X						G	PROC
Contractor-Determined Schedules	T110																X						G	PROC
Implementation Responsibility Matrix	T111				X					X							X					X	S	PROD
Team Building	T112				X				X														G	PROC
Constructibility Engineers	T113			X			X		X		X						X						S	PEOP
Post-Construction Reviews	T201						X				X									X			G	PROC
Project Constructibility Agreement	T202				X					X							X						S	PROD
Agency Constructibility Checklists	T203											X									X	X	S	PROD
Formal Processes	T204		X							X													S	PROD
Constructibility Champion	T205				X																		S	PEOP
Value Engineering	T206								X								X						G	PROC
Idea/Lessons Learned Log	T207							X					X						X	X		X	S	PROD
Critical Path Method	T208							X				X											G	PROD
Cost/Benefit Analysis	T209							X					X				X						S	PROD
Constructibility Resources	T210			X			X		X		X						X						S	PEOP
CAD/GCCA	T301							X				X											S	PROC
Databases	T302						X				X										X	X	S	PROD
Hypermedia/Multimedia/CD ROM/Hypertext	T303						X				X	X							X				S	PROD
EDI/Bar-Coding/Pen-Based Technology	T304																		X			X	G	PROC

LEGEND

S — specific
G — generic
PROC — Process
PROD — Production
PEOP — People

* Please refer to page A0.9 for the framework showing all the constructibility functions

Policy and Objective Statements (T101)

A constructibility policy is a written and circulated document regarding the constructibility goals of the agency. This is the initial tool that an agency can use to implement a project constructibility program. This statement needs to address the following key items:

1. statement of constructibility program goals for the agency,
2. indication of the level of management and agency commitment,
3. identification of the agency executive sponsor,
4. ties to project-level implementation.

The level of detail within this statement can vary greatly from a simple guide to an exact step-by-step outlined procedure. Figure T101.1 gives an example of a constructibility policy statement, and Figure T101.2 gives an example of factors that influence constructibility strategies.

Constructibility Implementation Policy

Consistent with the National Quality Initiative (NQI), a Constructibility Review Process (CRP) is a major practice our agency is pursuing to continuously improve our project development process. Our agency has endorsed the cost savings potential of constructibility efforts. According to our definition, constructibility is "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives." Constructibility Review Process guidelines are available as a resource to promote project-level implementation.

In view of our continuing efforts to provide the highest degree of quality and cost-effectiveness from our projects, it is our agency policy to implement constructibility to the fullest degree possible. This applies to all phases: project planning, design, and construction. We will ensure that we take full advantage of the high potential of constructibility to achieve savings during the earliest phases of project planning and prior to the start of PS&E development.

__________is hereby designated as the Executive Sponsor for Constructibility, and will oversee the constructibility program, ensure consistency with other continuous improvement processes, implement changes, and regularly report to me on its effectiveness.

State Engineer__________Date____

FIGURE T101.1

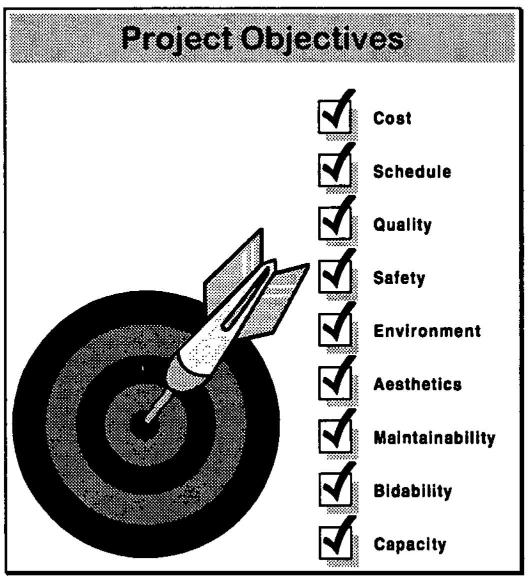


FIGURE T101.2

Constructibility Meetings (T102)

At a constructibility orientation team meeting, the team concept allows the expertise of each individual member to be shared with all group members. A team can eliminate barriers that occur across the different project phases (planning, design, and construction) within the process. Teams should be formed early within a constructibility program and remain throughout the entire project with only minor changes of personnel, depending on the needs of the team. Figure T102.1 gives a plan for constructibility team orientation meetings. To facilitate the use of teams, team members need orientation and reorientation at predetermined milestones within a project's duration. These meetings are critical when presenting overall project objectives. These meetings are also a key tool for conducting constructibility reviews. Figure T102.2 gives a milestone plan for constructibility review meetings.

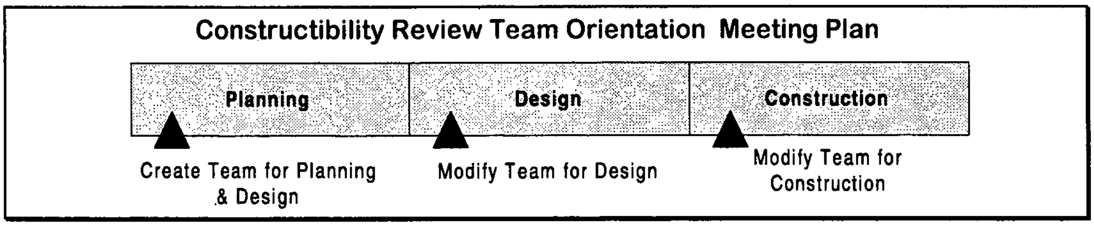


FIGURE T102.1

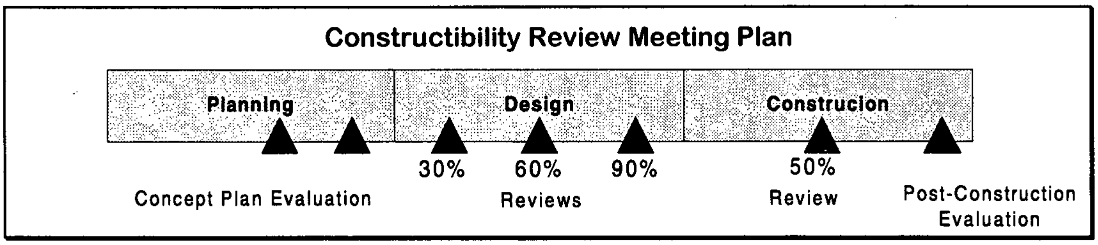


FIGURE T102.2

Operations and Maintenance Input (T103)

Operations and maintenance personnel inherit the finished product. They benefit from well-conceived designs and constructed facilities, but must deal with deficiencies of design and construction. It is, therefore, necessary to design for ease of operation and maintenance. Operations and maintenance personnel should be involved in the earliest stages of planning and design and have the opportunity to review and comment on concept plans and design documents, in order to eliminate problems with the finished facility throughout its lifetime. Once a project is completed, there needs to be feedback to the designer from operations and maintenance. This continuation of input from operations and maintenance personnel, regarding the long term performance of the constructed facility, is extremely important when the agency has similarly designed facilities. Figure T103 is a questionnaire that can be used to obtain feedback from operations and maintenance personnel.

Yearly Maintenance and Operations Questionnaire

Name:____ **Date:**________
Organization:____
Project Name:____

Project Description

Are there problems or potential problems with material selection?
☐ Yes ☐ No

Comments

Are there traffic control problems?
☐ Yes ☐ No

Comments

Are there interference problems?
☐ Yes ☐ No

Comments

Are there drainage problems?
☐ Yes ☐ No

Comments

Are there accessibility problems?
☐ Yes ☐ No

Comments

General Comments

FIGURE T103

Constructibility Organization Structure (T104)

An agency infrastructure is required to support constructibility. This includes the establishment of a Constructibility Champion (T205) as well as a constructibility program manager and database custodian. The constructibility program manager is responsible for coordinating day-to-day agency-wide constructibility efforts, supervising project constructibility coordinators, and tracking of agency constructibility program goals. The database custodian is responsible for documentating, tracking, and distributing constructibility ideas and experiences. Figure T104 shows an example of a constructibility organization structure.

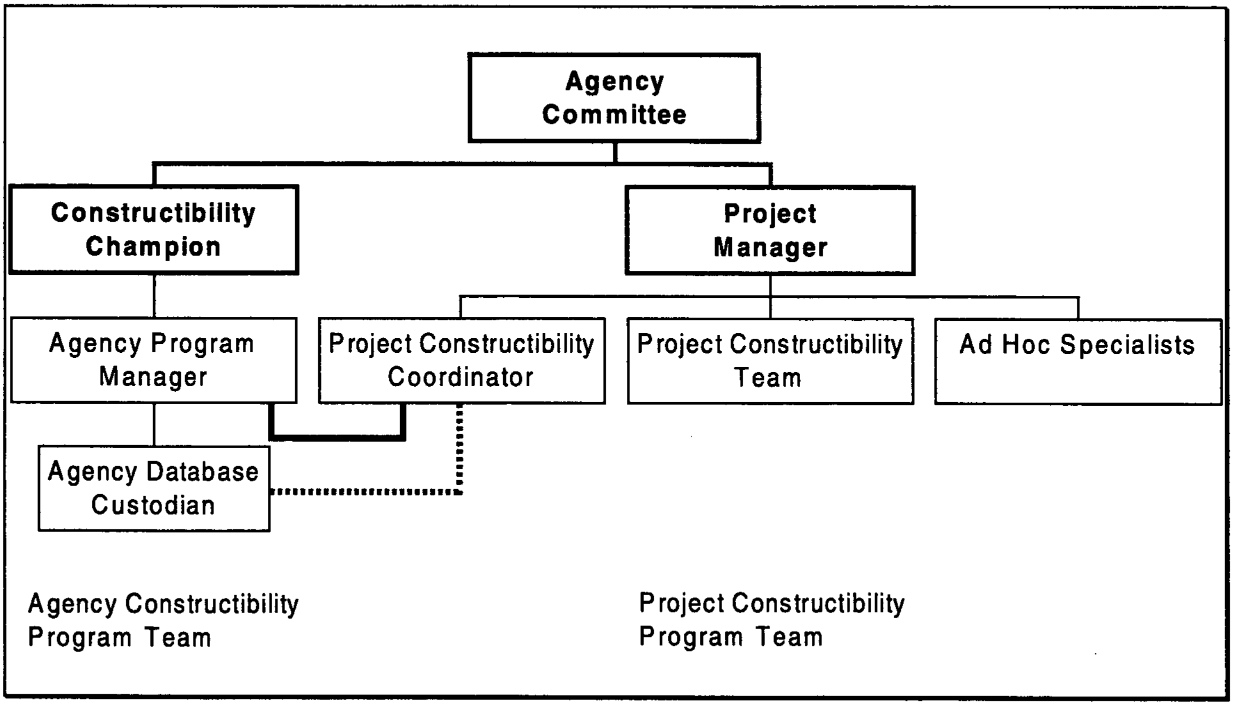


FIGURE T104

Suggestion Forms (T105)

A suggestion form is a tool to capture all possible ideas, solutions or comments on concept plans and design documents from a constructibility perspective. Such a tool is used in conjunction with a solicitation for constructibility improvements suggestions, such as at a constructibility review meeting. Figure T105 gives an example of a suggestion form.

Suggestion:______________________________
Discipline/Craft Affected:________________________

Description & Illustration:________________________

Originated by:____________________ **Date:**________
Project:______________________________

Assessment of Impact to Project: (to be completed by the Constructibility Coordinator)

Cost:____________________
Schedule:____________________
Quality:____________________
Safety:____________________
Engineering:____________________
Need to change/update corporate standard specs?____________
Other:____________________

Approvals:

Comments:________________________

FIGURE T105
Constructibility Suggestion Form

Pre-Bid Conference (T106)

This conference is a meeting of all potential participants of a particular project prior to the submission of bids. A pre-bid conference is designed to enable flow of information from the owner to the contractor and vise versa. Prior to bid, all bidders are brought together and the owner explains the intent of the project design. Any problems or ambiguities related to the project would be brought to the owners' and bidders' attention. These conferences will clarify the project scope and help to eliminate unknowns and assumptions made by the contractor, thus reducing uncertainty. Improvements in the design for construction are addressed and clarification on roles of the responsible parties are identified. Contractors need to have design documents sufficiently ahead of time so that they can study them before the conference. Also, this conference needs to be held prior to the letting of the bid so as to allow the feedback received from the conference to be incorporated into the project documents and requirements. The pre-bid conference provides a forum to ensure that the parties know and understand the constructibility improvements that are compiled and adapted for the project.

Pre-Construction Conference (T107)

This conference is a meeting between the contractor and agency, and is held after the bid is awarded. The objective of this conference is to resolve concerns of both the agency and the contractor. This conference allows both parties to convey their intent and implement any new procedures and policies that will improve construction. The pre-construction conference should lay the framework for dialog throughout the construction phase and provide a clear channel for constructibility feedback. It is also an opportunity to identify and obtain additional constructibility issues from the contractor's perspective.

Contract Clauses/Incentives (T108)

The contract is the rule book as to how each party should perform. This instrument is used to create and enforce certain behavior. Certain contract clauses and incentives will provide the impetus for a constructibility program to be used by the contract parties and for feedback of lessons learned required by the agency. The use of the contract as a tool to implement constructibility is very useful and powerful. These clauses stipulate the desired actions regarding performance. Within the contract, the agency can specify what type of processes will be followed to improve constructibility for both participants.

Partnering (T109)

Partnering is a program through which agencies and contractors focus on developing a contractual relationship (not a contractual requirement) that creates a project team united by a common mission and objectives. The key elements of partnering include commitment, trust, mutual advantage, and opportunity. Partnering begins with a workshop held at a neutral site prior to construction. During this workshop, which is often facilitated by an impartial third party, representatives from each participating organization become acquainted. Workshop participants identify possible obstacles to a successful relationship, establish goals for the project, create a mission statement, develop methods for resolving issues, agree to time tables and assign responsibilities in the interest of improving relations during the project. The use of partnering allows the information to flow between the contractual parties without the secrecy and rivalry that tend to develop without partnering efforts. Ease in obtaining information will reduce the barriers often present between the phases of the project. The use of partnering sessions will allow free flow of ideas needed for constructibility. This will eliminate the adversarial positions that tend to develop among designers, contractors, and owners. In order for partnering to work, particular behavior patterns based on an attitude of trust and mutual respect must be developed. There is also a need for commitment to the concept of team work for all benefits of partnering to impact the project. From a constructibility standpoint, a portion of partnering can be devoted to the identification of constructibility issues.

Contractor-Determined Schedules (T110)

The contractor is responsible for meeting the milestones of a project. These milestones are construction driven and decided upon by having a desired project completion date and the time to complete each required activity. Working backwards, one can find when each activity must begin in order to meet the completion date. These schedules are more accurate if they are determined by the contractor. The contractor has a better knowledge of the production rates and duration required to perform each task. These schedules are determined by the methods used by the contractor and the specific equipment available. The contractor prepares performable schedules with available resources, thus optimizing the work schedule and satisfying the established requirements.

Implementation Responsibility Matrix (T111)

An implementation responsibility matrix is a graphical description of constructibility functions that are performed and the key players or functional divisions responsible for performing them. The matrix is a result of placing the responsible entities on one axis and functions performed on the other axis. The key players and/or the functional division responsible for each function is related to the appropriate function by placing a mark at the intersection of each within this matrix. Figure T111.2 gives an example of an implementation responsibility matrix. Figure T111.1 shows some example functional players and their responsibilities.

Functional Key Players / Constructibility Review Process Functions	Program Manager	Project Design Engineer	District Construction Engineers	Contructibility Engineer	District Maintenance Engineer	Local Contractor Association
Identify Major Constructibility Issues	✓	✓	✓	✓		
Consult Lessons Learned for Planning		✓		✓	✓	✓
Evaluate Concept Plans for Constructibility	✓	✓	✓	✓	✓	

FIGURE T111.1
An Example of Implementation Responsibility Matrix

Team Building (T112)

Team building is an organizational approach toward management that emphasizes the pooling of individual skills toward a singular goal. This is an optional tool best used on moderately to highly complex projects with diverse groups who have never worked together before. The strength of the team comes from the synergy developed among the members. The team development process consists of the following stages:

1. **Forming:** characterized by hesitation and the familiarization of the team members.
2. **Storming:** begins when team members begin to panic at the amount of work ahead and begin to brainstorm possible approaches to complete tasks.
3. **Norming:** characterized by the group beginning to work together, rather than against each other.
4. **Performing:** the final stage, the team effectively works together toward the completion of required tasks.

Functional Key Players / Constructibility Review Process Functions														
Establish Project Constructibility Strategies														
Determine Formality of Constructibility Program														
Identify and Evaluate Means to Obtain Constructibility Inputs														
Create Constructibility Team														
Identify Major Constructibility Issues														
Consult Lessons Learned for Planning														
Evaluate Concept Plans for Constructibility														
Modify Constructibility Team														
Finalize Project Constructibility Procedures														
Consult Lessons Learned for Design														
Evaluate Plans and Specifications														
Validate Constructibility Improvements														
Review and Approve Constructibility Improvements														
Summarize Constructibility Improvements														
Review Bid Documents														
Initiate Field Constructibility														
Identify Constructibility Experiences and Ideas														
Document Constructibility Experiences and Ideas														
Review Project Constructibility Process														
Update Constructibility Lessons Learned														
Obtain Feedback from Maintenance and Operations														

FIGURE T111.2
Implementation Responsibility Matrix

Constructibility Engineers (T113)

This position/role requires an experienced and knowledgeable individual who provides guidance and specific analysis of constructibility issues and suggested improvements. This position requires someone who has both the perspective of the agency and the contractor. An understanding of the design process is also essential. This individual can come from any constructibility resource or through a qualified project team member.

Post-Construction Reviews (T201)

This tool documents and records the actual performance of a project once the project is completed. These reviews and write-ups are performed at the termination of any project or completion of significant phases within a project. All the responsible participants meet together and discuss the project. Comments, good and bad, must be captured. This is usually the last opportunity for lessons learned to be documented, hopefully to derive benefit from them for future projects. The resulting information should be organized for reference and review at a later date. Post-construction reviews from past similar projects can be consulted when reviewing constructibility lessons learned. Figures T201.1 and T201.2 are examples of post-construction review forms. Partial examples of these forms are shown (see references for sources of a complete set of forms).

Project Name____________________Project ID____________________
Design Supervisor______________________________________
Construction Project Manager______________________________
Reviewers____

Right of Way

Post-Construction Rating	Very Good	Good	Fair	Poor
	4	3	2	1

Discussion:____

Horizontal Fit

Post-Construction Rating	Very Good	Good	Fair	Poor
	4	3	2	1

Discussion:____

FIGURE T201.1

Project Name____________________Project ID____________________
Design Supervisor______________________________________
Construction Project Manager______________________________
Reviewers____

Project was: Roadway / Bridge / Intersection / Signalization

Were the plans clear with sufficient detail and free from error?
Yes No
If no, what details were lacking, omitted, or in error?

____

FIGURE T201.2

Project Constructibility Agreement (T202)

An agreement should be formed between all personnel and organizations involved in the constructibility process. This agreement identifies project constructibility strategies and objectives as well as objectives of the team, regarding communication and responsibilities. Figure T202 shows an example project constructibility agreement.

The (design/project) constructibility team members believe proactive efforts to promote optimal buildability and bidability in their project designs have considerable potential for cost and schedule savings, increased safety to workers and the public, and improved quality of the completed facility.

Statement of Project/Constructibility Objectives

List and describe the top three to four objectives. Also describe special considerations or constraints of the project.

Performance Objectives

List other project objectives in addition to the ones listed above that should be goals of the team.

Communications Objective

1. Weekly meetings to discuss schedule, progress, and difficulties.
2. Team approach is where everyone is important and must contribute.
3. Clear, concise, complete, and timely communication.
4. Be open, honest, consistent, and positive in all activities.
5. Encourage and promote participation through active learning.
6. Maintain enthusiasm and a sense of humor.
7. Inform other team members of individual activities and decisions.
8. Project decisions are made timely and without interruptions.
9. Emphasize face-to-face communications.
10. Keep the community advised of activities and progress.

Conflict Resolution Plan

State how conflicts will be resolved including a list of the decision makers and the time frame in which a solution should be reached.

Documentation

State the method for collecting constructibility suggestions.
Determine who collects suggestion forms, who will review suggestions before submitting to agency, etc.

We the undersigned agree to make a good faith effort to undertake and implement the above as applicable to each of us.

Signatures

FIGURE T202

Agency Constructibility Checklists (T203)

A checklist identifies potentially significant areas in the project design where constructibility may be an issue. A standardized agency checklist will ensure that these issues (or features) are considered from a constructibility perspective. This checklist can be general, such as a set of questions concerning various aspects of the project scope, or specific to certain types of tasks such as clearing/grubbing/excavation. Figure T203 gives a partial example of a checklist developed for the Florida Department of Transportation (see reference Ellis, Kumar, and Ahmad).

1. CLEARING/GRUBBING/EXCAVATION				
Item No.	**Feature to be Checked**	**OK**	**Not OK**	**N/A**
1-1	Delineation of limits of grubbing, clearing, and landscaping.			
1-2	Sites for temporary fill and top soil storage. Laydown area on same side of road as fill area. Indication of dump sites.			
1-3	Provisions (such as phasing of work) to minimize borrow and use of excavated material for fill.			

Suggested Changes (to be completed for items checked "Not OK")	
Item No.	**Description of Changes**
Designer's Comments:	

FIGURE T203

Formal Processes (T204)

A constructibility process can be implemented with varying degrees of formality. Most agencies have some level of informal constructibility program. When the process is formalized, it ensures that constructibility issues are addressed in a systematic manner. Figure T204.1 shows factors that influence the level of formality of a project CRP. Figure T204.2 describes different attributes of a project CRP based on level of formality and project complexity.

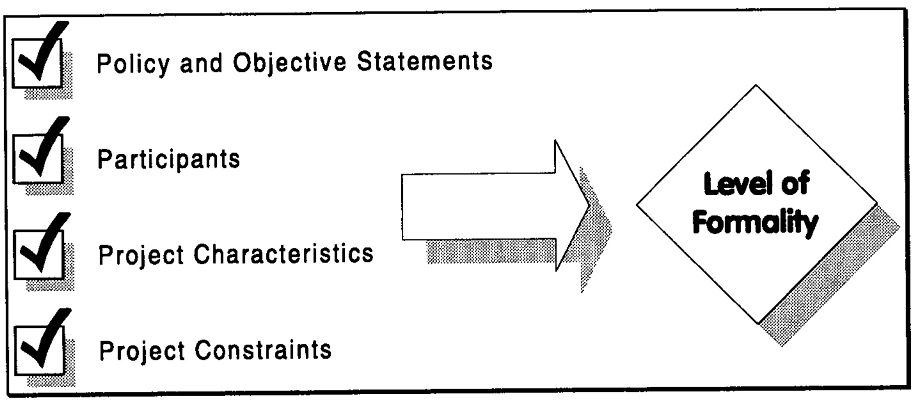


FIGURE T204.1

Project Complexity	Standard/Small Projects	Moderate	High/Large Projects
CRP Attributes	Informal	Semiformal	Formal
Resources	1 Person w/Ad Hoc Assistance As Needed	Multi-Discipline	Team Structure w/ Core and Ad Hoc Members
Frequency of Reviews	Periodic Milestone Reviews	Periodic Reviews w/ Scheduled Reviews at 30/60/90%	Continuous w/ Scheduled Reviews at 30/60/90%
Time/Commitment Required	10% Project Team Time in Constructibility Role	Assigned by Constructibility Coordinator; Part-Time Constructibility Coordinator/Engineer	Full-Time Project Constructibility Coordinator and/or Constructibility Engineer
Leadership	Project Leader	Constructibility Champion	Constructibility Champion
Sources of Constructibility Information	File Cabinet/ Personal Experiences	File Cabinet/ PC/ Personal Experiences	Networked PC/ Databases/ Personal Experiences
Procedural Approach	CRP As Is — No Specific Project Documentation	Modified CRP to fit Project w/Limited Project Documentation	Develop Project Specific CRP and Document Approach

FIGURE T204.2

Constructibility Champion (T205)

A constructibility champion is an individual who has the authority and responsibility for implementation of and adherence to the constructibility program within each individual project. The champion must be available to a project throughout all phases. The champion's responsibilities are to focus attention on constructibility issues and to ensure lessons learned are documented. For a constructibility program to have an impact, the champion must have access to the resources necessary for tasks to be performed effectively. These resources will require a financial commitment to be implemented up front.

Value Engineering (T206)

Value engineering is a process by which a project is analyzed by function. Brainstorming is used to identify possible approaches to achieving the owners functional performance requirements. The objective of this analysis is to determine the most basic approach to fulfill the required functions. Once this base is determined, all improvements are analyzed on the basis of the additional cost over the base, compared with the value of the improvements. Costs are determined and the value must be measured by the agency as to the perceived benefit. Value engineering should be used during the initial stages of development, but a value engineering analysis can also be performed by the contractor and owner prior to construction. During these studies, constructibility issues will emerge and alternate methods will be introduced. The use of benefit/cost criteria is used to find the best solution/approach toward a constructible project. Value engineering should be used as a tool to determine not just those functions that have a cost savings associated with them, but also those having a constructibility aspect to them.

Idea/Lessons Learned Log (T207)

An Idea/Lesson Learned Log provides an architecture for documentation of both suggestions (ideas) and lessons learned identified throughout a project. This log provides a location for coding and describing each idea/lesson learned. Areas of application are denoted such as by project phase and function (traffic, pavement design, etc.). The log aids in tracking the status of each idea/lesson learned during the project's life, including its benefit/cost. For example, if an idea/lesson learned is approved as a constructibility improvement for the project, a project approval column is checked. The idea/lesson learned will be included in the agency database or on the agency constructibility checklist, if the appropriate columns are checked. Figure T207 gives a working format for an Idea/Lessons Learned Log.

Critical Path Method (T208)

The critical path method (CPM) is a planning, scheduling and controlling tool. This method is based on a network of activities required to complete a project that are sequentially interconnected. Once the activities have been placed within the network, one can determine the minimum time to complete the project. A CPM network is made up of several branches of activities beginning at a single node, then branching out and converging upon a single ending activity. The sequence of activities that require the maximum amount of time is considered the critical path. If any delays occur along this critical path, the entire project is delayed. Within the noncritical branches there is surplus time available to complete various activities. This excess time is termed "float." The float of an activity can be used to schedule activities that can begin at a later start date. The float can be used throughout the project. The major benefit of CPM is that it gives an overall sequence of planned activities that provide an accurate model against which to measure the daily or weekly activities, including delivery of material and labor performance. CPM is a tool to analyze fast tracking as a constructibility issue or to coordinate complex interactions of activities. Although CPM is used for overall schedule control, at the concept plan developement stage, it can be used to investigate the feasibility of a contractor-driven shedule.

An alternative scheduling method to CPM is linear scheduling. Linear scheduling uses what are known as balance charts, whose vertical axis contains cumulative progress for a particular system that is a repetitive operation and whose horizontal axis is time. As long as the slopes of these plotted lines are either equal or decreasing as one moves to the right, the project should proceed satisfactorily. If early scheduling shows an operation proceeding too rapidly, with a high slope compared with those preceding it, conflicts become rapidly apparent.

CPM should be used, for example, during the planning phase to evaluate major construction phasing alternatives when a specific completion date drives the project. CPM should also be used, for example, during the design phase to analyze specific construction phasing and sequencing plans to determine the most constructible approach. Linear scheduling should be used, for example, during the construction phase to optimize schedule time for horizontal construction that is highly repetitive, such as several miles of highway pavement.

Benefit/Cost Analysis (T209)

Benefit/cost analysis is a tool that focuses on the costs of a particular action and the comparison of these costs with the measured gain or benefit resulting from such actions. Benefit/cost analysis involves the measurement and comparison of values and expenses of alternative approaches towards fulfilling a requirement. By quantifying the gains resulting from various actions or expenses an organization is provided the ability to base judgments on hard

Issue Code	Idea/Lessons Learned	Phase	Functions	Benefit/Cost	Approval		
					Project	Database	Checklist
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐
					☐	☐	☐

FIGURE T207
Idea/Lessons Learned Log

data. Figures T209.1 and T209.2 illustrate examples of benefit/cost forms that may be used in the benefit/cost analysis of constructibility suggestions.

Constructibility Resources (T210)

Constructibility resources are any organization or person that is brought into a project with the necessary construction experience. These sources of construction knowledge and expertise come in the form of construction management services, value engineering firms, retirees, or other contracting agencies (Figure T210). The use of an outside source allows the agency to obtain knowledge on constructibility issues which is not available within its own organization.

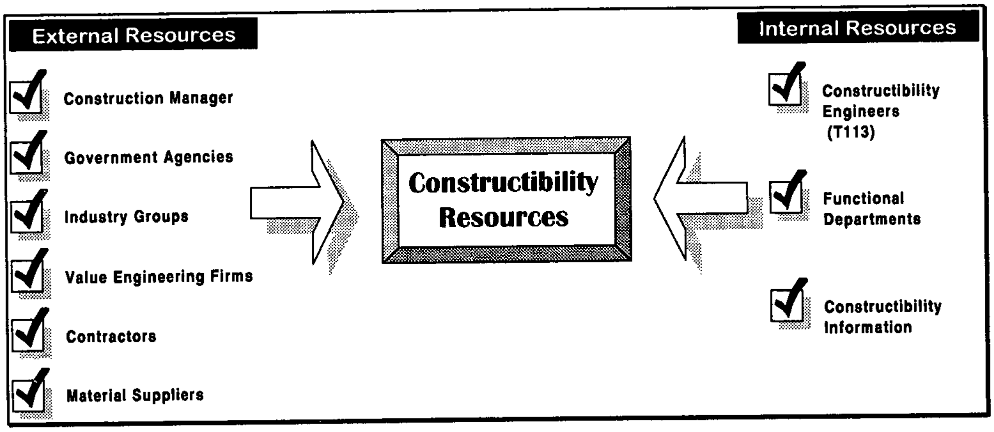


FIGURE T210

Computer Aided Drafting/Graphical Computer Constructibility Analysis (T301)

Computer Aided Drafting (CAD) uses a computer to perform the tasks of a conventional drafter. These tasks are performed with the aid of CAD software packages that are widely used and easily available. The use of computers for drafting has revolutionized this time-consuming process, allowing for immediate updating of graphical data and the ability to overlay or "fit up" segments of the whole. Graphical Computer Constructibility Analysis (GCCA) is the use of CAD information and animation techniques to perform prescribed construction tasks for any particular design, in order to measure the ability or ease of construction of various alternate designs. These tools allow for many alternatives to be studied without the expense of constructing physical models for maximizing the design at a minimum cost, including time.

Databases (T302)

A database is a collection of various information that has been organized into related areas and structured in a manner so as to provide easy access and quick retrieval. Contained within the database is a structure of the information regarding its relationships, nature, and behavior. This allows the user to retrieve any level of detail of the area of interest. A user can retrieve all the objects that are components of a particular system or retrieve the information regarding one specific object. Figure T302 shows how the database is built from suggestions to lessons learned to an approved database.

Project Name:

Existing Design Description:

Alternate Design Description:

Phase of Project at Proposal

☐ Planning ☐ Design ☐ Construction

% Complete of Phase ______

Assessment of Cost Impact to Project

Redesign Cost		Original Cost	
Labor	______	Labor	______
Material	______	Material	______
Equipment	______	Equipment	______
Schedule	______	Schedule	______
Engineering/ Design	______	Engineering/ Design	______
Other	______	Other	______
Total	______	Total	______

Assessment of Beneficial Impact to Project

Cost Savings

Actual (Hard $)		Perceived (Soft $)	
Labor	______	Schedule	______
Material	______	User Savings	______
Equipment	______	Other	______
Engineering/ Procurement	______		
Other	______		

TOTAL BENEFIT ______
% ACCURACY OF COST FIGURES ______

FIGURE T209.1
Constructibility Suggestion Benefit/Cost Form

Existing Design Description A	% Complete of Total Project at Proposed Change	Alternate Design Description B	Cost Difference Between A and B	Benefit: Actual (Hard$)	Benefit: Perceived (Soft$)	% Accuracy of Cost Data
			Redesign: Labor: Material: Equipment: **Total:**	Labor: Material: Equipment: **Total:**	Schedule: User: **Total:**	
			Redesign: Labor: Material: Equipment: **Total:**	Labor: Material: Equipment: **Total:**	Schedule: User: **Total:**	
			Redesign: Labor: Material: Equipment: **Total:**	Labor: Material: Equipment: **Total:**	Schedule: User: **Total:**	
			Redesign: Labor: Material: Equipment: **Total:**	Labor: Material: Equipment: **Total:**	Schedule: User: **Total:**	
			Redesign: Labor: Material: Equipment: **Total:**	Labor: Material: Equipment: **Total:**	Schedule: User: **Total:**	
			Redesign: Labor: Material: Equipment: **Total:**	Labor: Material: Equipment: **Total:**	Schedule: User: **Total:**	

FIGURE T209.2
Benefit/Cost Summary Analysis

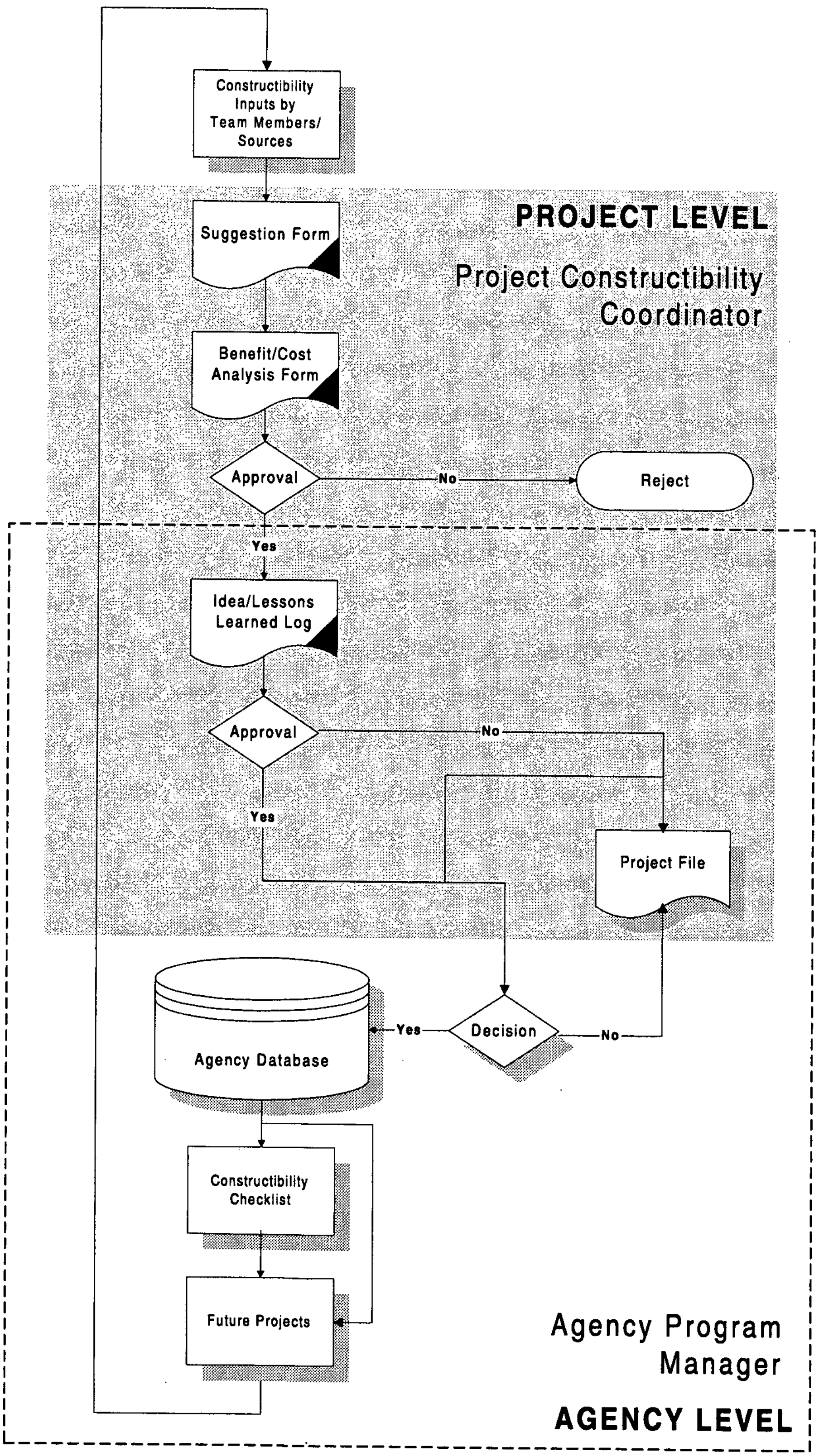


FIGURE T302
Building Agency Lessons Learned Database

CD ROM/Multimedia/Hypermedia (T303)

All three of these tools are based on having a computer provide user information upon demand. Hypermedia is the use of a computer to search a database for associated key words and phrases. Users type or click on a word or a phrase for which they wish to obtain information, and the computer sorts through all the data, and returns only the information relating to the key words entered. Multimedia uses pictures, words, and sounds to teach the user the answers to the questions asked. With the invention of CD ROM (compact disk-read only memory), the ability to store and retrieve these pictures, video, sound, and other forms of data is feasible. CD ROM technologies allow for millions of bits of information to be placed on a single compact disk approximately four inches in diameter. The nature of the compact disk allows for permanent storage without possibility for alterations, hence the term read only. These forms can be used separately or integrated with each other. These computer tools can be used to teach designers, planners and contractors about issues that normally would not be feasible. These forms of teaching will not replace the experience gained in particular fields, but will complement them.

Figures T303.1 through T303.6 illustrate a constructibility tool developed for and used by the Indiana Department of Transportation (INDOT). The application runs in Windows 3.x® and Windows 95® operating systems and requires a CD-ROM drive (2x minimum) and speakers. A minimum hardware configuration is 486-33 mhz with 8 MB of RAM. The application can be obtained through the Indiana Department of Transportation. It is a CD-ROM and requires approximately 1.5 MB of free space on the PC hard drive. The install routine creates a program group and icon.

The application is started by double clicking the INDOT Constructibility icon within the INDOT Constructibility group. Figure T303.1 shows this icon located in the INDOT Constructibility group. Double clicking the icon will launch the application by first loading the "Information Base" through Folio Views and then opening the initial screen shown in Figure T303.2. From this one screen, the user navigates with the mouse to a particular lesson. The screen is divided into four quadrants. The navigation process starts in the window shown in Figure T303.2 and moves to the other windows that are opened by clicking on an icon. This navigation path is shown in Figure T303.3. The user moves from one window or level to another by selecting an icon and double clicking. The Detailed Level Display contains "Lessons Learned" icons. Double clicking a lesson learned icon opens a graphic in the Lessons Learned Background Display window. These graphics are a visual depiction of the lesson. This last window serves as the launching area to a lesson. Currently, this window activates a search for the lesson and opens and displays the lesson on the screen. A visual explanation of this process is shown in Figures T303.4, T303.5, T303.6. Double clicking on the Roads icon in the Organizational Level creates the screen in Figure T303.4. Double clicking on the Drainage icon in Figure T303.4 opens the drainage window which contains four lessons, each represented with an icon in Figure T303.5. Double clicking on one of these icons (e.g., Properly Size Manholes) opens the fourth window containing a figure representing the lesson (Figure T303.6). Specific lessons learned are in the main workbook under functions A122, A213, and A221.

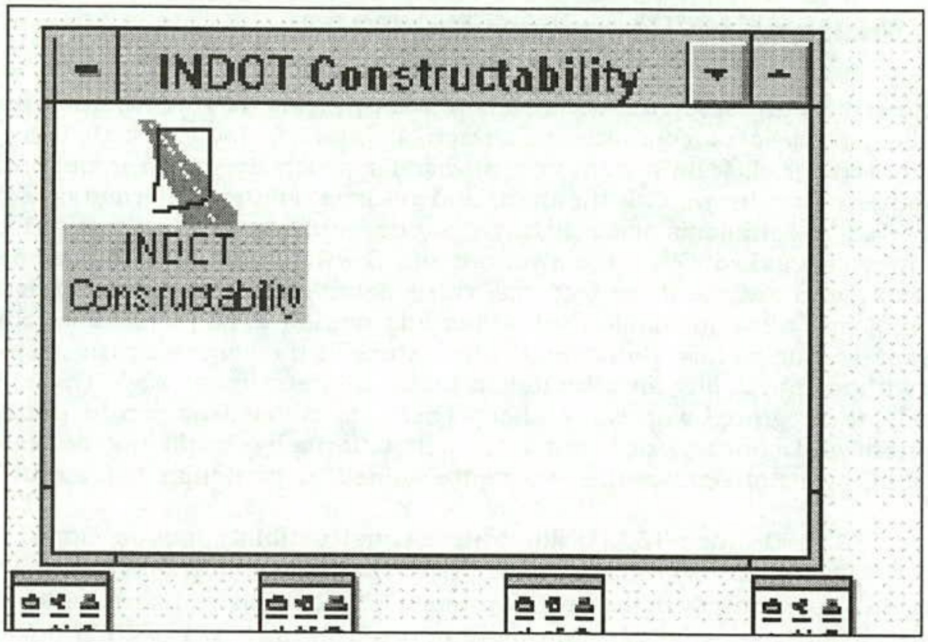


FIGURE T303.1
Program Group and Icon

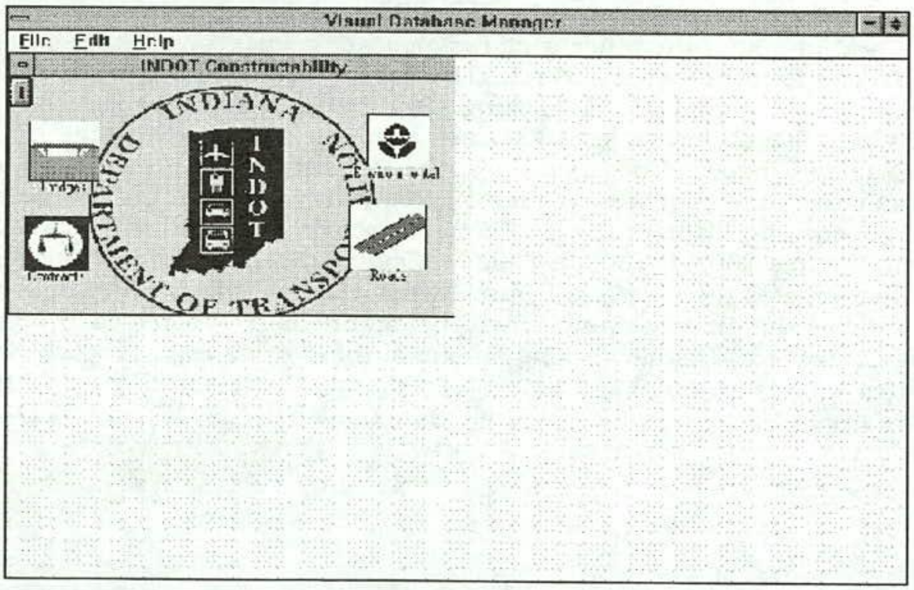


FIGURE T303.2
User Interface Screen

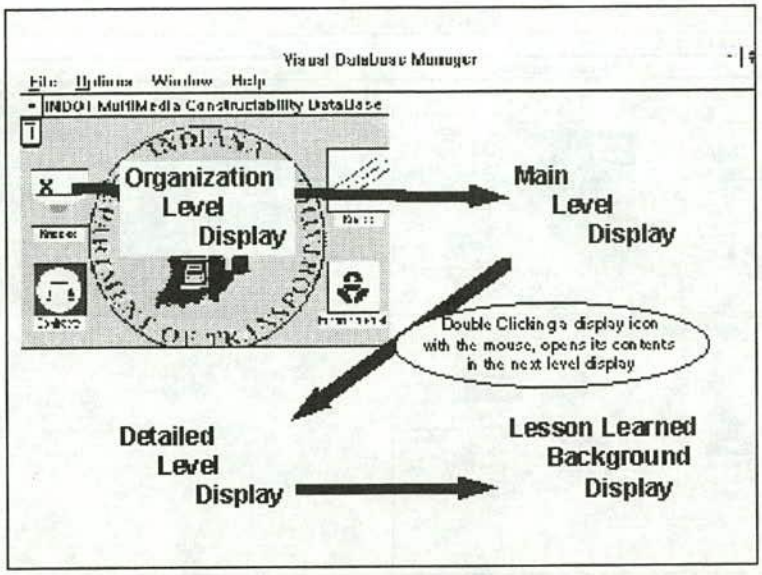


FIGURE T303.3
Screen Organization and Navigation Path

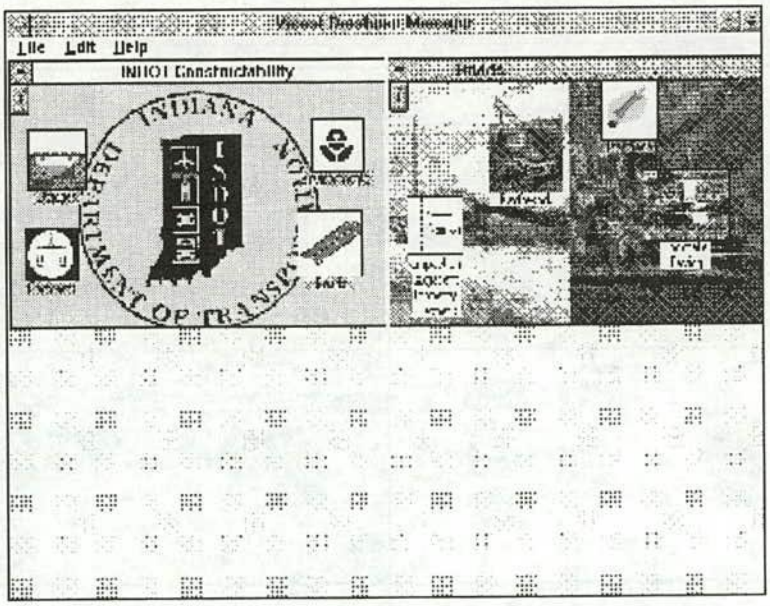


FIGURE T303.4
Main Level Window

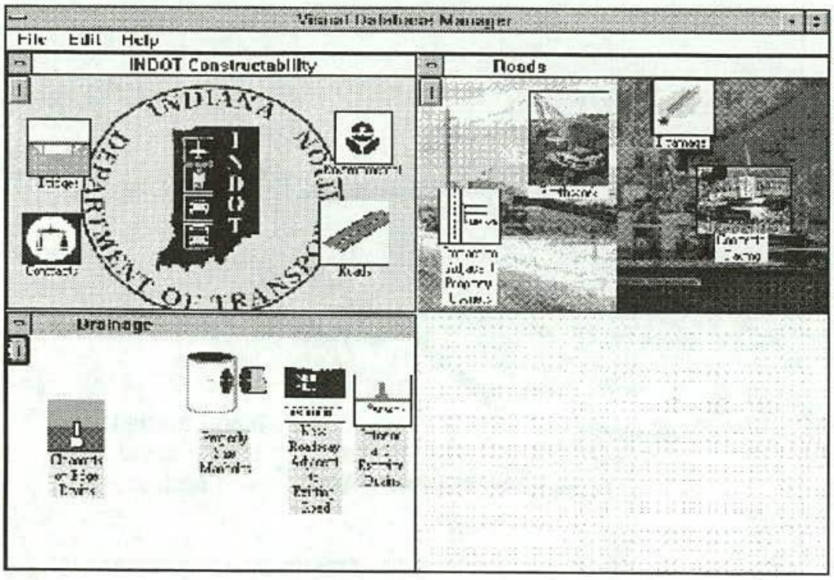


FIGURE T303.5
Detail Level Window

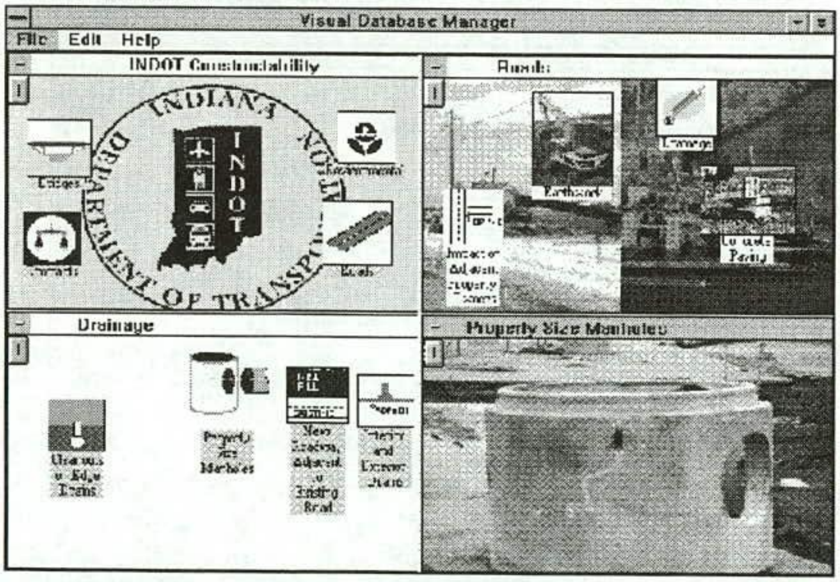


FIGURE T303.6
Lessons Learned Window

EDI/Bar Coding/Pen-Based Technology (T304)

Electronic Data Interchange (EDI) allows multiple access communication delivered exclusively on and between computer networks. EDI systems allow information to be transferred between any member, within real time over communication lines. EDI systems have data formatting standards that allow for shortened messages. This saves time and reduces entry errors. This system makes for a paperless environment that enables large amounts of information to be sent or received around the world in real time. Bar coding uses computer technology and pattern recognition to monitor transactions. Each item or activity is assigned a code which is represented by a specific arrangement of bars. When any activity or item is manipulated (that is, bought, sold, used, or performed) this activity is recorded within a computer simply by entering the code (typically by visual scanning) and a few simple commands. Bar coding has evolved into a pen-based technology. Bar codes are used to identify each object and a hand-held light pen is used to enter this information into the computer. Pen-based technology allows the transactions to be monitored within the field with hand-held equipment.

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Appendix B.2

ADVANCED CRP TOOLS

This appendix contains 25 tools that can be used by an organization whose constructibility review process is more mature. These tools are not included within the workbook format; however, the purpose of this appendix is to give more detailed information about the tools and to demonstrate their relationship to each constructibility function. This appendix contains generic descriptions of each tool and citations to find more information about the tool.

Each of the constructibility functions is implemented by using an associated tool. The tools are divided into T4100's, T4200's, and T4300's. The T4100's are used to understand/communicate constructibility. The T4200's are used to implement/measure constructibility, and the T4300's are cutting edge technology/computer tools. Unlike Appendix B.1 workbook tools, these tools are all of a generic nature. Table 1 is a matrix that links each of the CRP functions to a tool. Each of the functions is implemented by using an associated tool. Column 3 of this table indicates which tools are process based (PROC), and which are products (PROD).

Following Table 1 are detailed definitions and figures describing these tools, followed by application tips describing how to utilize these more advanced tools with each of the CRP functions to which they are linked. Finally, this appendix contains references on where one can obtain more information about these tools.

TABLE 1

Matrix Linking Functions♣ to Tools

Name of Tool		A111	A112	A113	A114	A121	A122	A123	A211	A212	A213	A221	A222	A223	A231	A311	A312	A321	A322	A331	A332	A333	
		Constructibility Functions																					
Influence Diagramming	T4114							X				X					X					X	PROD
HOT Diagramming	T4115	X				X				X													PROD
Storybook Management	T4116										X									X			PROD
Design/Build Approach (Alternate Contracting)	T4211	X																					PROC
Concurrent Engineering	T4212	X							X														PROC
Decision Trees	T4213																			X			PROD
Root Cause Analysis	T4214																	X					PROD
Regression Analysis	T4215															X							PROD
Forecasting Models	T4216							X								X							PROD
Sensitivity Analysis	T4217												X				X		X				PROD
Process Modeling	T4218																		X		X		PROD
Multiple Criteria Decision Making	T4219																			X			PROD
Financial Modeling	T4220							X					X				X		X				PROD
Linear Programming	T4221												X				X		X				PROD
GIS/Graphical Modeling/Digital Imaging	T4305																						PROC
Simulation	T4306							X				X					X						PROC
Case-Based Reasoning	T4307						X				X									X			PROD
GPS Technology	T4308															X							PROC
Expert Systems/Rule-Based Reasoning	T4309		X				X				X									X			PROD
Visual Spreadsheets	T4310												X				X		X				PROD
Virtual Reality	T4311											X					X						PROC
Neural Networks	T4312											X									X		PROD
Fuzzy Logic	T4313											X					X						PROD
Visual Interactive Modeling/VIM Simulation	T4314											X					X						PROC
Voice Recognition	T4315																					X	PROD

LEGEND

PROC — Process
PROD — Production

♣ Please refer to page A0.9 for the framework showing all the constructibility functions

Influence Diagramming (T4114)

Influence diagramming is a method of tracing the root causes of a particular action. Such a diagram shows all the variables and their hierarchical interdependence within a graphical presentation. This provides the framework in which to determine the exact relationships within a process. Influence diagrams can have many levels of detail and enable all relationships to be remembered. An influence diagram begins with an output of a process. Factors which directly influence the output are identified. After this first set of influence factors is complete, each factor is analyzed separately to determine the factors influencing it. This process is continued until an appropriate level of influence is obtained. This tool allows for the determination of the effect of actions performed during the initial stages of a process upon the final output. Influence diagramming will provide an organization with a direct cause and effect link between activities that are separated by physical location, personnel or long periods of time. Figure T4114 gives an example of an influence diagram for a modular bridge span.

HOT Diagramming (T4115)

Hierarchy of objectives technique (HOT) diagramming is a method that allows the exploration of high and low order managerial or technical objectives. This technique begins by identifying the high order objectives that are characterized as organizational strategies and project concepts. These high order objectives give a process the reasons why actions are performed. Once these high order objectives are identified, investigation into how actions are to be performed determines the low order objectives known as tactics or ideas. As one follows the logic network of this diagram from left to right, the 'how' is identified and as one follows the network right to left, the 'why' is identified. Hot diagramming focuses on objectives more so than functions and allows one to communicate the complex and detailed hierarchy. Figure T4115 gives an example of a HOT diagram for enhancing constructibility through specifications.

Storybook Management (T4116)

This management technique involves teaching lessons and communicating policy through the use of stories. The use of pictures, video or simply text allows this information to be conveyed in a manner easily absorbed by the recipient. These stories must consist of accurate description of problems that are unpolitical, defensible, nonjudgmental and unbiased toward any side. By using this storybook approach, complex ideas can be expressed in a manner that can be easily followed. This approach provides a less structured learning environment, one learns by example and association rather than by step-by-step learning of a rule base. The advantage of this technology is the ability to facilitate learning by creating the environment where learning is enjoyable.

Design/Build Approach (T4211)

A design/build approach is one in which the contractor provides the complete construction service to the agency, including design and construction. The agency typically states the performance criteria, and the contractor essentially hands the agency the keys to the finished product that satisfies all the performance requirements. This approach allows the design and construction phases to occur under the same roof, thereby eliminating the seams between the two phases of the project. This allows for a comprehensive constructibility program to be implemented due to direct access of construction knowledge. This construction knowledge can be infused into the design at the earliest stages.

Concurrent Engineering (T4212)

Concurrent engineering is a planning and design approach in which the separate phases of the process are conducted at the same time. This approach allows interaction between the phases during the entire process allowing ideas to be bounced between phases which would not be possible if activities were performed in a sequential manner. This approach toward planning and design results in shorter lead times on design changes and an overall reduction in product development time. The concurrent engineering approach forces interaction among the disciplines because incomplete or in progress designs are being exchanged. Concurrent engineering is best accomplished by using a team concept where each team is focused upon the 'goods' to the total organization (product values, customer needs, company interests). These teams engage in parallel work groups using collaborative tools, while working fairly independently of the other groups with only information exchange connecting the concurrent processes. The autonomy of the individual parallel work groups is important to provide the freedom for innovation and improvement that must be balanced with the need for continuous updates and modifications to be shared with all participating groups.

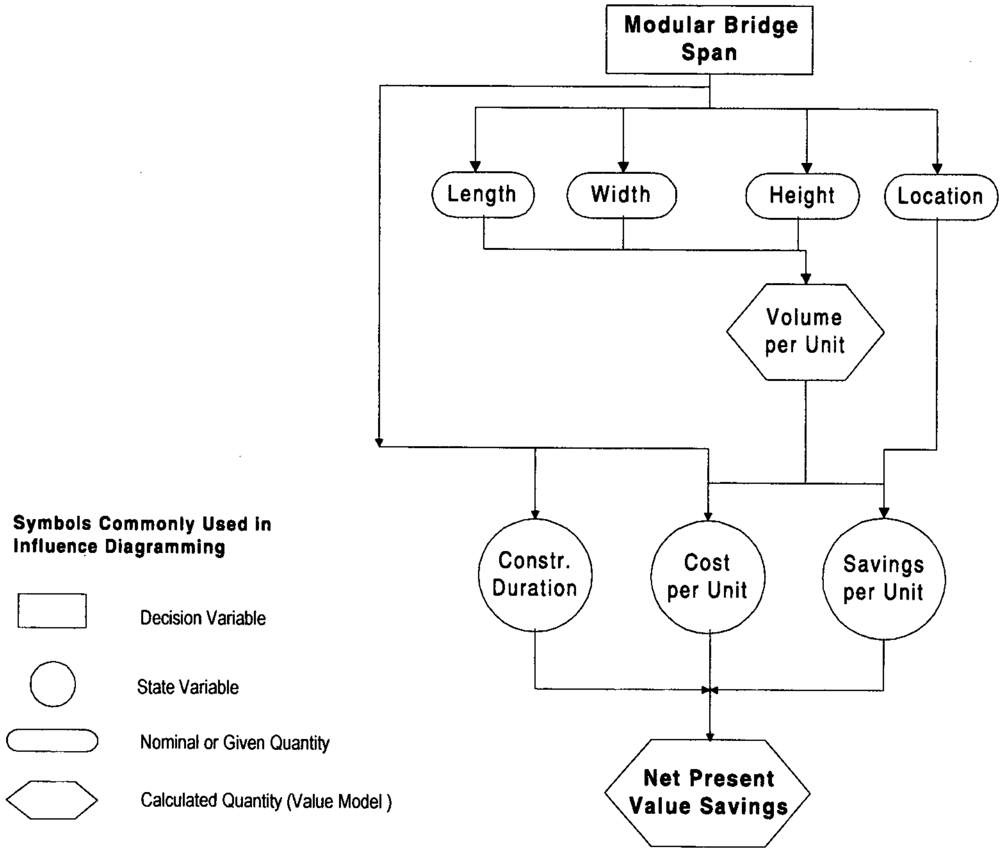

FIGURE T4114
Influence Diagram

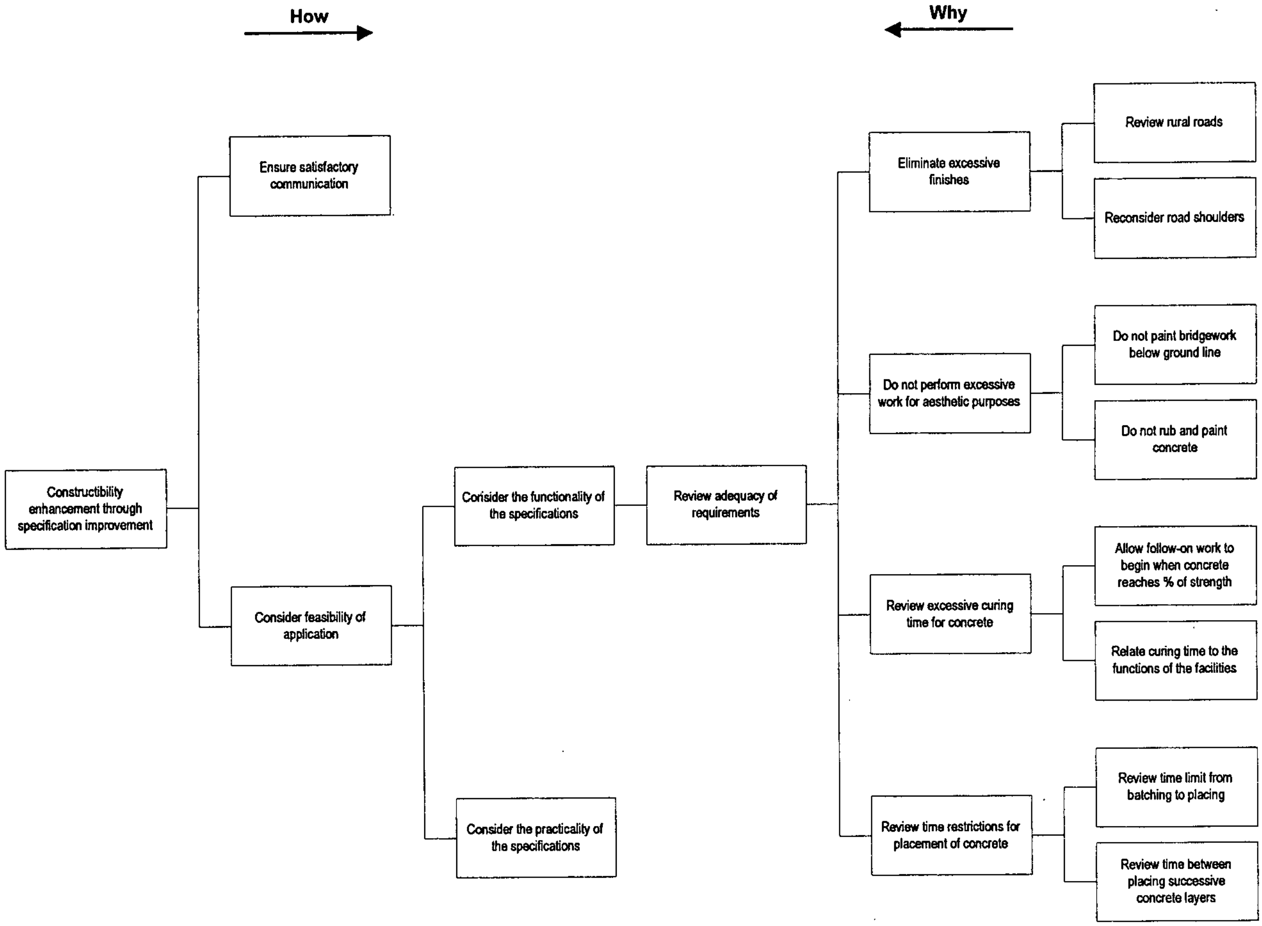

FIGURE T4115
HOT Diagram

Decision Trees (T4213)

A decision tree is a graphical representation of the relationships within levels of a problem. They are composed of hierarchical goals within a process that are linked to each other by decisions. By following the logic of the tree network and entering the decisions at each goal a final solution will be reached. These decision trees are good tools to show how an individual should follow through the agency's proper sequence of goals to obtain the proper action. Decision trees assist personnel in problem solving and maintain consistency in design and problem solving throughout the organization. Figure T4213 gives an example of a decision tree for evaluating contract strategy, based on what drives a project, from a trade-off analysis perspective.

Root Cause Analysis (T4214)

Root cause analysis is a method of determining the ultimate cause of any problem by tracing the reliance of each failure upon its input. Once a problem is identified, all the factors contributing directly to the problem are determined. These factors are then analyzed to determine their contributing factors. Root cause analysis implements a structure to determine the cause of a problem by forcing the investigator to continue asking why until the original or root cause is discovered. This method of determining all the "why's and how's" ultimately leads to the base or root cause, which when corrected eliminates the problem for good. There are several types of root cause analysis structures:

1. fishbone
2. fault-tree
3. simple (Figure T4214).

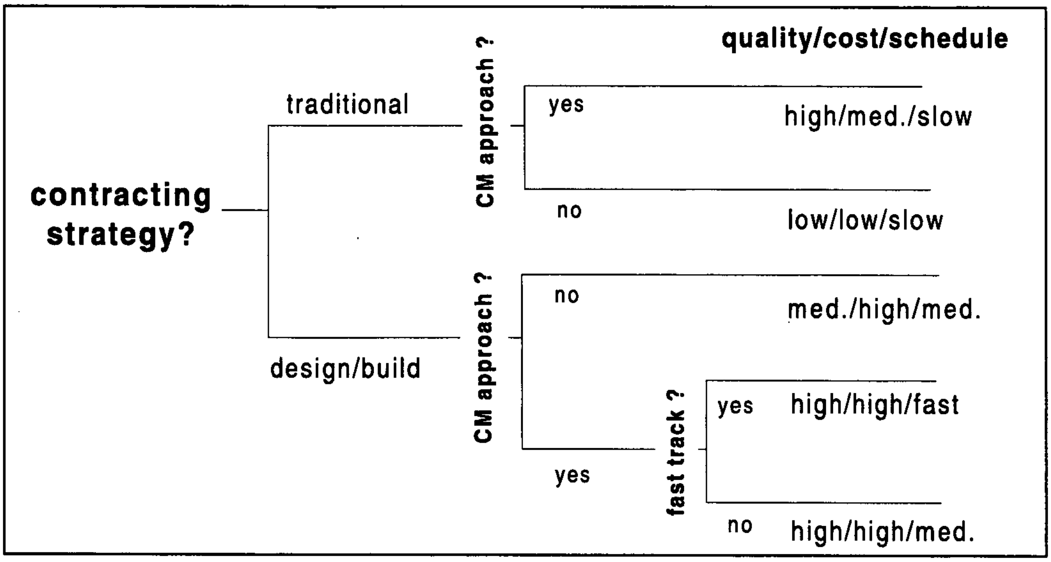

FIGURE T4213
Decision Tree

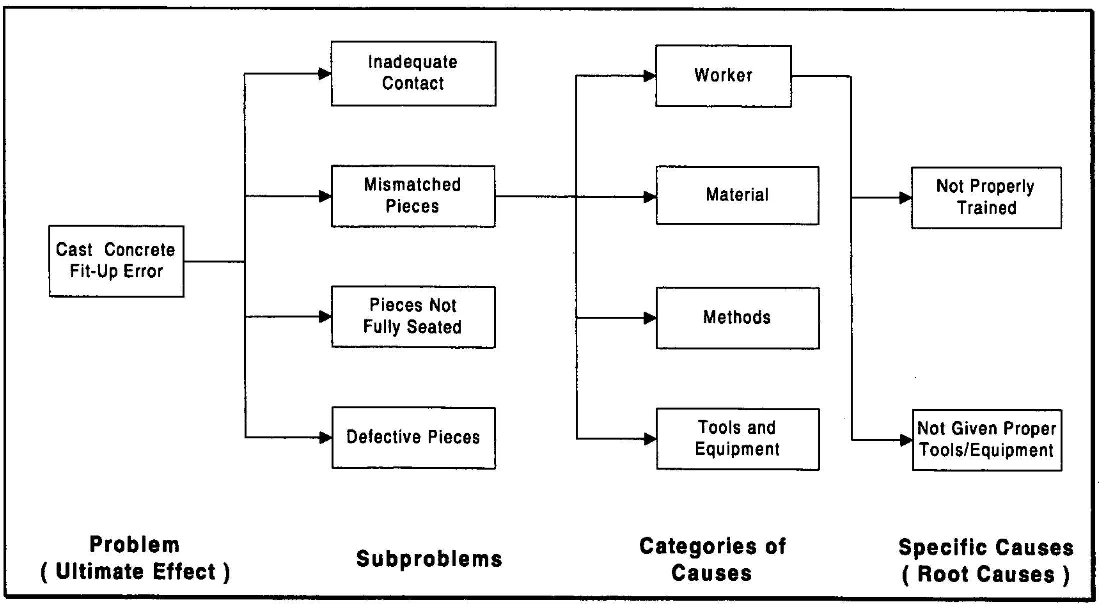

FIGURE T4214
Simple Root Cause Analysis Structure

Regression Analysis (T4215)

Regression analysis determines the relationship between two or more variables. The goal in performing regression analysis is to predict the value of one variable based on the value(s) assumed by the other variable(s). This tool is valuable in the analysis of decision making and financial forecasting.

Forecasting Models (T4216)

Forecasting models attempt to predict what the future holds. Forecasting can be divided into four categories of methods: judgment method, counting method, time-series analysis, association or casual methods. Judgment methods are based on expert opinions and are subjective estimates. The counting method is based on experimentation or surveys and is more objective than the judgment method. The time-series analysis is based on past behavior to predict future behavior. Association or casual methods are cause-effect relationships based on data analysis. Many forecasting models are available on the market. These models can be used as a sequel or in conjunction with CPM.

Sensitivity Analysis (T4217)

Sensitivity analysis is similar to "what-if" analysis. It allows the inputs to a model to vary with some result or measure of performance as an output. It allows for flexibility in a decision-making role as well as provides a better understanding of the model because of the variability of inputs with designated outputs. This tool can be used as a sequel or in conjunction with benefit/cost analysis.

Process Modeling (T4218)

Process modeling is the use of graphical methods to describe the flow of information and activities through an organization. Process model diagramming provides a visual description of how a process works. By graphically representing these activities along with their predecessor and dependent activities, an organization can analyze; streamline, through elimination of duplication of effort; and formalize their procedures. IDEF0 is one method that allows process modeling to be performed by the use of cell modeling. This method involves functions being represented by cells, with each cell having inputs and outputs. The behavior within each cell is determined by controls and mechanisms. IDEF0 allows these cells to be decomposed into subcomponents allowing a process to be described at various levels of detail. The greatest benefit provided by process modeling is the formalization of the procedures involved within the process modeled. Once a process model has been developed and the operation is streamlined, deviation or modification by individuals can be easily determined and eliminated or incorporated into future practice. A modeled process is easily learned, therefore, elimination of costly training is a result.

Multiple Criteria Decision Making (T4219)

Multiple criteria decision making is a tool that allows for structured decisions. The user may graphically display a complex decision analysis problem with multiple criteria used for evaluation. This type of software allows the user to make decisions based on multiple choices and allows for the criteria to be separately weighted and rated. Many software programs that utilize multiple criteria decision making are available on the market today.

Financial Modeling (T4220)

Although much financial analysis is performed with spreadsheets, there are many stand-alone packages specifically for financial modeling. One advantage of a financial modeling package is that models are algebraically oriented instead of calculation oriented. These packages can produce financial reporting, forecasting, sensitivity analysis, and many statistical evaluations.

Linear Programming (T4221)

Linear programming is an excellent optimization tool. It deals primarily with the optimization of particular resources among activities. There is an infinite number of solutions to any one allocation problem; however, linear programming allows for a search procedure that produces the best solution(s) in a timely manner. Every linear programming problem is described by decision variables, an objective function, optimization, coefficients of the objective function, constraints, input-output (technology) coefficients, and capacities. Decision variables are the variables whose values the user wants to examine. The objective function is the linear mathematical function that measures goal attainment such as total profit. Optimization is either the minimization or maximization of the values of the objective function. The constraints are described in a set of linear inequalities and the input-output coefficients indicate the rate at which a resource is depleted or utilized and appear on the left-hand side of the constraint equations. The capacities appear on the right-hand side of the constraints and denote the availability of the resources. This tool can be used to optimize labor, equipment, or materials during the constructibility process.

GIS/ Graphical Modeling/ Digital Imaging (T4305)

These technologies use spatial data of physical features which are entered into the computer. Once entered, this digitized information can be manipulated and analyzed. Graphical imaging systems (GIS), digitize maps, and map-like information then integrate these data within other databased information in order for a particular solution to be developed. With the recent advances in computer aided design products, many specialized graphical imaging systems have become available. These systems have the ability to import CAD and graphics files created elsewhere and perform a variety of specialized tasks to these data and then incorporate these improved designs into the original drawings. Graphical modeling and digital imaging systems similarly digitize spatial data within a computer and allow manipulation of this information to test what can and cannot be performed within the real world. These technologies allow many 'what-if' scenarios to take place without any changes to the physical world. The use of GIS, graphical modeling, and digital imaging will reduce the risks of fit up errors, alignment problems, and unforeseen problems once a project gets into the field.

Simulation (T4306)

Simulation is a method of reproducing the characteristics of reality within an abstract model. This model allows the user to perform experiments, or 'what if' test scenarios within it and measure the outcomes. Simulation tools typically are used within a statistical domain. The real world processes are defined by mathematical manipulations or functions of all the inputs. By varying these inputs the user is able to determine the effects of changing a single input or several inputs. This tool allows many options to be tried in order to solve a problem in the optimum fashion. By using simulation, the need for trial and error within the physical world is reduced. There are several commercially available simulation software packages that can be used as the framework for any simulation application. This tool can be very useful to analyze the constructibility of any tasks by performing the simulated task within the model. Through simulation, the factors which have the greatest impact can be identified and improved in order to achieve the best model for the least amount of resources.

Case-Based Reasoning (T4307)

Case-based reasoning is an approach to problem solving that uses previous cases which have similar attributes to the current problem and adaptation of the previous solutions to fit the current problem. This approach to problem solving closely matches human problem solving techniques known as inference. For case-based reasoning to be performed, there must be an ability to analyze relevant cases and find the closest match to particular problems. Case-based reasoning uses experience as a reasoning tool. In order for this form of problem solving to be used, there must be good records of past projects from which to learn. This database must be organized in a manner to facilitate retrieval by a variety of different project characteristics. By the use of case-based reasoning, there is an elimination of duplication of effort by the organization.

GPS Technology (T4308)

Global positioning system (GPS) is a technology that allows locations on the earth to be measured with high accuracy. The use of satellites enables positions to be fixed without the use of traditional surveying equipment. This system is based upon the triangulation of a sensor through the use of radio transmissions. A main receiver is placed at a known position. Several smaller senders/receivers are placed at locations which are to be measured. The position of the smaller transmitter is determined by having four satellites receive and transmit the signal along with the main receiver. Using the time differences in receiving the signal, the position is fixed in three dimensions. This GPS technology converts the signals and position immediately into the reference frame specified by the user; therefore, bad data can be found immediately rather than after an entire survey has been completed and compiled. This technology, can overcome line of sight conflicts that occur in traditional surveys by placing relay signals at the highest positions. These devices are not limited by weather or by lack of light. The use of this technology will expedite the surveying process, reduce error in location, and standardize the format of all surveys.

Expert Systems/Rule-Based Reasoning (T4309)

An expert system is any system which provides the user with solutions to problems asked. An expert system is a structured program which requests information that allows it to apply rules and select possible outcomes. An expert system is constructed around criteria defined by a human expert and based upon a decision tree designed by an expert within a specific domain. The system is designed to ask the user a set of questions which leads to a solution to the problem. The response to each question leads the user down a particular branch of the decision tree and narrows the possible solutions to a point where the computer suggests a solution based upon all the factors given. An expert system can be based upon a certainty system such that, depending on the answers to the question, the solution is assigned a certainty factor. An expert system provides a permanent collection of solutions for particular symptoms and can infuse the knowledge of many experts. Currently, there are many expert system software packages that can be used as a shell for any particular usage. The expert system can include simple Boolean logic or even neural networks. An expert system should be used as a tool to assist in the planning, design, and construction phases by providing advice to augment the knowledge base of an organization's expert.

Visual Spreadsheets (T4310)

Visual spreadsheets allow the user to follow formulas and time sequences easier than basic spreadsheets. Visual spreadsheets allow for the same calculations as spreadsheets, but they do not have cells, columns, and rows. Instead, the visual spreadsheet utilizes influence diagrams to portray the information needed to be presented. The visual spreadsheet uses symbolic elements instead of cells. An example is the use of triangles as variables in a formula. Many of the visual spreadsheet programs have "what-if" modeling and "goal-seeking" modeling available within the program. This tool can be used as a sequel or in conjunction with the benefit/cost analysis.

Virtual Reality (T4311)

Virtual reality is any model or representation of physical experiences which are conveyed through a different medium. This model can be expressed through more than one medium at a time, i.e., sight, sound, and even touch. With the aid of computer technology, users have the ability to model the real world, replay these sensations, and experience the physical world through artificial stimuli. Virtual reality allows individuals to perform tasks without actual physical changes to the model. This allows physical activities to be optimized before any physical alterations are performed. Through the use of virtual reality devices, organizations can optimize designs for ease of construction. This technology allows workers to have hands-on training and to practice difficult operations before performing them in the field. Virtual reality devices can be as simple as a two dimensional program on a screen, similar to a video game or as advanced as a holographic three dimensional image with mechanical devices attached to the body which place pressure that simulates the physical sensations associated with the image.

Neural Networks (T4312)

This technology employs pattern recognition to make decisions based upon partial, incomplete or inexact information. Neural networks are based upon the biological structures of the human brain. These man-made logic structures are designed to simulate the activities of neurons within the human brain. These networks allow complex problems to be solved using computers to mimic human learning and application processes. Currently, many software manufacturers have available neural network shells or frameworks that can be used and modified to fit a multitude of operations. The use of neural networks provides an organization with the ability to program a computer to perform the complex and time consuming task now performed by extremely valuable personnel.

Fuzzy Logic (T4313)

This technique uses the mathematical theory of fuzzy sets to simulate the process of normal human reasoning to deal with uncertainty. A fuzzy set describes an event or object, not as a specific quantity, but as a set of certainty factors. A singular piece of information can belong to two or more characterization groups, a particular piece of data can belong to 25% of one particular set and 75% of an opposing set. The functions performed by the computer can differ according to the relative weights of the fuzzy data sets. Fuzzy logic allows the computer to be more flexible and to shift through multiple alternatives to find the 'closest' match for an answer.

Visual Interactive Modeling/VIM Simulation (T4314)

Visual Interactive Modeling (VIM) utilizes computer graphic modeling to present real situations and their outcomes. The user can intervene in the decision-making process and view the results in a graphical environment. This tool is a graphical decision-making tool. To many managers, a picture that can depict a model of the real world is more understandable than a table with figures and formulas. This tool can be used as a sequel to or in conjunction with simulation.

Voice Recognition (T4315)

Voice recognition is the process of having the computer recognize the human voice. It allows the user to communicate with the computer by simply speaking to it. Voice recognition may be applied to work in the field such as taking field notes or surveying measurements. Many times items are missed or transposed. Voice recognition would allow the user to speak directly to a computer that would record the information correctly.

Tips on Where and How to Use Advanced CRP Tools

Establish Project Constructibility Strategies (A111): HOT diagramming (T4115) is a way to organize, communicate, and align the hierarchy of project objectives with constructibility objectives during step 1. HOT diagramming helps the user to get to the root objective. Because it is graphical, it can be conducted quickly and easily. It is during this early stage of the process that innovative project execution strategies to implement constructibility should be considered. Two tool examples of this constructibility implementation strategy are structuring contracts into a design-build approach (T4211) and structuring the design effort into a concurrent engineering execution approach (T4212). Both of these tools need to be decided upon early in the planning phase of the project.

Determine Formality of Constructibility Program (A112): A rule-based expert system (T4309) is helpful when determining the level of formality of a CRP. The expert system can ask the user about certain attributes that influence the level of formality such as project size, project type, project complexity, and level of involvement of the agency. The expert system would ultimately arrive at an automated answer for level of formality.

Identify Major Constructibility Issues (A121): The constructibility team should revisit the HOT diagram (T4115) that was created during function A111, modifying it where necessary to fine-tune project objectives from a constructibility perspective.

Consult Lessons Learned for Planning (A122): One efficient high-tech way of automating the process of accessing past lessons learned is through a rule-based expert system (T4309). This system would take the user through a series of questions, matching lessons learned on similar past projects with the current project that is being executed. Case-based reasoning (T4307) is an even further enhancement to accessing lessons learned. It will actually match attributes of similar projects and call up the case or past project of a similar nature for matching lessons learned.

Evaluate Concept Plans for Constructibility (A123): In reviewing concept plans for constructibility, influence diagrams (T4114) can be used to develop the improvement ideas that result from this process by identifying the decision variables (both certain and uncertain), the uncontrollable variables (both deterministic and random), and the outcome variables. Financial (T4220) and other forecasting models (T4216) can be used to analyze, justify, and implement the variables that have been identified through influence diagramming. Finally, computer simulation (T4306) and GIS (T4305) can be applied at this stage, to perform sensitivity analyses of the variables, especially the uncertain/random ones, by "what-if" analysis.

Modify Constructibility Team (A211): During the design phase, the team is modified and if concurrent engineering (T4212) is chosen as a project execution strategy during the planning phase, the new members of this team need to be informed of and educated about this approach.

Finalize Project Constructibility Procedures (A212): During the design phase, projects objectives are revisited by the modified team and an efficient way to communicate project objectives from a constructibility perspective is to review the HOT diagrams (T4115) developed and modified during the planning phase.

Consult Lessons Learned for Design (A213): Past lessons learned can be communicated in a very powerful and innocuous way (especially the negative ones) between past and current projects with storybook management (T4116). As previously mentioned in function A122, this transfer of knowledge can be automated using rule-based (T4309) and case-based reasoning (T4307).

Evaluate Plans and Specifications (A221): During the design phase, detailed plans and specifications are reviewed from a constructibility perspective and influence diagrams (T4114) can be used to develop any improvement ideas that result from this process by identifying the decision variables (both certain and uncertain), the uncontrollable variables (both deterministic and random), and the outcome variables. Influence diagrams graphically portray any improvement ideas that result from this process, arriving at root outcome variables. Financial (T4220) and other forecasting models (T4216) can be used to analyze, justify, and implement the variables that have been identified through influence diagramming. Finally, computer simulation (T4306) and GIS (T4305) can be applied at this stage to perform sensitivity analyses of the variables, especially the uncertain and random ones, by "what-if" analysis. There is now enough detailed design information at this stage to begin applying more high tech computerized tools, such as virtual reality (T4311), neural nets (T4312) to model patterns, visual simulation (T4314) to model such things as traffic phasing and staging, and fuzzy logic (T4313) to simulate uncertain events.

Validate Constructibility Improvements (A222): Benefit/cost analysis can be prioritized and implemented using sensitivity analysis (T4217), financial modeling (T4220), and linear programming (T4221). A computer tool that allows users to follow formulas and time sequence easier is visual spreadsheets (T4310).

Review Bid Documents (A311): In reviewing bid documents for potential constructibility issues, quantitative tools, such as regression analysis (T4215) and forecasting models (T4216) can be used as implementation tools to check for completeness and to identify issues for future use.

Initiate Field Constructibility (A312): In reviewing plans, specifications, and procedures during the construction phase, influence diagrams (T4114) can be used to develop and communicate the improvement ideas that result from this process by identifying the decision variables (both certain and uncertain), the uncontrollable variables (both deterministic and random), and the outcome variables. When implementing the recommended field changes from preconstruction review, linear programming (T4221), financial modeling (T4220), and other forecasting models (T4216) can be used to analyze, justify, and implement the variables that have been identified through influence diagramming. A sensitivity or "what-if" analysis (T4217) can be performed on the benefit/cost analysis. At this stage, computer simulation (T4306) can be applied to model these variables and fuzzy logic (T4313) to simulate uncertain events. Because the design is complete at this stage, field operations can be simulated graphically, using visual spreadsheets (T4310), virtual reality (T4311), GIS (T4305), or visual interactive modeling (T4314).

Identify Constructibility Experiences and Ideas (A321): When reviewing field change orders and identifying constructibility experiences and ideas, root cause analysis (T4214) is an appropriate tool to determine the root cause of these issues in order to implement the ideas.

Document Constructibility Experiences and Ideas (A322): When sorting and categorizing experiences and ideas, appropriate tools for analysis and implementation are sensitivity analysis (T4217), process modeling (T4218), financial modeling (T4220), and linear programming (T4221). A recent visual computer graphical tool to capture these experiences and ideas are visual spreadsheets (T4310).

Review Project Constructibility Process (A331): As was stated during the design phase, lessons learned can be communicated in a very powerful and innocuous way (especially the negative ones) between past and current projects with storybook management (T4116). These lessons learned can be implemented using decision trees (T4213) and multiple criteria decision making (T4219). Also, as previously mentioned, this transfer of knowledge can be automated using rule-based (T4309) and case-based reasoning (T4307).

Update Constructibility Lessons Learned (A332): Process modeling (T4218) can be used at the end of a project to document and update all of the experiences and ideas that have been collected throughout the constructibility process to facilitate their future use. Neural networks (T4312) are computer tools that help to isolate patterns that have occurred during post-project review.

Obtain Feedback from Maintenance and Operations (A333): In obtaining feedback from maintenance and operations, influence diagrams (T4114) can be used to develop and communicate the ideas generated from this process by identifying the decision variables (both certain and uncertain), the uncontrollable variables (both deterministic and random), and the outcome variables. Voice recognition (T4315) is a automated computer tool that makes collection of this information more expedient.

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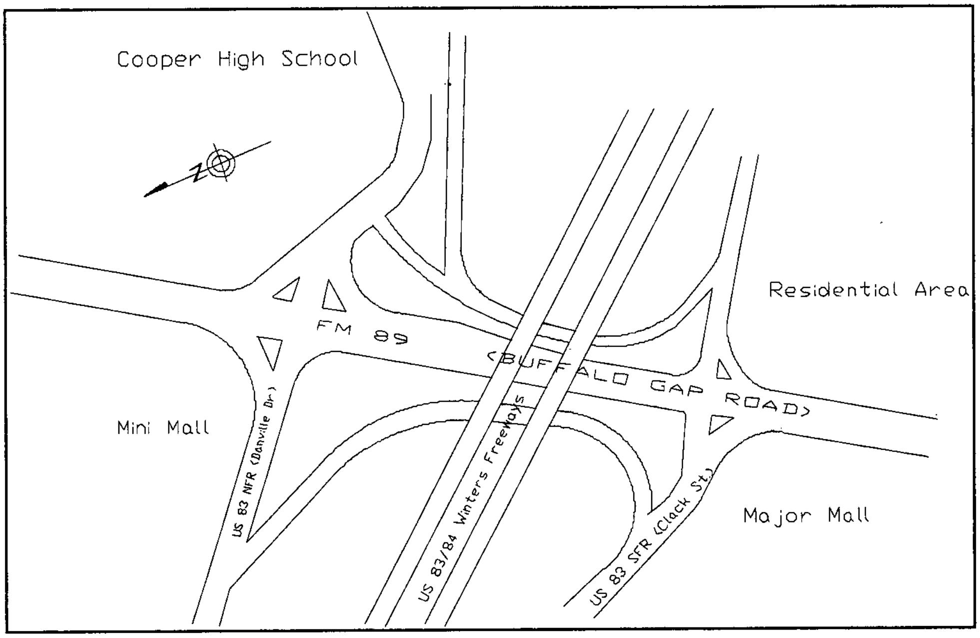
Appendix C

The Buffalo Gap Intersection

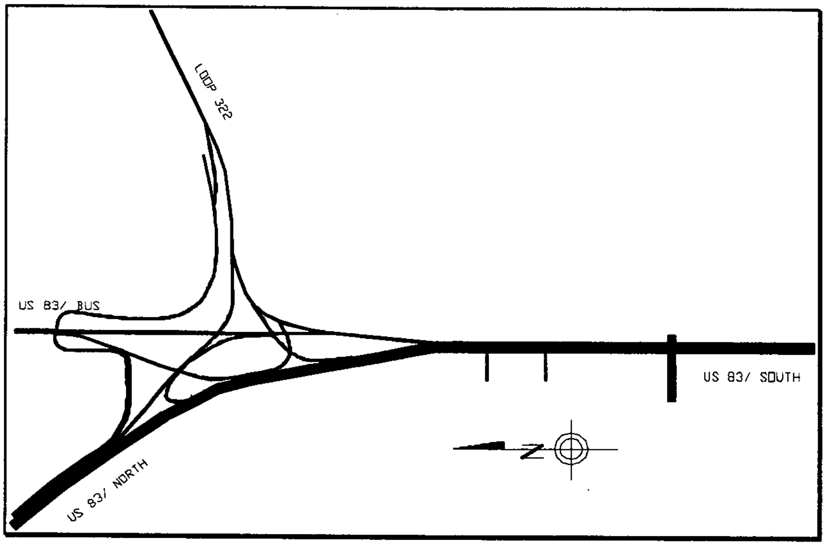


- Upgrading of a freeway facility, consisting of grading, flex base, one course of surface treatment, hot mix concrete paving, lighting, and striping.
- Widening of a non-freeway facility, consisting of grading, asphalt stabilized base, concrete pavement, hot mix concrete pavement, curb and gutter, lighting, signals and striping.
- Upgrading consisted of added capacity by providing additional lanes for left turning traffic to US 83 North.
- This intersection has the highest traffic volume generated in the city, provides primary access between north and south urban areas and to major mall areas.
- Average daily traffic — 20-year projection: 28,000
- Vertical clearance (US 83 Overpass) — 14 ft. 1 inches (desirable 14 ft. 6 inches)
- Horizontal distance between piers (82 feet)
- Terrain — Flat
- Utilities — Cleared
- Turn around movements vary (one way traffic)
  - East to West (high traffic volume)
  - West to East (lightly used)
- Project cost $1.6 million
- Project life cycle 20 months

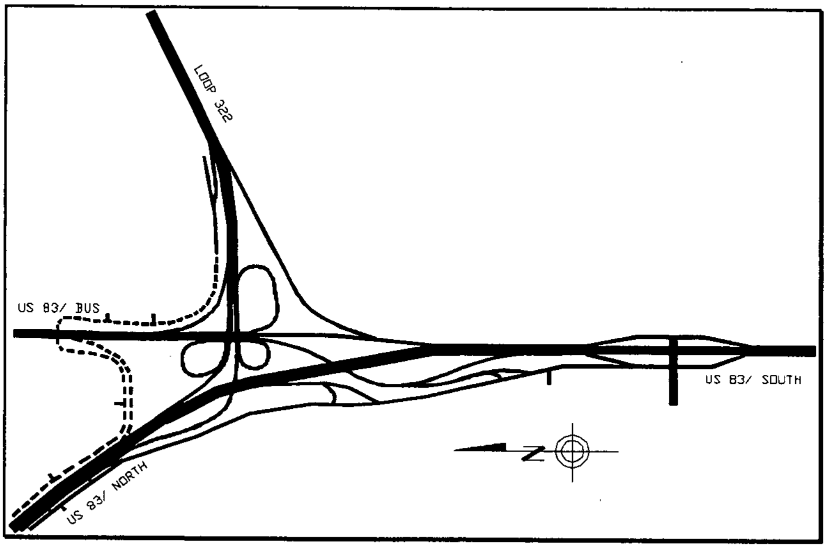
  Planning — 4 months
  Design — 6 months
  Construction — 10 months

- Agency performed planning and design

The Loop 322 Interchange



Existing layout



Proposed layout

- New interchange construction of grade separated overpasses connecting three highways
- Average daily traffic — 20-year projection: 16,000
- Project cost $16 million
- Project life cycle 7 years
  - Planning — 2 years
  - Design — 2 years
  - Construction — 3 years
- Agency performed planning and design

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 400 committees, task forces, and panels composed of more than 4,000 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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