# Effects of Constructibility Reviews on Highway Project Duration

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**Abstract**

Increases in the volume of construction work and number of work zones will increase delays to motorist and have an adverse impact on the local businesses. Therefore, state highway agencies are interested in decreasing the duration of construction projects. One approach to decreasing the duration of a highway project is to reduce the number of change orders during the construction phase with formalized constructibility reviews. Constructibility review brings construction experience and knowledge into the design process. Only about one- quarter of state highway agencies currently have a formal program. The effects of constructibility reviews on the design and subsequent construction phases of a project are modeled and analyzed. Constructibility reviews can reduce overall durations but increasing the time it takes to conduct constructibility reviews eventually fails to offset the shortened construction time.

**Keywords**: project management, constructibility, duration

## Introduction

State highway agencies (SHAs) are now performing less new construction and more rehabilitation and/or reconstruction of highway facilities. Efforts to maintain existing highway facilities remain a high priority for all transportation agencies. Because more dollars have been allocated to this work through the Transportation Equity Act for the 21$^{st}$ Century, an increase in construction work will occur. Correspondingly, the number of construction work zones will increase sharply (Anderson and Ullman, 2000).

Large highway reconstruction projects can cause significant disruptions to motorist travel patterns and economic activity. Reducing the impacts on highway users and businesses requires that innovative and effective transportation management actions be developed and implemented (Janson et al., 1989). State Highway Agencies across the country are seeking approaches that can be readily implemented and improve construction operations. A research project funded by the National Cooperative Highway Research Program (NCHRP) has identified "constructibility" and "methods to minimize project duration" as two of several critical issues necessary for improving construction and the quality of highway projects (Russell and Anderson, 2000).

An increase in the number of highway construction projects and the relative impacts on traffic flows have increased the need for accelerating construction and, thereby, reducing project duration. There are various approaches to accelerating construction such as improved task productivity, better training of craft, or increased use of technology. Implementing various contracting methods such as design-build can shorten the overall duration of a project. One approach to shortening the duration of a project is minimizing errors and inefficiencies in designs. Deficiencies in plans and specifications can cause an increase in construction delays, claims, and the duration of construction operations. This impact was cited as an important issue in the NCHRP project (Russell and Anderson, 2000). Review of designs and specifications to identify constructibility issues is a primary means of reducing project durations by minimizing errors and inefficiencies. Mendelsohn (2000) provides an example of a constructibility issue:

> "A bridge was to be designed to span four lanes of highway from abutment to abutment. Because of ground conditions and traffic, it would have been very difficult to locate cranes of sufficient capacity to place the large pre-cast girders called for in the plan. A pier was placed on the median strip, at mid-span and as a result, it was possible to use shorter, lighter girders that could be handled by a smaller crane. Additionally, the depth of the beams was considerably reduced; permitting a lower grade to the bridge deck and thereby reducing earth fill to the approaches. The savings were more than enough to pay for the additional mid-span pier, and the schedule was reduced by three months."

Constructibility problems that are not captured during design can have a negative impact on project performance. Specifically, how to effectively use constructibility reviews to reduce project durations is an important issue for construction project management.

## Problem Description

Constructibility is the integration of construction knowledge, resources, technology, and experience into the engineering and design of a project (Fisher, 1996). Constructibility reviews of highway projects during the planning and design stages have the potential to minimize the number and magnitude of changes, disputes, cost overruns, and delays during construction (Anderson and Fisher, 1997a). A constructibility review process (CRP) can reduce deficiencies in plans and specifications that can potentially result in increased project durations.

An effective CRP should decrease project duration, decrease the quantity of changes, and improve the quality of the constructed facility. Field data suggest that benefits may be as large as twenty-five times greater than costs. As indicated in a 1997 survey (Anderson and Fisher, 1997a), despite the possible benefits of project constructibility analysis, only 23% of SHAs use a formal constructibility process. Several factors that limit the implementation of a formal process include a lack of construction experience of designers, inadequate communication between construction and design personnel, the absence of a record of past construction changes, and traditional engrained procedures that emphasize immediate concerns. Anderson and Fisher (1997a) used a survey of state transportation agencies to identify the three most critical issues related to implementing constructibility in transportation projects as: 1) the lack of feedback to the designers, 2) the need to improve plans and specifications, and 3) inadequate time to review. These results may suggest a lack of understanding of how constructibility review processes can impact project performance.

A primary rational for performing constructibility reviews is the belief that these reviews improve project schedule performance by identifying and improving inferior designs before construction and, thereby, reducing the duration of the construction phase. An increase in the duration of the design phase to perform the reviews and iteration for constructibility analysis is generally accepted as a cost of constructibility reviews. However few, if any, tests of this widely held hypothesis have been performed. In fact, for sequential phases, constructibility reviews can only decrease total project duration if the decrease in the construction phase duration exceeds the increase in the design phase duration. There is no guarantee that this is the case for a given constructibility process and management policy. Can constructibility reviews improve project schedule performance in terms of reducing construction and overall project duration?

One basic form of constructibility management is the allocation of resources for reviews. This decision largely determines the average amount of time spent reviewing each design work package for constructibility issues. Managing constructibility reviews at even this basic level is difficult due to a lack of complete understanding of the causal structures through which review processes impact schedule performance. Too little review may increase construction phase durations more than necessary. Too much review may extend the design phase beyond the benefits provided to construction. How much constructibility review benefits a project most? How do benefits change depending on how constructibility reviews are managed? Are improvements large enough to justify improving the understanding of how policies for managing constructibility reviews impact schedule performance?

This paper addresses the lack of understanding of how constructibility reviews impact one dimension of project performance, project duration, by addressing the following questions:

- How do project and constructibility review features and design processes interact to affect project durations?
- How does the time spent on constructibility reviews affect the durations of design and construction and overall project duration in highway projects?

## Research Methodology

A modeling approach was taken to improve the understanding of how constructibility reviews impact project durations. An extensive literature review of constructibility review processes was augmented by an interview of a constructibility review professional to develop an understanding of constructibility review practices. These sources of information were used to extend an existing simulation model of project progress to explicitly include constructibility reviews. The mathematical modeling of constructibility review processes improved the understanding and ability to test hypotheses by requiring explicit and precise descriptions of the components of constructibility review practices and the relationships among those components that cause a CRP to influence project duration. After validation, the model was used to predict the relative durations of projects under various management policies that could guide a CRP.

A summary of the literature review is presented next, followed by a description of the field data collected through an interview. The structure of the model of constructibility reviews is followed by brief descriptions of model testing and behavior. The model is then used to evaluate constructibility review policies and, thereby, expand the understanding of how these reviews impact design and construction.

## Literature Review

A comprehensive literature review of CRPs of highway projects investigated current practices and existing research. The literature review resulted in the identification of the following general themes:

- SHAs are aware of the importance of constructibility reviews

- Many CRPs have been developed and methods documented to facilitate implementation
- Most SHAs lack the funds and personnel resources to adequately formalize a CRP
- SHAs resist change from historical procedures to unproven methods
- Past studies have failed to adequately address and identify methods to assess the benefits associated with a CRP

Moreover, a presentation by DeWitt at the American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Construction annual meeting outlined the results of a national survey that summarized the current use of CRPs by SHAs. Some key statistics are as follows (DeWitt, 1999):

- Twenty-six percent of states use a CRP
- Eighty-eight percent of states have no methods for quantifying benefits
- Ninety-seven percent of states do not document costs of review
- Fifty-five percent of states claim that personnel resources limit implementation of a review process
- Fifty-nine percent of states perform post-construction reviews

The literature review of past research studies and assessment of constructibility in highway projects is summarized in the paragraphs below starting from the early 1990s to the present.

The "Highway Construct*Ability Guide" outlines the important issues and suggests methods and procedures that can be effectively integrated into planning, designing, and constructing highway projects. The benefits of a constructibility policy on project duration include increased contractor productivity, reduced delays, and reduced road user costs. To maximize the benefits of an effective policy, constructibility reviews should be conducted as early in the project design as possible, where the value of construction knowledge and experience can render the highest dividends (Hugo et al., 1990).

In "Improving Highway Specifications for Constructibility", O'Connor, Hugo, and Stamm (1991) state that poor specifications can cause delays and construction rework. In their research, it was found that 22.1% of all constructibility problems related to ineffective communication of engineering information, plans, or specifications. Since such a large number of issues arise from plans and specifications, the article focuses on specific problems in written communication including inadequacies in contract specifications. A specification problem information base was developed to act as a source for specification-constructibility issues in highway designs.

Ellis, Kumar, and Ahmed (1992) document that few SHAs have formal constructibility review systems. In most cases, constructibility reviews are built into the usual district level plan review process. As a result, the design is evaluated for construction feasibility and possible omissions and errors. Only a few SHAs have attempted to outline any such system to achieve effective designs and efficient construction. A report entitled, "Life Cycle Reconstructibility," suggests methods for performing reviews at 30%, 60%, 90%, and 100% design completion. The report further outlines a database program that can maintain important information obtained from constructibility reviews (Ellis et al., 1992).

Russell and Swiggum (1994) in their report to Wisconsin Department of Transportation (WisDOT) present a constructibility work process that facilitates construction input in design, creation of constructibility teams, continuity and communication between design and construction, and continuous improvement of highway projects. The report presents twenty-eight tools to assist in implementation of constructibility on highway projects. The tools fall into four categories: 1) work process, 2) lessons learned, 3) constructibility review, and 4) timing of implementation. During the design of WisDOT projects constructibility is conducted at approximately 80% completion of design. The review is returned to the designers who modify the plans as needed to correct potential constructibility problems.  These potential problems are entered into a lessons learned database. The database is updated after construction is complete (Russell and Swiggum, 1994).

In his thesis entitled, “Constructibility Review Process Framework for Transportation Facilities,” Limam (1995) describes a process to implement constructibility in the transportation industry. Delays, cost overruns, change orders, and disputes are problems characteristic of heavy highway construction projects. These problems can be substantially reduced if plans, specifications, and other contract documents developed through planning and design ensure efficient construction processes. Limam used the IDEF0 function modeling technique to build a constructibility review process framework.

In “Automated Constructibility Analysis of Work-Zone Traffic-Control Planning,” Fisher and Rajan (1996) state that work-zone traffic control is one of the most critical factors impeding the constructibility of highway projects. Lack of efficient constructibility reviews is due to a lack of personnel, an inability to replace experts that retire, and an inability to effectively learn from past mistakes. An automated method to capture constructibility lessons learned from completed projects and query the information for use in future designs is presented (Fisher and Rajan, 1996).

Anderson and Fisher (1997a) in NCHRP Report 390 "Constructibility Review Process for Transportation Facilities" developed a systematic approach and methodology for CRPs that incorporates constructibility concepts and existing analytical review tools. The CRPs were specifically designed to be adaptable to SHA projects and management strategies. Research of current practices was assessed for the study through two surveys. The surveys indicated that most agencies used informal CRPs and further implementation was slowed by several factors including lack of feedback to designers, lack of input from construction personnel, poor clarity in plans and specifications, and the availability of money and resources for formal reviews. The CRPs described in the report are divided into three phases: 1) planning, 2) design, and 3) construction. For each of the twenty-one constructibility functions, specific information was modeled including inputs and outputs of each function, people and tools used in performing functions, and constraints that govern how the functions are performed. Functions were then linked together based on the information flow between them (Anderson and Fisher, 1997a).

NCHRP Report 391 "Constructibility Review Process for Transportation Facilities – *Workbook*" describes implementation guidelines that can be used to develop a constructibility review program. Report 391 uses the information and results of Report 390 as a basis for developing of specific a CRP applicable to SHAs. The workbook answers the questions: Why use a CRP?, How are CRPs implemented?, and What are the benefits of a CRP? Implementation guidelines that provide easy to understand directions demonstrate how to implement a CRP (Anderson and Fisher, 1997b).

AASHTO Highway Subcommittee on Construction produced a draft "Constructibility Review Best Practices Guide." The report states that plans and specifications do not always allow projects to be constructed as detailed. When the plans and specifications cannot be constructed, projects are delayed, costs increase, and construction claims develop. The "Best Practices Guide" was written to help SHAs develop CRPs that will meet the needs of their individual transportation agency. The AASHTO guide does not present a constructibility review plan, but offers suggestions in possible areas of needed improvement (AASHTO, 2000).

The existing research has identified the potential of constructibility reviews for improving construction projects and a lack of widespread implementation. In addition the literature indicates that the inefficient management of resources is an important barrier to the more effective use of constructibility reviews. An improved understanding of how constructibility resource management policies affect project schedule performance is needed to advance the use of constructibility reviews in highway projects.

## Data Collection

A more comprehensive understanding of how constructibility reviews were incorporated into the SHA design process was necessary to develop a project specific model for evaluating the potential impact constructibility reviews have on project duration. An on-site interview with the

Bryan Texas District office of the Texas Department of Transportation (TxDOT) was conducted to validate and augment the understanding developed from the literature. This SHA was selected for purposes of convenience. Further, TxDOT has decentralized the responsibility for detailed design to their District Offices. Thus, expertise in both design and construction reside within the local district offices. Finally, the technique described later in the paper to model the impacts of constructibility reviews requires less data to develop than many other modeling techniques. Thus, data from one source is considered sufficient to analyze the potential impacts of constructibility reviews on project durations.

An expert interview was conducted for the purpose of investigating constructibility review methods used by the TxDOT Bryan District. A TxDOT design manager was interviewed. During the discussion, the design manager summarized the TxDOT design review process and constructibility review process, described the organization of the Bryan District office, and provided estimations of typical project characteristics by answering a series of guided questions.

The technical staff of the TxDOT Bryan District office is organized as displayed in Figure 1.

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Insert Figure 1 about here

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**Design Process**

The design of highway projects is conducted both in-house and through contract consultant services. The TxDOT design process is separated into stages defined by the detail of the design drawings. The project is staged at 30%, 60%, 90%, and 100% (letting) of design completion. The design process begins with a schematic or a general scope definition. Design engineers complete the design of the project to 30%, with a continuous checking and editing process monitored by the design manager. The 30% design package is sent for review while the design process continues. Comments and suggestions from the 30% review are incorporated into the 60% design. The 60% design package is completed with continuous checking by the design manager and sent for review. The design proceeds and corrections are incorporated from the 60% design review. Finally, the 90% design package is compiled for review. The finalized design is subsequently forwarded to TxDOT headquarters in Austin for contract preparation and bid letting.

**Constructibility Reviews**

TxDOT conducts reviews of all projects in order to minimize delays from claims and change orders. Constructibility is one of the parameters that are considered when internal TxDOT personnel review plans and specifications. Therefore, a constructibility review is implemented after each stage (30%, 60%, and 90%) of the design process. Various personnel conduct the review of the project design, as shown in Table 1.

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Although the TxDOT Bryan District office does not have a formal constructibility review process, it generally appreciates the importance of incorporating aspects of constructibility into its designs. In addition to the milestone reviews discussed above, TxDOT has a five-year program for new engineers that rotates them between the field and office. The experience gained in the field, as professed by the design manager, is reflected through better, more “constructible” designs.

Construction inspectors are the only personnel who review drawings exclusively for constructibility issues. The level of effort and time spent on reviewing a project during design is directly proportional to the probability that an inspector will be assigned to the project for the construction phase. The design manager commented that when construction inspectors are aware that they will be assigned to a construction project, they complete a more thorough constructibility review of the design drawings and offer more suggestions for change.

A majority of the constructibility issues reside in the 60% design package. This level of design provides the reviewer with enough information to forecast potential constructibility concerns. In the opinion of the informant the 30% design package does not involve sufficient detail to warrant a constructibility analysis since a majority of the initial constructibility issues have been addressed in the programming efforts of TxDOT. The 90% package review concentrates mostly on potential design errors and omissions, some of which could influence project constructibility.

The design manager provided estimates of several characteristics of a “typical” project designed by the TxDOT Bryan District office. The design manager estimated that a typical project would have a total project cost of $3 million and total project duration of 4 years (2 years for design and 2 years for construction). It was estimated that there are 30 to 40 change orders during a typical project. Of these, half (15 to 20) are design changes that impact construction efforts (cause delays) and half (15 to 20) are administrative changes that do not cause delays. Of the design changes, the design manager anticipates that one half of these can be prevented during the design phase. In summary, a comprehensive constructibility review process can prevent seven to ten of the estimated 30 to 40 change orders in a typical project.

## A Model of Constructibility Reviews

The model focuses on a relatively narrow aspect of project management, the impact of constructibility review policies and practices on project durations. Therefore, although many development processes and the resources, management, and behavioral features of project participants interact to determine project schedule performance, only those features that describe constructibility review policies and the fundamental processes they impact are modeled. Simulated performances of different review policies are, therefore, considered relative and useful for comparing CRPs and developing insights, but not sufficient for final policy design.

The system dynamics methodology (Sterman, 2000; Forrester, 1961) was applied to model the delayed information feedback, flows and accumulations of work, and nonlinear relationships that characterize projects and constructibility review. System dynamics is a methodology for studying the management of dynamically complex systems. When applied to projects this approach focuses on how performance evolves in response to the interactions of managerial decision-making and development processes. System dynamics has been successfully used to explain failures in fast track process implementation (Ford and Sterman, 1998; Abdel-Hamid, 1988), impacts of changes by owners on costs (Rodriguez and Williams, 1998; Cooper, 1980) and other project management issues. Model structure is based on previously validated models of development project processes, management, and field data. The model is a set of nonlinear differential equations that describe the information structures and decision-making processes used to manage CRPs. Because closed form solutions are unknown the behavior of the system was simulated over time. Complete model equations are available from the authors.

The model has two subsystems. One subsystem models the flow of work and constructibility-related changes through a project's design phase. The other subsystem models the flow of work and constructibility-related changes through the project's construction phase. The two subsystems have similar structures, including:

- Work is modeled in work packages that are defined to be uniform in size, small, and interchangeable.
- Each phase is modeled with four types of activities: initial completion (finishing a work package the first time), quality assurance (inspection to identify constructibility issues or approve work), iteration (changes for constructibility), and the release of work to subsequent project activities, phases, or to users.
- Activities are separated by backlogs of work packages that are waiting to be processed by one of the activities. The four types of backlog are: work not completed, work completed but not checked by quality assurance, work to be changed, and the accumulation of approved work.
- The design and construction phases are sequential, consistent with standard practice in most state transportation departments

- All constructibility changes released to the construction phase from design are addressed, but work does not flow from the construction phase back to the design phase. This is consistent with the traditional design-bid-build process used by SHAs.

The arrangement of the backlogs and activities describe the flows of work through the phases. All work initially resides in the backlog of work not completed. As work packages are completed they move to the backlog of work completed but not yet checked. Work packages needing changes are discovered through quality assurance. Based on the process described by the informant, two types of quality assurance are modeled in the design phase. The first is a review by engineers, inspectors, or the design manager, depending on the progress of the design (see Table 1). This review is performed continuously as the design is completed, reflecting the practice in the Bryan TxDOT District (Figure 2, left). If no work packages require changes or those changes are not discovered during quality assurance the work leaves the backlog of work completed but not checked and passes into the backlog of approved work. When designers discover constructibility issues the work moves from being completed but not checked to the work waiting to be changed. This work is checked again after changes are made (Figure 2, left) because changes can be generated during iteration as well as during initial completion. Approved work is released for constructibility review. Both field data and literature were used as the basis for modeling the discrete release of designs when 30%, 60%, 90% and 100% of the design work packages are complete (Figure 2, center). Constructibility review is the second type of quality assurance modeled in the design phase (Figure 2, right)[4].

[4] A constructibility review is included in the model although the informant believed one to be unnecessary based on the review performed by construction inspectors on the 30% design (see Table 1) and the focus on constructibility of these reviews.

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The constructibility review process is modeled in a manner directly analogous to the internal design quality assurance process described above. Discovered change needs for constructibility are accumulated as work waiting to be changed and change needs that are missed are released with work that does not need changes. To be consistent with the field data the constructibility review portion of the model includes two important differences from the modeling of the designer's internal quality assurance processes. First, designs found to need constructibility changes are assumed to be changed correctly and are not checked again. Second, the final 10% of design is not reviewed for constructibility issues and passes directly from the stock of approved design work to released design work once the final designs are approved.

Work in the construction phase of the model flows through the same four types of backlog as in the design phase illustrated in Figure 2 (work not completed, work completed but not checked by quality assurance, work to be changed, and the accumulation of approved work), but does not include constructibility review backlogs or flows. In contrast to the release of some constructibility issues by the design phase, it is assumed that all constructibility issues that reach the construction phase are discovered there and addressed. This prevents changes from being released from construction and allows the use of a single measure of performance (durations). Work to be changed is corrected and returned to the backlog of work completed but not checked stock. In the construction phase work is released immediately. Modeling discrete release policies does not change project durations.

**Model Testing**

The model was tested for usefulness in evaluating constructibility review policies using the three types of tests of system dynamics models suggested by Forrester and Senge (1980): 1) structural similarity to the actual system; 2) reasonable behavior over a wide range of input values; and 3) behavior similarity to actual systems. Basing the model on the literature and data collected during the fieldwork improves the model's structural similarity to development processes and constructibility review practices. Model behavior remained reasonable with extreme input values. For example increasing the fraction of work packages requiring changes increases durations and discovering no design changes reduces design phase duration and increases the construction phase duration. These tests increase confidence that the model generates realistic behavior patterns. The model's behavior is consistent with informant descriptions of project behavior. Based on these tests the model is considered useful for CRP description and analysis.

**Model Behavior**

To illustrate model behavior and as a basis for comparison of policy alternatives a base case was generated with a scope of 100 work packages. Figure 3 shows the backlog of designs waiting for constructibility review and the design work released to construction from the constructibility review process. The three vertical jumps of 30 work packages each at approximately days 8, 20, and 43 in the Constructibility Review Backlog reflect the receipt of discrete releases of approved design work for constructibility review. This behavior is consistent with the practices described by the informant. The reductions in this backlog following each jump are due to the completion of constructibility reviews. The resulting approval of work packages and discovery of constructibility issues and subsequent changes smooth the rate of accumulation of work ready for construction, as shown by the graph of the Work Released from Constructibility Review. The final vertical jump of 10 work packages near day 165 represents the approval of the final design work without constructibility review, as described by the informant.

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Insert Figure 3 about here

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Figure 4 illustrates the behavior of the construction phase with the accumulation of construction work that requires checking and the construction work that has been approved and released. The construction phase begins in day 165, only after the release of all design work, and builds up work that needs inspection for constructibility issues. The subsequent quality assurance and change work on these packages produces the relatively steady release of construction work.

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## Constructibility Review Policy Evaluations

The model was used to investigate the effects of different constructibility review policies on project durations. To address the issues described in the Problem Description section above the generic project was repeatedly simulated using a constant amount of resources for constructibility review and different amounts of time spent reviewing each work package. As described, increasing the time spent for constructibility review increases the fraction of constructibility issues discovered and improved, causing more work to pass through the Discover CReview Changes flow and less through the Approve Designs by CReview flow (Figure 2). This causes more work to need constructibility changes, increasing the design phase duration but reduces the constructibility issues released to the construction phase. Increasing the average time spent reviewing each work package also decreases the quality assurance rate during design and thereby potentially increases the duration of the design phase. Figure 5 shows the durations of the design phase, construction phase, and project for these simulations.

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As expected, the design phase durations increase and construction phase durations decrease as more time is invested in each constructibility review. Design phase durations increase starting at 2.5 hours spent reviewing each work package, on average. These conditions reflect the time per work package that begin to "starve" the design activity of quality assurance resources. Construction phase durations decrease relatively quickly as the time per work package increases from 0 to 1.5 hours per work package because construction can "speed up" with fewer constructibility issues. But improvement slows as the time per work package increases farther from 1.5 to 5 hours per work package and construction resources constrain progress. The project duration for the optimal constructibility time in the base case is 18% less than the duration using very little time for reviews (70 weeks versus 85 weeks). The simulations support the traditional belief that constructibility reviews can significantly improve schedule performance (i.e. reduce durations) and demonstrate a reasonable causal structure that can explain how reviews impact durations. Although project features not included in the model may impact results, the size of the potential improvement suggests that an improved understanding of how constructibility review policies impact project progress can improve project management.

A second type of constructibility review policy was tested using the model that addresses the size of the releases of work from design for constructibility review. The base case simulates the common policy of releasing design for constructibility review in three sets of 30% of the design scope (i.e. when 30%, 60%, and 90% are complete). Reasonable alternative policies could release the same 90% of the scope in more but smaller release packages. Do these policies improve schedule performance over a policy of releasing design for constructibility review when it is 30%, 60%, and 90% complete? Project schedule performance using a policy that released 90% of the design work in nine sets of 10% of the scope and using a policy that released 90% of the design work in six sets of 15% the scope were simulated. The durations using these policies are not different than the performance using three 30% releases. This is because different distributions of a given amount and effectiveness of constructibility reviews do not, in isolation, change the number of constructibility issues discovered or improved prior to releasing design to construction. Therefore neither the design nor construction phase durations change significantly.

This points out the importance of understanding the causal structures through which management policies impact project performance.

To extend this line of reasoning and test a more complex policy the model was used to simulate project progress using a continuous review process in which the same resources are applied to constructibility review but are allocated differently as suggested by Anderson and Fisher 1997a,b). In this policy constructibility reviews are performed integrally with design reviews. It is assumed that half of the post-design-release constructibility review resources are shifted to during-design reviews. Two model changes were made to reflect this policy: 1) the fraction of constructibility issues discovered was split evenly between post-design-release reviewing and during-design reviewing; and 2) half of the post-design-release constructibility review resource capacity was shifted to during-design review. Figure 6 shows the durations of the design phase, construction phase, and project using this policy across a range of times allocated to constructibility review.

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Insert Figure 6 about here

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As in the base case, the design phase durations increase and construction phase durations decrease as more time is invested in each constructibility review. The project still benefits from constructibility reviews, with a maximum 11% reduction in project duration. The optimal time spent on reviewing a work package is less in an integral review process than the traditional process (1.0 hours versus 2.5 hours), reflecting the advantage of the early detection of constructibility issues.

**Conclusions**

This paper has described the role of constructibility reviews in improving construction project schedule performance and the challenges of designing effective constructibility review policies by building and using a model that relates constructibility review policies to project durations. The direct relationship between the time invested in constructibility review and design phase durations and the inverse relationship between the time invested in constructibility reviews and construction durations have been shown to be capable of creating an optimal constructibility review duration that minimizes total project duration. The size of design releases for constructibility review and frequency of reviews were not found to significantly affect schedule performance when policy changes did not impact the fraction of needed changes that were discovered. However, a policy of integrating constructibility reviews into design activities instead of reviewing after designs have been completed and approved was shown to decrease both phase and project durations.

Future research can expand this study by adding other important project features to the model such as other types of changes, sensitivity of construction to constructibility issues, responses to schedule pressure, and dynamic resource allocation. These can be used to improve understanding of how these features impact the role of constructibility reviews on performance. This study uses a single measure of project performance (durations). Future work can model quality and cost. These can be used to investigate trade-offs among performance measures and search for constructibility review policies that may improve performance in multiple dimensions simultaneously. Improving models of how review policies impact behavior through a project's causal structure can facilitate the development of processes and project management policies that improve project performance.

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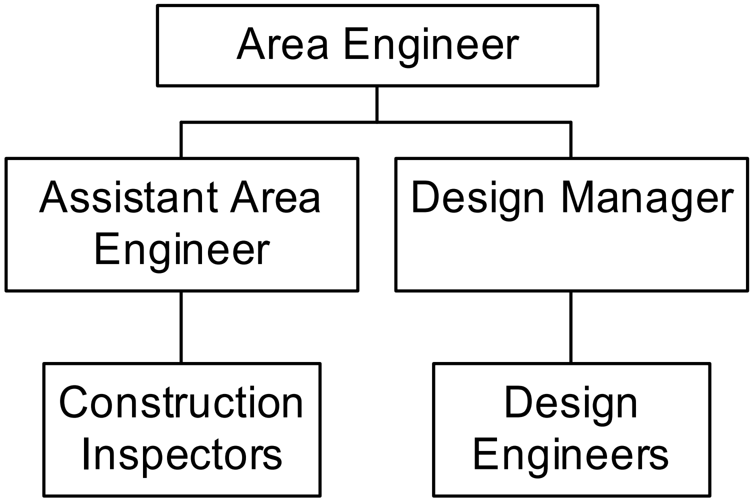
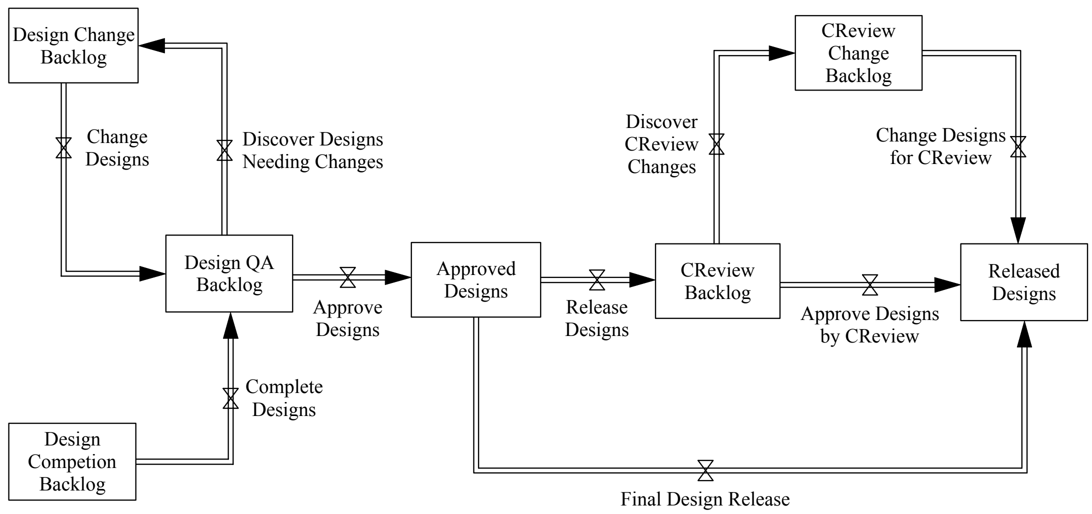



Figure 1. Organizational Structure of TxDOT Bryan District

**Table 1: Constructibility Reviewers**
**Texas Department of Transportation, Bryan District**

| Review | Design Engr. | Construction Inspector | Design Manager | Asst. Area Engr. | Area Engr. | District Engr. |
|---|---|---|---|---|---|---|
| 30% complete | Yes | Yes | Yes | Yes | Yes | No |
| 60% complete | Yes | Yes | Yes | Yes | Yes | No |
| 90% complete | No | No | Yes | Yes | Yes | Yes |
| 100% complete | No | No | No | No | No | No |




**LEGEND**
CReview - Constructibility Review

Figure 2: Flows and Accumulations of Work Packages in the Design Phase

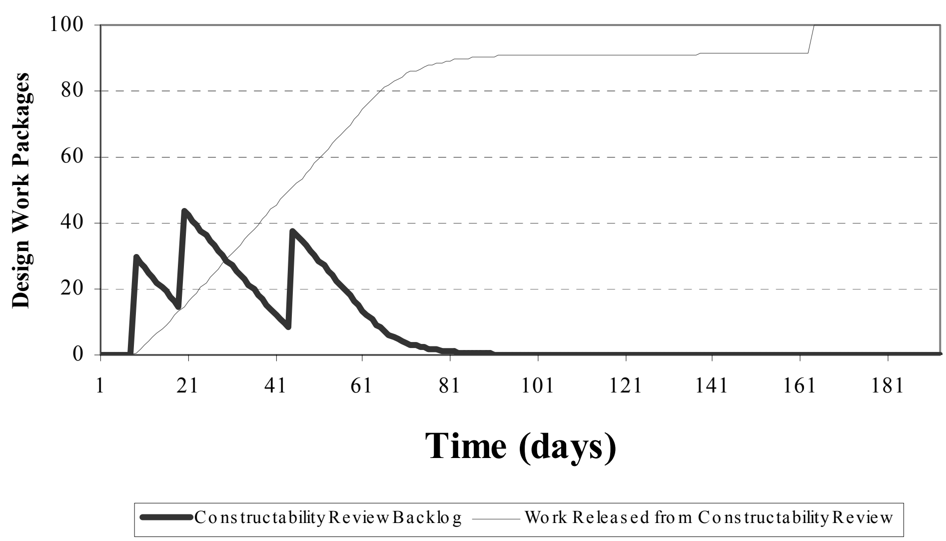



Figure 3: Base Case Behavior
Constructibility Review Backlog and Work Released from Constructibility Review

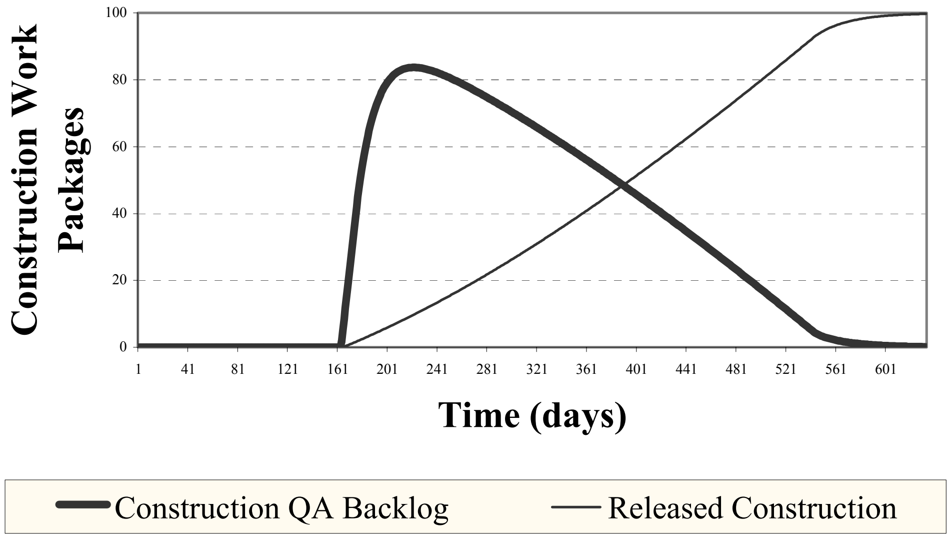



Figure 4: Base Case Construction
Quality Assurance Backlog and Work Released

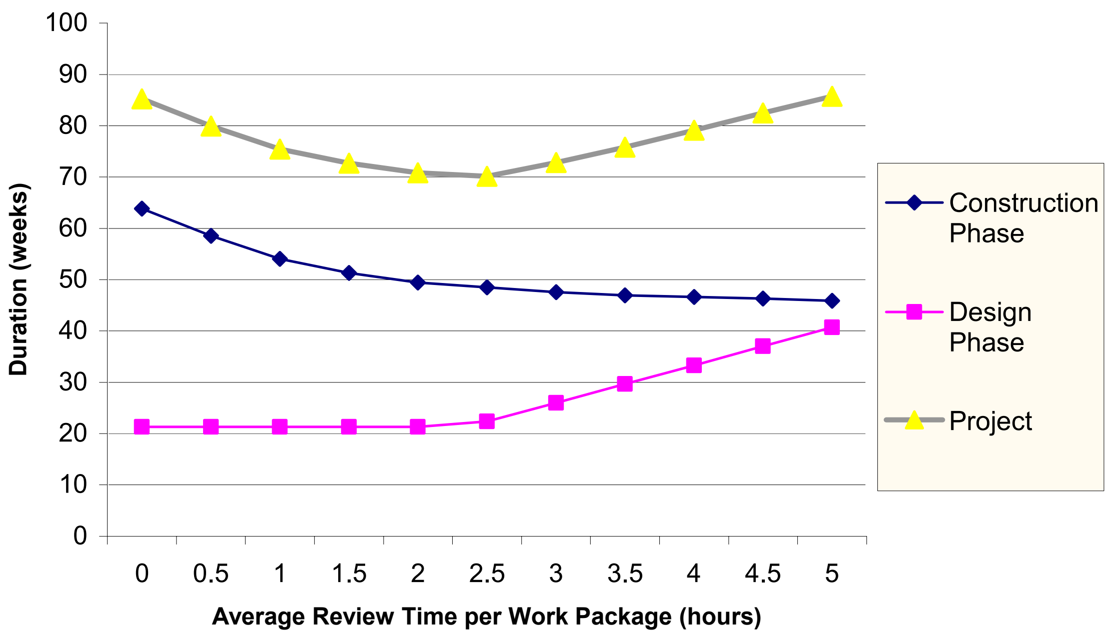



Figure 5: Average Review Times versus Durations for the Base Case

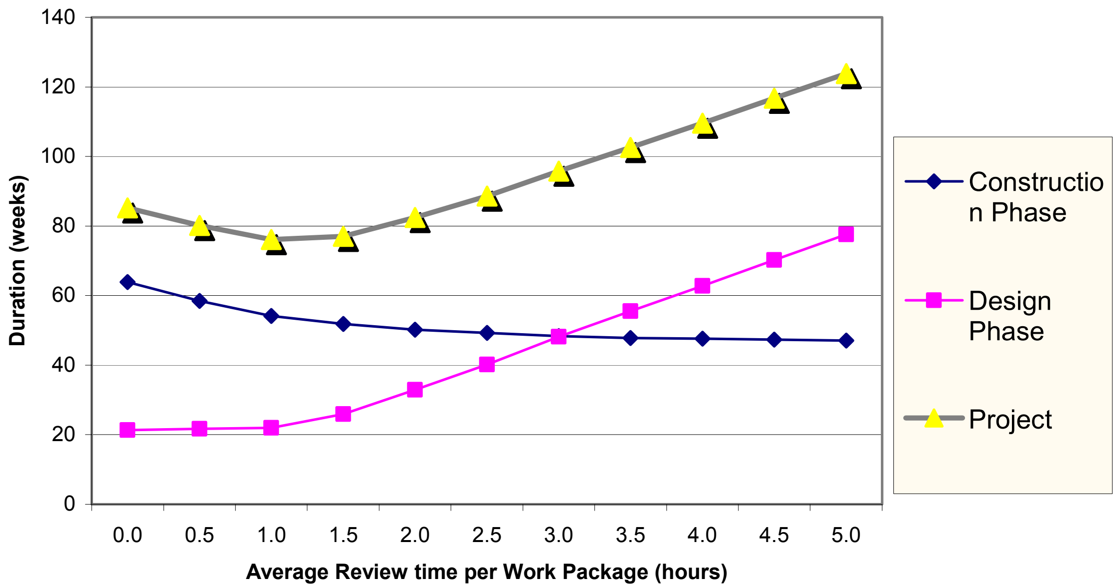



Figure 6: Average Review Times versus Durations for an Integral Review Process