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TOOLS FOR APPLYING CONSTRUCTABILITY CONCEPTS TO PROJECT DEVELOPMENT (DESIGN)

Interim Report

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16. Abstract

The purpose of this report is to document the activities of Phase I of the research effort and present the development of the Constructability Review Database developed for the Kentucky Transportation Cabinet. The database provides the basis for entry and collection of constructability reviews and allows for the identification of trends leading to potential improvements of the process. The database can be used to summarize activities, generate reports for a project, and be capable of quantifying the benefits from the process.

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TABLE OF CONTENTS

Introduction 1
Literature Review 4
Terminology 5
State Efforts 5
Category Definition 8
Database Design 14
Category Development 14
Comment Severity 17
Review Timing 18
Database Relationships 20
Database Analysis 23
Comment Type 23
Comment Category 23
Review Year 24
Reviewers 26
Severity 28
District 30
Conclusions 32
Recommendations 32
Phase II: Ongoing Efforts 33
Appendix A KYTC Highway Design Memorandum NO. 6-05 37

List of Figures

Figure 1 - Feedback Channels in the Project Life Cycle (Kartam et al. 1999) 4
Figure 2 – Review Comment Frequency for Literature Review Categories 15
Figure 3 - Project Delivery Core Processes (KYTC) 19
Figure 4 - User Interface 21
Figure 5 – Database Relationship 22
Figure 6 - Category Frequency by Year 25
Figure 7 - Categories by Reviewers 27
Figure 8 - Category Frequency by Severity Level 29
Figure 9 - Number of Reviews by District 30

List of Tables

Table 1 - Category Frequency 7
Table 2 – Frequency of Comments by Category and Type 24
Table 3 – Frequency of Comment Type by Year 25
Table 4 – Frequent Categories by Year 26
Table 5 – Number of Constructability Reviews by Reviewer 26
Table 6 – Comment Type by Reviewer 27
Table 7 – Frequent Categories by Year 28
Table 8 – Frequency of Comment Type by Severity 29
Table 9 – Frequent Categories by Severity Level 30
Table 10 – Frequency of Comment Types by District 31

INTRODUCTION

Roadway projects are developed through a phased team process that ensures delivery of the most appropriate solutions. Significant benefits (e.g., cost savings, shortened schedules, and improved quality) are realized when construction expertise is integrated early and throughout the design phases of a project. Studies have shown that the lack of integration between construction and design is the root cause for many of the cost, schedule, and quality issues faced in the construction industry (Gambatese et al. 2007).

For many years, the Kentucky Transportation Cabinet (KYTC) has attempted to consistently review design documents for constructability issues before they reach the construction stage. This has been accomplished through a variety of methods, including independent constructability reviews and value engineering studies. The integration of the construction perspective within the design phase of projects is improving statewide. The existing Constructability Review practices involve a group of four reviewers conducting individual Constructability Reviews. However, the current process is more of an ad hoc approach that lacks a systematic means for collecting the required data and identifying potential benefits. The Quality Assurance Branch at KYTC is placing significant effort into improving their Post Construction Review Process, Value Engineering Program and the Lessons Learned Database ("Quality Assurance" 2012). The Constructability Program is building a systematic method for cataloging the results of the process, analyzing their findings with rating and cost associations, and yielding direct tools for design engineers to use on future projects.

The study described is divided into two phases. The results of Phase I, described herein, developed the tools with the capability of summarizing activities and quantifying the benefits from the process. Phase II, which is still ongoing and yet to be reported, quantifies the benefits (such as cost, time, schedule, magnitude, or others) materialized from these reviews or for tracking their success throughout the lifecycle of a project.

With the increasing need for road improvements and the diminishing availability of funds, it is important to critically examine the project development process. A variety of efforts and processes have been initiated by several states aiming to reduce projects costs. Some target specific phases of the project while others apply a more generic approach. For example, Value Engineering is typically applied in early design phases utilizing functional analysis to identify alternative designs that could reduce costs and increase value for a project. Similarly, Post Construction Reviews are conducted once the project is complete and attempt to consolidate the information gained from the project, providing helpful information on avoiding costly mistakes in the future. The Practical Solutions approach that Kentucky implemented attempts to maximize the rate of return for a project by identifying a solution that targets the project needs (Stamatiadis and Hartman 2011).

The purpose of constructability reviews is to evaluate design options and identify areas where benefits can materialize. The practice of addressing potential project oversights and minimizing problems during construction has been in place by several states' Departments of Transportation (DOTs) (Anderson and Fisher 1997). This practice allows for a systematic review of projects during various phases in their development aiming at minimizing future disputes and scope changes with construction issues. The process usually relies on the expertise of construction engineers and integrated knowledge of techniques, advancements, and experience while trying to avoid future project oversights. Efforts to produce a systematic Constructability Review process have been discussed in NCHRP Report 390 (Anderson and Fisher 1997) where preliminary benefits for the process were also identified.

A recent effort also demonstrated that the benefit/cost ratio of Constructability Reviews is greater than two (Dunston et al. 2002). The report noted that effective Constructability Reviews would not only decrease costs but could easily affect the project duration and improve the quality of the constructed facility. Despite the possible benefits of such reviews, NCHRP Report 390 found that only 23 percent of state DOTs use a formal Constructability Review process (Anderson and Fisher 1997). While it is likely that more state DOTs now utilize a form of Constructability Review process, the survey noted that the implementation of a formal process is typically limited due to designers' lack of construction experience, inadequate communication between construction and design personnel, and the absence of a record of past construction changes.

A final issue with these reviews is their timing in the project development process. Projects moving through the various development phases become less capable of changing as they approach the construction phase. It is important to conduct such reviews in the early stages of design in order to maximize flexibility in plans and avoid potential redesigns. It is apparent that a review prior to construction may identify possible oversights, but at the same time any changes at that point will require additional costs and time for the project to be completed. It is therefore imperative to properly time these reviews to allow for a sufficient amount of time to address the issues during the early stages of a project.

Another aspect of a systematic cataloguing of the reviews is the development of a lessons learned database that can identify common areas of potential problems and provide an opportunity for addressing them in a timely manner. Moreover, such a database could be used as a training tool for personnel involved in the various phases of the project development process, thus providing the required understanding of the critical areas where checks are essential.

The issues noted here indicate that there is a need to perform a systematic Constructability Review and identify the benefits from such practices. This is an area that this study will address by providing the required tools and quantifying the benefits from constructability reviews.

This study builds on preliminary research by KYTC personnel (Hancher et al. 2003). To develop the required tools and to quantify the benefits of Constructability Reviews, a two-phased approach was developed. The first phase involved a review of literature; cataloguing and organizing past reviews using Microsoft Access and GIS database; and identification of trends to improve practices. The second phase will present a set of case studies to quantify the Constructability Reviews conducted and establish possible benefits to KYTC. Specifically, Phase I was completed through the following tasks:

- Task 1: Review of literature and research work relevant to identification of practices in conducting Constructability Reviews; identification of potential categories to be used in the database.
- Task 2: Cataloguing of past reviews using the categories defined in Task 1 and development of the GIS database.
- Task 3: Analysis of database and identification of trends aiming to improve the quality and systematic approach of the Constructability Reviews.
- Task 4: development of an interim report summarizing the findings of Phase I.

The work to be completed in Phase II will focus on the following tasks:

- Task 5: Acquisition of the appropriate case study data and preliminary analysis of the data to estimate metrics and benefits for Constructability Reviews.
- Task 6: Identification of metrics to be used for estimating the benefits from Constructability Reviews.
- Task 7: Assignment of values that correlate with the case studies and the metrics for evaluating the estimated benefits from each Constructability Review.
- Task 8: Preparation of final report.

LITERATURE REVIEW

A comprehensive literature review was conducted to investigate the current practices and existing research regarding lessons learned databases for constructability issues. Often, lessons learned from past construction and maintenance of roadway facilities were not properly documented, and therefore not effectively used for the development of future projects. One of the most important features of a database is organization. If Constructability Reviews can be properly categorized, efficient and accurate queries are possible.

In *Constructability Knowledge-Intensive Database System,* Kartam et al. (1999) discuss a new idea for databases related to construction issues. Figure 1 shows the feedback channels for lessons learned on the life cycle of a project.

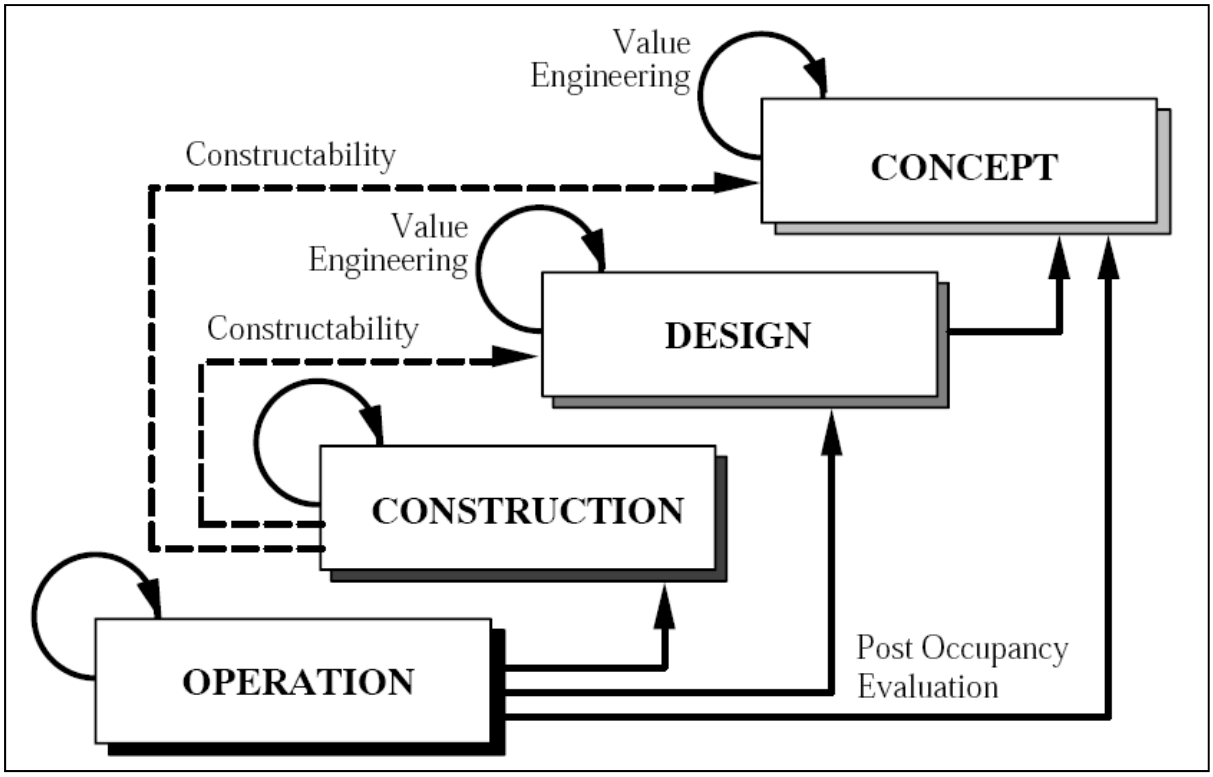

Figure 1 - Feedback Channels in the Project Life Cycle (Kartam et al. 1999)

Modeling the constructability knowledge is the next obstacle (Kartam et al. 1999). Each lesson learned needs a title, a description of the problem or situation, a description of the solution or method, additional comments and a sketch or reference to other documented information. Next, the information regarding the source of the lesson learned is necessary. Finally, the last component needed for a lesson learned is a classification system. The classification system will allow the user to quickly review selected and relevant lessons from the knowledge database. If categories are too broad, it will be easy to classify the lessons, but it will not be as user friendly. If the categories become too specific, they may become overwhelming to the user.

Terminology
There are several terms used throughout the research that may seem similar but have very different meanings. The term comment and category are not used interchangeably. Comments are a series of words or sentences describing one type of concern on a set of project plans. Comments on a set of plans may also label an issue or concern. The comments are describing ways to increase the constructability of project plans. The term "category" describes a certain group of terms used to help distinguish one comment from another comment. Therefore, similar types of comments are assigned to the same category. The use of categories is to assist in the querying of the database for later analysis. For example, the category of drainage can be queried and all drainage comments can be produced.

State Efforts
A research of state agencies was undertaken with the goal of identifying categories that are consistently being used throughout the nation in the Constructability Reviews. Several State Transportation Agencies (STA) across the nation perform Constructability Reviews and use constructability checklists. The American Association of State Highway and Transportation Officials (AASHTO) published a report entitled Constructability Review Best Practices (2000). Within this report, AASHTO identifies states with Constructability Review Programs. A systematic review of the current practices for each state identified in the report was conducted as part of this literature review.

The state agencies that were reviewed for their current report format include:

- California Department of Transportation (CALTRANS)
- Connecticut Department of Transportation (CTDOT)
- Florida Department of Transportation (FDOT)
- Indiana Department of Transportation (INDOT)
- New Jersey Department of Transportation (NJDOT)
- New York Department of Transportation (NYSDOT)
- Pennsylvania Department of Transportation (PENNDOT)
- Washington State Department of Transportation (WSDOT)

Some checklists are comprised in a question format, where a "Yes" or "No" answer was necessary to complete the form. Other checklists were simply statements that were intended to stimulate the reviewer's thinking process. Once the different types of checklists were established, a collaborated list was formed that encapsulated the individual categories and topics that varied throughout each STA (Table 1).

The Kentucky Transportation Center (KTC) has conducted reports in the past relevant to Constructability and Lessons Learned Databases (Hancher et al. 2003, Goodrum and Taylor 2009). Categories were established as a result of these research reports. Since the categories originated as a direct result from issues associated with KYTC, these categories were also used to establish the proposed list of frequent categories.

In the Division of Highway Design, the Quality Assurance Branch contains both the Constructability Review Program, as well as the Post Construction Review Program. Post Construction Review solicits input from various stakeholders following project completion to be used on future projects (KYTC 2012). The input from the stakeholders is then documented in a Lessons Learned GIS database, which utilizes a list of Categories and Sub-Topics. The main category headings will be mimicked for the Constructability Review categories.

Categories from the State Transportation Agencies listed above, along with KTC and KYTC, were consolidated into one list shown below. This list was then used to identify the most frequently used categories throughout all constructability programs.

- **Claims Prevention** – Issues to prevent claims on the project and increased costs due to litigation.
- **Construction** – Issues pertaining to the construction process and ways to improve constructability.
- **Cost Estimating** – Verifies that the cost estimations are accurate.
- **Design** – Issues concerning geometric features and roadway alignments are addressed.
- **District Office Engineer** – Reviews the project plans.
- **Drainage** – Issues pertaining to both temporary and permanent drainage are addressed.
- **Earthwork** – Issues pertaining to clearing (removing trees), grubbing (removing roots) and excavation (moving of cut and fill materials) are addressed.
- **Environmental** – Aspects of a project that affect the environment, such as disturbing endangered species.
- **General** – Addresses constructability issues that pertain to all aspects of the project.
- **Geotechnical** – Issues pertaining to geotechnical related design issues and notes throughout the project plans.
- **Hazardous Waste** – Issues concerning hazardous waste designs are aligned with the district's hazardous waste procedures.
- **Hydrology** – Issues for drainage basin designs are addressed to protect property and highways against flooding.
- **Landscape Architecture** – Issues concerning the design plans for landscape architecture are addressed.
- **Maintenance** – Issues pertaining to access for maintenance personnel, such as trash, landscape, electrical, structures and parking.
- **Maintenance of Traffic** – Issues concerning the Traffic Control Plan, i.e., traffic control signs and barricades.
- **Pavement** – Issues concerning the pavement that will be placed on the project (estimation of quantities).
- **Pay Items** – Issues pertaining to pay items, such as omissions or errors on quantities are addressed.
- **Pedestrians** – Issues concerning pedestrian mobility throughout the project.
- **Permit Requirements** – Issues concerning permit requirements for utility agreements or environmental permits are addressed.
- **Phasing** – Issues concerning the step by step process of construction are addressed and adjusted for optimizing production.
- **Plan Content** – Review the Plan Notes and Comments to ensure clarity throughout the design plans.
- **Railroad** – Issues concerning nearby railroad facilities or any future problems that may arise are addressed.
- **Removal Structures** – Issues pertaining to the demolition of structures that are currently on the job site are addressed.
- **Right of Way** – Issues that arise from obtaining the necessary land needed to construct the project are addressed.
- **Signalization and Electrical** – Issues with lighting plans, or intersection signals matters in the design plans are addressed.

- **Site Investigation** – Issues concerning the current site conditions and how they differ from those shown on the plans are addressed.
- **Structures** – Issues pertaining to any bridges or culverts that are to be erected on the project are addressed.
- **Surveying** – Issues concerning the site survey or control points are examined and addressed.
- **Utilities** – Issues with coordinating underground or overhead wiring on the project with other related activities are addressed.
- **Vertical Construction** – Issues concerning retaining walls or wall panels on the project are addressed.

Table 1 was used to identify the most frequently used categories within the existing practices. The categories were separated into three groups based upon their frequencies: 1. greater than 50 percent, 2. 50 percent to 30 percent, and 3. below 30 percent. These categories represent the majority (greater than 50 percent), the close majority (50 percent to 30 percent) and the minority (below 30 percent).

Table 1 - Category Frequency

Categories	NY	FL	NJ	CT	CA	IN	PA	WA	PCR	KY 1	KY 2	Totals	Frequency
Claims Prevention Checklist											1	1	9%
Construction					1				1			2	18%
Cost Estimating						1						1	9%
District Office Engineer					1							1	9%
Drainage		1	1	1	1	1	1	1	1		1	9	82%
Plan Content	1			1		1	1					4	36%
Earthwork		1	1				1	1		1	1	6	55%
Environmental		1			1	1		1	1		1	6	55%
General										1		1	9%
Geotechnical		1			1			1	1	1		5	45%
Hazardous Waste					1							1	9%
Hydrology					1							1	9%
Landscape Arch.					1			1				2	18%
Maintenance		1			1							2	18%
MOT	1	1	1	1	1	1	1	1	1	1	1	11	100%
Pavement			1					1	1	1		4	36%
Pay Items						1						1	9%
Pedestrians				1								1	9%
Permit Requirements								1				1	9%
Phasing	1	1	1			1	1	1			1	7	64%
Railroad				1		1						2	18%
Removal Structures		1									1	2	18%
Design	1				1	1	1	1	1		1	7	64%
ROW	1		1		1	1	1	1	1			7	64%
Signalization/Electrical		1	1	1			1				1	5	45%
Site Investigation	1		1					1				3	27%
Structures		1	1	1			1	1	1	1	1	8	73%
Surveying		1		1	1						1	4	36%
Utilities		1	1	1		1	1	1	1	1	1	9	82%
Vertical Construction				1								1	9%
TOTALS	6	12	10	10	13	11	10	14	10	7	12	109	

Notes: KY 1 – Hancher et al. 2003 and Goodrum and Taylor 2009; KY 2 – KYTC 2012; PCR – Post Construction Reviews

The data in Table 1 indicates that categories with a frequency of 50 percent or greater include:

- Drainage
- Earthwork
- Environmental
- Maintenance of Traffic (MOT)
- Phasing
- Design
- Right of Way
- Structures
- Utilities

Categories with the frequency of 30 percent to 50 percent include:

- Geotechnical
- Pavement
- Plan content
- Signalization/Electrical
- Surveying

The categories with a frequency of over 30 percent have been identified as categories to be used in this research.

The Kentucky Transportation Center also conducted a study over the frequency of Change Orders (Goodrum and Taylor 2009). This study documented a high number of Change Orders for guardrail and barriers, and this category has been added to the proposed categories. All other items that were examined in this study that caused an increase in change orders could be classified into one of the other categories established above. The list of categories, with the addition of guardrail and barriers, is to be further analyzed to ensure that each category will enhance the database.

Category Definition

Each category is presented below (in alphabetical order) and is examined to determine the most frequent problems or situations that need to be identified.

Design (Frequency 64 percent)

The category of design is a category including Structures Design, Roadway Design and Preliminary Design. The main concern with design was receiving each department's inputs early to avoid redesign later. Designers should have some indication of what permits will be required for the contract. Right of way and drainage should be considered early to help the design choose a proper alignment to address potential issues. Horizontal and vertical alignments need to be addressed early, e.g., curve data, sight distance and vertical datum. Preliminary studies should be conducted for the structures along with preliminary investigation for materials to be used. All of the work shown on the plans needs to be adequately described in the Standard Specifications. The plans should also show embankment foundations and settlement estimations, slope design and subsurface/groundwater control.

The KTC Constructability Review Checklist Report notes that appropriate lessons learned from previous projects be reviewed (Hancher et al. 2003). There should be cross-referencing between various contract documents for consistency. The roadway design plans and structure

design plans should also be examined to confirm that they match up. The Post Construction Reviews of KYTC showed that the largest concerns result from plan omissions, which could be reduced with a proper and intensive review of plan documents. Other issues noted were incorrect quantities reported, incorrect guardrail type, and borrow and waste estimates.

Drainage (Frequency 82 percent)

Drainage is used in the Post Construction Review by KYTC and has sub-categories, which include pipes, omissions, ponding, existing pipes, drop box inlets, ditches and culverts.

Other typical areas with comments in this category address temporary construction drainage. If an overlay of an intersection, gutter or curb is to be placed, then the effect on drainage must be considered. This may be a problem because raising the elevation of existing surfaces can decrease flood capacity. Proposed methods of connecting new and old drainage facilities must be addressed. Sheeting or shoring should also be considered if the roadway needs to be protected during phased construction.

CTDOT has drainage comments directed toward drainage specifications. For example, culverts should not be set level, but at a minimum one percent grade, and any pipe with a diameter 36 inches or greater will need an oversized catch basin (CTDOT 2012). These specifications were frequent issues and the DOT wanted to make sure that this is resolved before construction. CALTRANS has different items that are addressed at the 30 percent, 60 percent and 95 percent milestones of the Design Process (CALTRANS 2006). The drainage plans are reviewed for consistency with the roadway and structures plans. Other concerns include the accuracy of quantities and acquiring all required documents and permits.

The phasing during construction of drainage facilities is extremely important. Many comments point out that drainage must be constructed from low to high elevations without interference. The installation of drainage structures also needs to be coordinated with the entire Project Phasing and Maintenance of Traffic.

The KTC Constructability Review Checklist Report indicates that drainage easements and elevations be shown on the plans (Hancher et al. 2003). The outfall locations of temporary and permanent drainage facilities should be shown, if there are any.

Earthwork (Frequency 55 percent)

Many of the items addressed the placement of stockpiling, storage or dump sites. Contractors use stockpiling and storage sites to keep excess equipment or materials. Dump sites are used by the excavation crew to store excess soil. The shrink and swell factors for soil are not currently represented in the KYTC plans. Designers however are required to consider these effects when establishing bid items.

The type of equipment to be used must meet project requirements, i.e., crane limits and height limits. Rock cuts need to be wide enough to accommodate construction equipment. The size of the construction equipment to be used needs to be considered when determining grading and fill widths. If the grading is too steep, the efficiency of the construction equipment will be impeded. The earthwork phasing needs to be compatible with construction requirements. The length of the phases needs to be reviewed to confirm that the earthwork to be done within that phase is feasible.

Other frequent issues to be considered include displaying the delineation of grubbing, clearing and landscaping on the plans. Any known subsurface obstructions, such as underground storage and sinkholes, must be indicated on the plans. PENNDOT requires that the classification and quantities of all earthwork items be clearly shown on the plans (PENNDOT 2012). If excavation is to occur below the water table, it is to be identified because operating earthwork equipment and performing earthwork operations below the water table can be dangerous. If the contractor is unaware of the water table, issues on the project could occur.

The KTC Constructability Review Checklist includes many of the issues noted above as well as provisions to minimize borrow and use of excavated material for fills (Hancher et al. 2003). Minimizing borrow could be accomplished by phasing adjustment to balance the project. All underground utilities need to be indicated on plans to prevent any difficulty. KYTC also specifies that soil lay-down areas be on the same side of the road as fill areas.

Environmental (Frequency 55 percent)

The most frequently occurring Environmental items needing to be addressed were the required permits needed for the project. INDOT only introduces environmental issues in the Preliminary Field Check Phase (INDOT 2010). They are concerned mainly with identifying environmental restrictions and anticipating their impact on the schedule. Other examples of concerns entail that the designer apply for all necessary permits. Local agencies may have different permit requirements that should be indicated on the plans. The prevention of groundwater contamination needs to be addressed. Sufficient space is needed (25-30 feet) for power mowers in areas where trees are to be planted.

KYTC Post Construction Reviews have encountered environmental problems such as asbestos, underground tanks, contaminated material, stream mitigation, and landscaping issues (Hancher et al. 2003). If environmental issues are encountered on site, it can cause a major delay on the schedule of the project.

Geotechnical (Frequency 36 percent)

CALTRANS recommends that a Material Report be completed for the following: structural section design, slope design, embankment foundations, settlement estimates, subsurface control, ground water control, earthwork and seismic design criteria (CALTRANS 2006). They also specify that all testing methods comply with California test methods, ASTM or an AASHTO alternative. Other issues in the Post Construction Reviews of KYTC are slides, subsurface issues, top of rock elevations and unsuitable material (Hancher et al. 2003).

Guardrail and Barriers[1]

Guardrail and barriers were identified as an issue that occurred frequently with significant change order costs in the Change Orders and Lessons Learned Report (Goodrum et al. 2009). The main problems with guardrail and barriers involve contract omissions, contract item overrun and owner induced enhancements. Reviewing and identifying the correct type and quantity of guardrail and barriers throughout the design will lead to a decrease in change orders related to these items.

[1] The category does not have a frequency because it was added based on the SAC input.

Maintenance of Traffic (Frequency 100 percent)

The review of the maintenance of traffic plans should be of utmost importance to the reviewers, since this was the single item consistent in all checklists and reviews. Many of the recurring concerns iterate that the traffic operation requirements be met, such as signing, pavement markings and signals. If detours are to be used, they should fit traffic needs.

Maintenance of traffic plans are typically reviewed to confirm the compatibility with the current site conditions. The lane closures should be compatible with expected traffic volumes. Adequate access for local residents and businesses in the area should be considered to prevent future problems. Accommodations for intersecting and crossing traffic should be taken into account when developing the plans. Alternatives should be created and considered to optimize any maintenance of traffic features. The exits and entrances to the work zones should be adequate and safe. Accommodations for bicyclist and pedestrians should be also considered.

The Post Construction Reviews of KYTC have a Maintenance of Traffic category with the most frequent sub-categories being omissions, safety, phasing, quantities, shoulders and striping (Hancher et al. 2003). The Constructability Review Checklists of KYTC suggest that the maintenance of traffic restrictions be printed on the plans, e.g., lane closures, general construction procedures and peak hour restrictions in urban areas. Sufficient clearance within the work zone should also be examined.

Pavement (Frequency 36 percent)

They suggest minimizing low production and hand work areas. In regards to constructability, the roadway needs to be designed wide enough to accommodate all standard equipment, such as concrete and asphalt paving equipment (NJDOT 2010). The haul distance for special materials needs to be available and within a reasonable haul distance.

The Post Construction Reviews of KYTC have several issues concerning pavement problems (Hancher et al. 2003). The main issues are the design of the pavement, striping plans, shoulder design and errors in the estimated quantities. The lessons learned from these reviews separate pavement into two different categories, Portland Cement Concrete Pavement and Asphalt Pavement, but to simplify the database these have been combined.

Phasing (Frequency 64 percent)

The main issues that arose involved verifying the compatibility of construction phasing and scheduling. Constructability Reviews typically consider the design and construction phasing in detail to evaluate whether it could be constructed. The expected duration and productivity rates need to be reasonable.

The Constructability Reviews of KYTC require that maintenance be allowed access to all occupied spaces during the construction of the project (Hancehr et al. 2003). The easements on adjacent properties need to be considered for storage and construction through the project's duration.

Right of Way (Frequency 64 percent)

Right of way was not included as a category in the KTC Constructability Review Checklist Report, even though it is a common category for several STA's (Hancher et al. 2003). The

majority of all other documents bring up a single concern regarding whether sufficient Right of Way has been acquired. Though this may seem to be an obvious issue, it can lead to major setbacks once construction has begun. Therefore, acquisition of right of way needs to be considered early in the design process.

Right of way for equipment, materials and hazardous waste storage needs to be taken into account. CALTRANS suggests that all construction and footing easements are identified (CALTRANS 2006). They also recommend that all utilities have Joint Use or Common Use agreements. WSDOT suggests that at the design report stage, a right of way estimate and purchasing cost be established. This could have the potential to affect which alternative is chosen.

Signalization and Electrical (Frequency 45 percent)

Signalization and electrical was combined into one category, since the two are closely related. There are several issues that need to be covered concerning signalization and electrical issues. If temporary signals or highway lighting is needed during staging or construction, they should be considered beforehand. Existing loop detectors should be identified. Pole locations should be identified, as well as whether there will be any conflicts with utilities or drainage structures. All signs that should be attached to overhead traffic signals should also be identified.

Structures (Frequency 73 percent)

Many agencies discuss the importance that the Traffic Control Plan be coordinated with construction roadwork phasing. Other frequent concerns include whether the water depth was sufficient to float barges if needed, and if the barges will block boat traffic. The site should be checked to verify if dewatering is necessary. Overhead utilities should be checked to see if there are conflicts with construction or if aerial utilities will limit crane usage. The KTC Constructability Review Checklist Report suggests that other structure characteristics be considered, such as mix design, strength, concrete and steel requirements. The Post Construction Review of KYTC main issues deal with the amount and size of reinforcement steel, omissions in the plan and guardrail for the structures (Hancher et al. 2003).

CTDOT is the only agency that has an extremely detailed structures checklist (CTDOT 2012). It begins with a general section and continues with a box culvert, prestressed, substructure and superstructure section. Each section is detailed with specific topics pertaining to that item. For example, the sub-category of superstructures has an issue: “Review the ratio of the flanges to webs on seismic retrofits. American Institute of Steel Construction (AISC) mandates a minimum 3/8’’ thickness. Even this is too thin, as with rolled sections the web will kink during process” (CTDOT 2012).

Surveying (Frequency 36 percent)

The main issue throughout the documents is that the control points are noted from project limit to project limit. Control points should also be on both sides of a structure to ensure accuracy. Retaining walls need bottom of footing and top of wall elevations. Right of way and property lines should be delineated on the plans. The existing topography should be accurate and up-to-date. The profile should fit the terrain, and the plans should be clear and legible.

The KTC Constructability Review Checklist Report has a Site Survey category that is used in collaboration with the Plan and Profile Checklist (Hancher et al. 2003). The checklist suggests

that benchmark data, elevations and curve data be shown on the plans. Water table elevations and requirements for dewatering should be addressed prior to construction.

Utilities (Frequency 83 percent)

This category includes existing and proposed utility problems. The main issue to be identified is that all existing utilities be properly marked on the plans. A list of all utility owners and contact numbers needs to be readily available as well. If utility conflicts with the proposed construction are to occur, they need to be indicated on the plans and relocations need to be identified. Underground utilities need to be considered and relocated if necessary. If utilities can be relocated before construction, it should be considered to help move construction along faster. Connection points between new and existing utilities need to be identified. If utilities crossing are a problem, it can be resolved by a temporary structure or scheduling restrictions, such as weekends or after hours. There needs to be verification that overhead utilities will not cause potential problems with operations and access of large equipment. If utilities have the possibility to conflict with drainage, the issue should be reviewed.

The Post Construction Reviews of KYTC have a Utilities Category with 12 different sub-categories. The most recurring issues are problems with existing utilities, relocation and omissions. The KTC Constructability Review Checklist Report indicates that sewer lines are placed below all water lines and gas lines are placed far above all other utilities (Hancher et al. 2003). Adequate space also needs to be provided for Right of Way and drainage structures to allow proper drainage.

DATABASE DESIGN

The main goal of the database is to allow the constructability reviewer to complete and easily assign categories to reviewers' comments for the Constructability Review document. A second goal is to develop a consistency in the reporting in order to address current differences in reporting content and style. Another important goal is the ability to query the database in order to develop reports and statistics regarding the completed reviews. The reviewer will be required to enter project-related information, such as Item Number, Route Number and Designer. The database relationships have been established to relate each single project, identified through its Item Number, to multiple comments. The database was developed using 2010 Microsoft Access.

The details to be entered in the Access database are grouped into two categories: project and review comments. To allow for consistency and ease of analysis, every comment is classified into specific categories that could concisely describe the comment. The reviewer can select as many categories that apply to that comment. Every comment is also classified with respect to its potential for budgetary or time implications in the event that the comment was not identified prior to construction using a severity index. Some additional project parameters that could be of use include the Date, Review Type, Design Phase, the Designer of the plans, and the Reviewer conducting the review. The following presents the parameters included in the database and the rationale for their inclusion.

Category Development

The categories for the review comments were developed in a two-step process. The findings from the literature review along with the review of the STA practices were used to develop the first list of categories. The Study Advisory Committee (SAC) met and reviewed the proposed list of categories in order to determine the final list of categories.

The list developed based on the literature review identified those categories that were common and most frequently used by the various DOTs and have been utilized in the KYTC Post Construction Review Database. These categories include the following:

- Design
- Drainage
- Earthwork
- Environmental
- Geotechnical
- Guardrail and Barriers
- Maintenance of Traffic
- Pavement
- Phasing
- Plan Note Clarity
- Right of Way
- Signalization/Electrical
- Structures
- Surveying
- Utilities

From the 2010 and 2011 periods, KYTC conducted 80 Constructability Reviews. These 80 reviews contained 1,053 comments and all the comments were grouped utilizing the categories

shown above. Figure 2 shows the distribution of the comments into the selected categories. It should be noted that the category “Plan Content” has been changed to “Plan Note Clarity” to be more reflective of KYTC terminology.

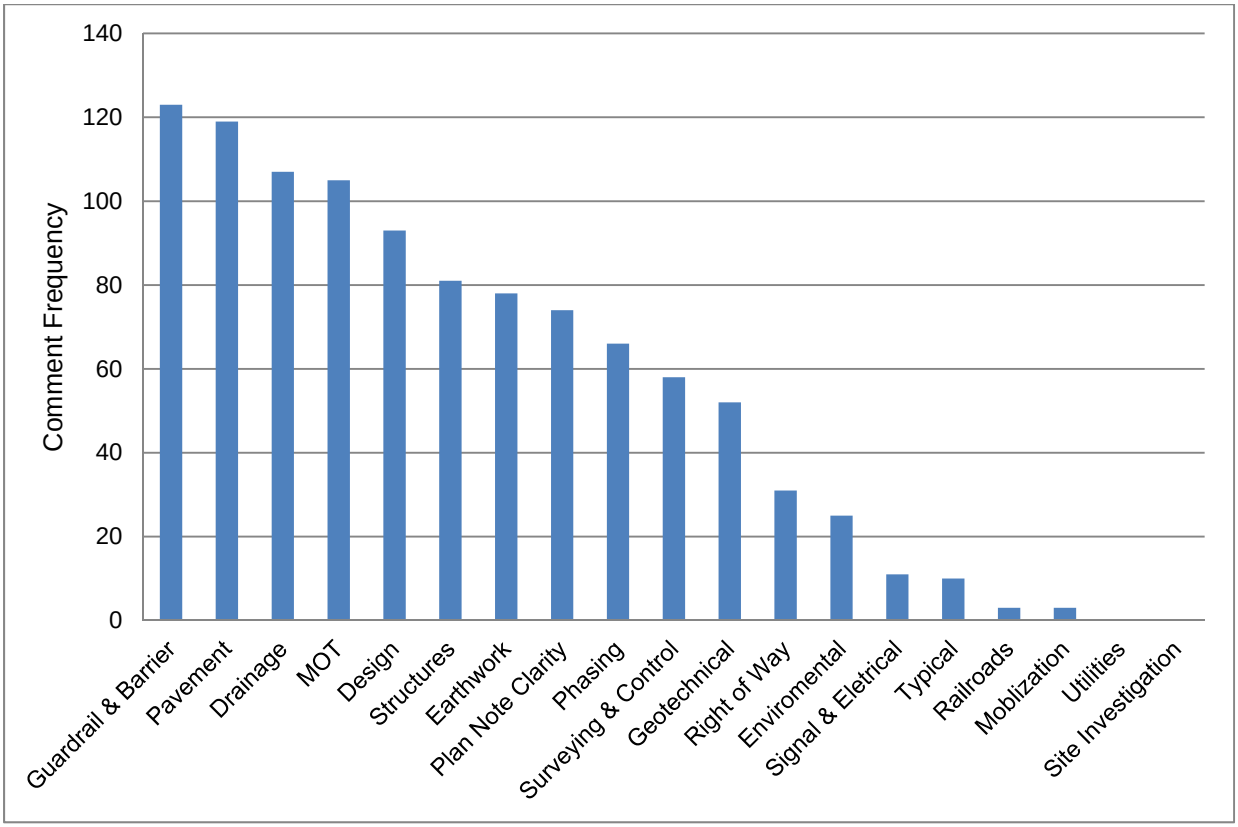

Figure 2 – Review Comment Frequency for Literature Review Categories

The categories of Plan Note Clarity, Typical Sections, Railroads and Mobilization were added to the list as it was developed because of the repeated frequencies of each category. Plan Note Clarity occurred in 74 of the comments, suggesting it to be a significant issue.

The categories that accounted for more than 50 percent of the comments were Guardrail and Barrier, Pavement, Drainage, Maintenance of Traffic, Design, and Structures. Comments comprised 12 percent of the total identified Guardrail and Barrier with the main issue identified as the wrong type of end treatments prescribed in the plans. Pavement issues were the second most frequent comment (11 percent) that included most of the comments pertaining to the over or under estimation of quantity calculations. Drainage occurred in ten percent of the comments and most pertained to pipe size alternatives. Maintenance of Traffic also occurred ten percent of the time and the majority of the comments were suggestions for alternative traffic routes. Design was included in nine percent of the comments and the main issues were with horizontal alignment, vertical alignment and superelevation transition. Structures issues occurred in eight percent of the comments and the main issues were adding the “Remove Structure” bid item to the project. Florida DOT has a checklist devoted to removals and demolitions on the project. Since the “Remove Structure” bid item is so often forgotten, it should be reiterated to designers that it must not be omitted.

These data were presented at a SAC meeting where the list was reviewed and adjusted to reflect specific needs and concerns relevant to KYTC. The two categories that received zero comments were Utilities and Site Investigation. Utilities plans are not reviewed because each District reviews these plans. However, the category of Utilities will remain in the database, to address potential regulation changes in the future. Site Investigation was not an issue and therefore it will be removed from the data.

Recommendations were made to expand the Design category into more detailed sub-sections. The new categories were based upon the categories established by the Post Construction Review Database and are as follows:

- Horizontal Alignment
- Vertical Alignment
- Coordination
- Cross-Section
- Superelevation

The category of Striping was added as an extension of the Pavement category. The Drainage category was broken down into three different types of drainage applications: Existing Drainage, Proposed Drainage and Temporary Drainage. More categories were added upon request of the SAC, including Easements, Seeding and Part-Width Construction. It was also determined to group the categories based on the type of the comment. The comment types to be used are Error, Omission and Plan Note Clarity. Many of the comments will either be correcting an error, adding an omitted section or bid item to the project plans or improving the clarity of the plan notes. The development of comment types will be a great advantage for any future lessons-learned database, since it will allow for systematically identifying the reasons for comment.

The final list of categories to be used for the Access Database is shown below:

- Coordination
- Cross-Section
- Design
- Earthwork
- Easements
- Environmental
- Existing Drainage
- Geotechnical
- Guardrail
- Horizontal Alignment
- Maintenance of Traffic
- Part-Width Construction
- Pavement
- Phasing
- Proposed Drainage
- Right of Way
- Seeding
- Signalization/Electrical
- Structures
- Superelevation

- Surveying
- Temporary Drainage
- Utilities
- Vertical Alignment

Comment Severity

Constructability reviews have the potential to reduce project costs and construction time, since they can identify issues that could result in change orders and time delays, if they made it to construction. It is therefore important to establish the severity of impact that each comment could have on the project if it was undetected. This should be captured in the database to allow for estimating the potential time and money effects. Each comment encapsulates different aspects of a project, and as such, each comment could have a different order of magnitude on the design process. Therefore, each comment is examined to estimate the cost and schedule impacts that it could impose on a project, and assigned a severity index.

Classifying the different levels of severity based on quantitative data is important to ensure consistency for the database. In order to gain a statistical basis for analyzing the data, the Change Orders and Lessons Learned database were reviewed (Goodrum and Taylor 2009). The data for the 1000-series projects from that report were used to develop the average cost of change orders as a percentage of the original contract amount. The projects used here are those that follow a standardized process through the KYTC project development process and are not influenced by extraneous factors, such as political decisions. The average change order amounts on new construction projects for KYTC are about 3.5 percent of the original contract amount. The same data showed that the average standard deviation is seven percent. These figures were used to establish the cost severity categories.

Project delays were included in the severity index as a binary variable. If not corrected before construction begins, the constructability issue would likely result in a project delay, then a value of one will be assigned to that comment. If no delay would occur, even if the constructability issue was not caught, then a value of zero will be assigned.

A two-step process is proposed for establishing the severity of the comment in order to address both cost and schedule impacts. First, the comment is classified based on the cost impacts using a three-level scale: low, medium and high. The guidelines for this classification are provided below. The second step involves the determination of the schedule impacts utilizing the binary choice noted above. This number will then be added to the cost severity so that if delay is anticipated, then the severity index will be increased by a level. For example, for a comment with medium severity, if a delay would have occurred, then the severity index will be upgraded to high. If no delay would occur, then the level would remain as assigned at medium.

Low Severity

Low severity comments should have both low cost and low schedule impacts. Low severity was usually associated with striping quantities estimated incorrectly and seal aggregate quantities. Low severity would be a comment that does not require a large change order and will not cause delay on the project. If the constructability issue was not corrected before construction begins, the error would likely result in a construction cost change order less than 3.5 percent of the proposed construction budget to correct once construction begins.

Medium Severity

Medium severity contains constructability issues that if not resolved before construction would require a change order, which could impact the construction cost. An example of medium severity would be when structure quantities are estimated incorrectly. Fabricated structural items, such as a beam can have a high impact on schedule. However, steel quantities that are incorrect are usually caught early enough that they are not a detrimental issue, other than additional cost. A contract item omitted can also have a large effect on schedule because a change order must be submitted to establish the bid item and continue work. Utility relocation plan issues can have an impact when the relocation is to be done by the roadway contractor.

The average cost of a change order is 3.5 percent, and one standard deviation is seven percent; the boundaries could be established as the average and one standard deviation (i.e., 10.5 percent). If a medium severity constructability issue is not corrected before construction begins, the error would likely result in a construction cost change order between 3.5 percent and 10.5 percent.

High Severity

High severity is associated with any structure redesign, misfabrication of materials, and alignment errors. Any comments that would alter the terms that the contractor agreed to by bidding on the project would have a large effect on the schedule. Other examples include imposing working hour restrictions or boundaries to work around streams. Impacts can also be felt with any type of insufficient right of way to tie slopes according to design. Most constructability issues concerning maintenance of traffic should be considered severe because they impact the driving public through delays and can create multiple traffic changes that may confuse some drivers. Most high severity items significantly remove control of the pace and sequence of the work from the contractor. If the schedule is changed, then the contractors plan is altered and construction becomes more difficult.

If a high severity constructability issue is not corrected before construction begins, the error would likely result in a construction cost change order in excess of 10.5 percent of the proposed construction budget to correct.

Review Timing

Constructability Reviews are completed during many different phases of the design process. Currently, KYTC conducts them at the Preliminary Line and Grade, Final Joint Inspection and Check Print phases of the project development. The Highway Design Manual of KYTC describes the delivery process for every design project (KYTC 2012). The diagram for the entire process is shown in Figure 3.

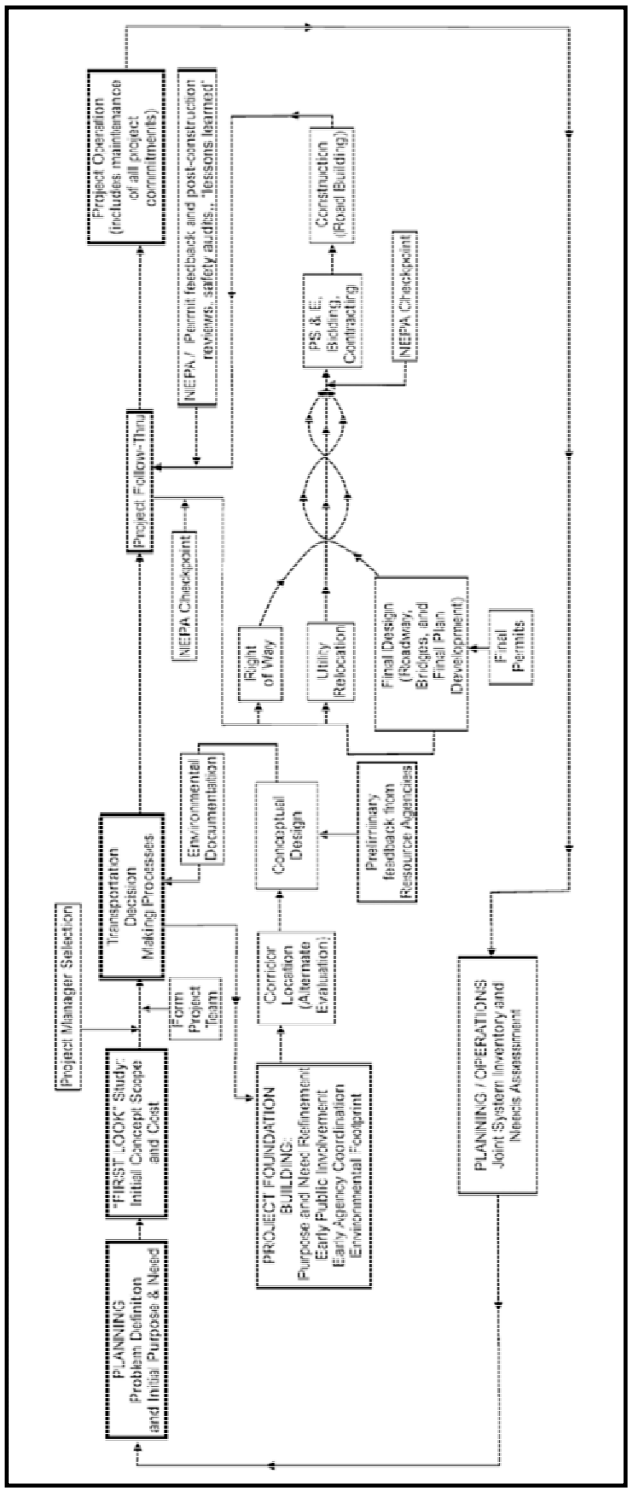

Figure 3 - Project Delivery Core Processes (KYTC)

Preliminary Line and Grade

The Preliminary Line and Grade is approximately when 30 to 40 percent of the design is complete. The meeting usually indicates the completion of the conceptual design phase. Therefore, alternative alignments are selected at this time and preliminary plans show a general layout for the proposed alignments. Potential Right of Way is identified and will need to be acquired. Environmental documents have also been approved for the project at this point.

Final Joint Inspection

The Final Joint Inspection meeting is generally held between 75 to 90 percent of the design is complete. The vertical and horizontal alignments are commonly set at this point. This meeting is an opportunity for many different project team members to come together and discuss any project concerns. The team members include representatives from the Drainage, Environmental, Utilities, Right of Way, Construction and Design Divisions. This gives each Division a chance to discuss problems that will affect more than one Division. Major alignment changes are usually not appropriate this late in the design process, but constructability input at this phase is extremely important. Contract time is also discussed and determined at this point in the process.

Check Prints

The Check Prints phase should occur around 95 percent of the design completion. This phase involves a last review of the plans by the Plan Processing Section of the Division of Highway Design approximately three months before the scheduled letting date. The Plan Processing Section will review that all Computer-Aided Drafting and Design (CADD) Standards have been met, the proper bid items have been used, and the right standard drawings have been referenced. This process strives to achieve a level of consistency. The contract time is also finalized. Plan Processing will then return the project plans with corrections and comments to the original designer.

Database Relationships

The Constructability Database uses the coded project information categories and comment information to set up working relationships within the database. The project information and comment information is entered through the user interface (Figure 4), which has multiple dropdown boxes and text boxes for ease of entering the data.

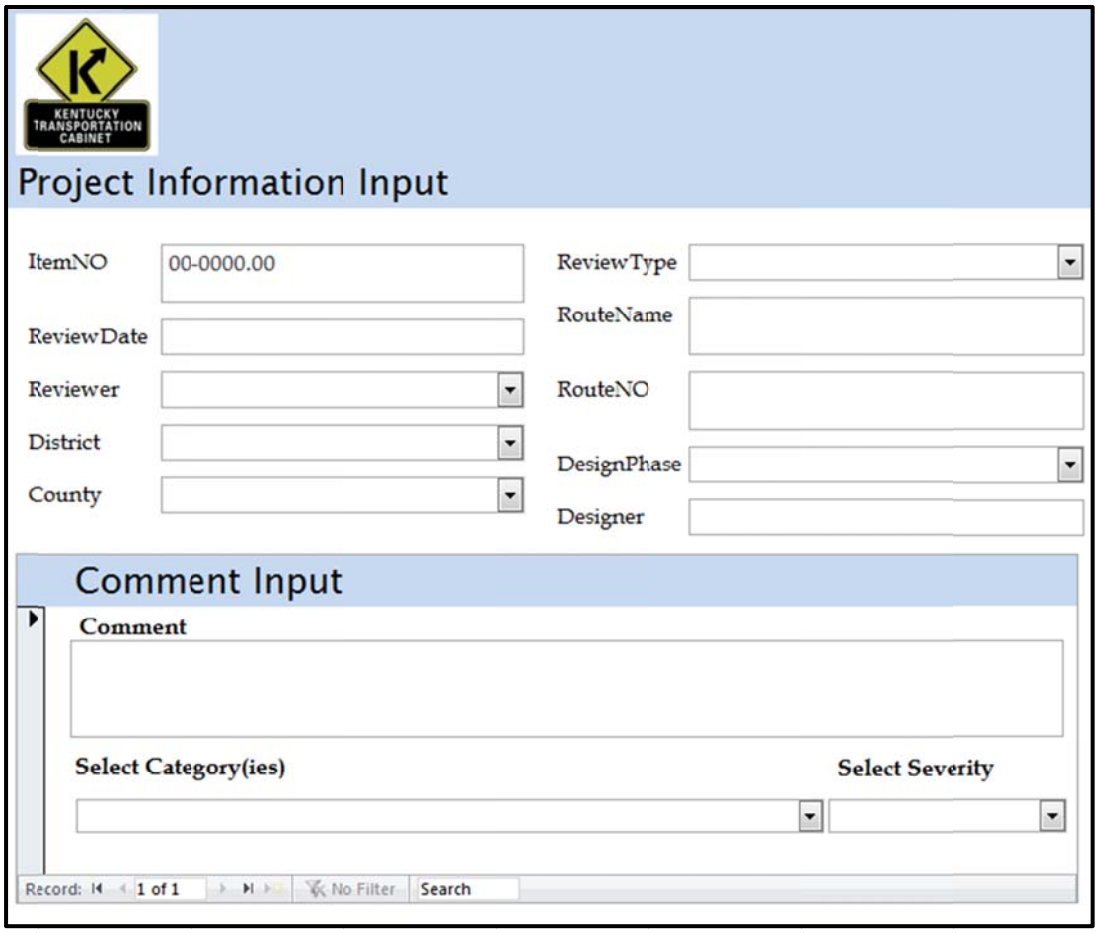

Figure 4 - User Interface

The content of each entry is described below:

- **Item Number** is the project number and has an eight-digit mask within the ItemNO cell. This makes the Reviewer only enter an eight-digit number. This mask will allow all Item Numbers to be consistent, and will decrease user input errors.
- **Review Date** is to document a time stamp for when the Constructability Review took place. By holding the cursor to the right of the Review Date cell, a calendar will appear to select the correct date.
- **Reviewer** is the KYTC Constructability Reviewer, and has a drop down menu with a list of the past and current KYTC Constructability Reviewers.
- **District and County** sections have a drop down box for the twelve districts in Kentucky and all of the Kentucky counties.
- **Review Type** identifies the plans reviewed and provides for a choice of Roadway, Structures or “Other” in case plans, such as lighting and signal, are reviewed separate from the roadway plans. Typically, these plans are part of the Roadway plans and they should be reviewed with them.
- **Route Name and Route Number** are text boxes for the reviewers to enter the information based on the subject project.

- **Design Phase** identifies the phase during which the review is completed and has a drop down box with the Design Phases identified above including an “Unknown” option. The reviews conducted in the past did not capture the Design Phase and therefore, past reviews entered in the database will have an “Unknown” Design Phase. However, every review in the future will identify the Design Phase at which it was conducted.
- **Designer** is the person responsible for the designs reviewed section and is a text box for the reviewer to indicate whether the plans were completed by the District, Central Office or contracted out to a Design Consultant. Many of the reviews previously conducted did not capture who the designer was; therefore many of the projects will have the Designer to be recorded as “Unknown”. However, in the future the Reviewer will have to record the Project Plan Designer.

The parameters are connected through strategic relationships. Figure 5 shows the database relationships for all of the parameters.

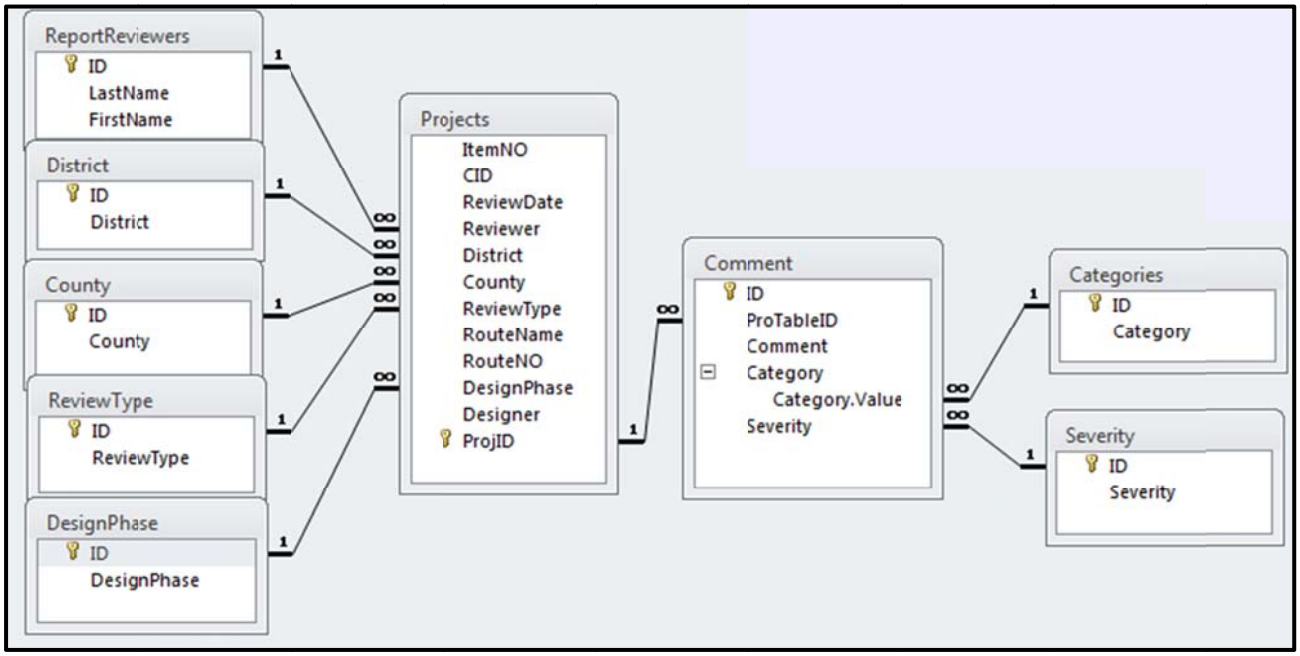

Figure 5 – Database Relationship

The database allows each design parameter on the left to be assigned to infinite projects. However, the comments have a unique relationship with the project table. The relationship is set up as one to infinity. This means that an infinite number of comments can be associated with one specific project ID. This will allow the Reviewer to input as many comments as are necessary to conduct a complete Constructability Review. This will also keep the Reviewer from having to continually repeat the Project Information for each comment. The Project Information will automatically be assigned to every comment pertaining to that review.

The Comment table has a direct relationship with the categories and the severities. The Reviewer can associate multiple categories with each comment.

DATABASE ANALYSIS

The completion of the Constructability Database Design led to the input of Constructability Reviews, which were previously conducted in 2010 through 2012. A total of 118 Constructability Reviews containing 1,110 comments were examined. The 24 categories established and stated earlier were used to classify the comments along with the comment types and other variables of interest.

A basic data description is presented in this section aiming to identify any potential trends that could be helpful in improving the quality of the data and providing the basis for training for future reviews.

Comment Type

The first variable examined was the comment type for each review conducted. Among the 1,110 comments, 372 dealt with Plan Note Clarity, 367 were Errors, 356 were Omissions, and eight dealt with Drawing Clarity. There were also seven comments with no type specified. The data indicates that the majority of issues dealt with the notations in the plans requiring additional clarification in order to improve the constructability of the project. Each of the three main types represent approximately one third of the total comments and it seems that there is no significant difference (practical or statistical) among these types. It should be noted that the Drawing Clarity type has very few cases (less than one percent) and therefore, it was not considered in the statistical analysis. This is because the Drawing Clarity comment type was added later in the process and it was not addressed in 2010 and 2011 reviews.

Comment Category

The comment category is examined, since it identifies the most frequent sources of issues on a project. The data shows that the most frequent categories are those of Pavement, Maintenance of Traffic, Guardrail, Existing Drainage, and Structure (Table 2). These five categories account for approximately 57 percent of the comment categories and hence could be considered as the most significant categories that are identified through a review process.

Table 2 also shows the frequency of categories by comment type to determine whether there is any particular pattern within each type. The total is greater than 1,110, since several comments were classified in more than one category. The data reveals that the same five categories are the most frequent within each comment type. Those five categories account again for over 57 percent of the overall categories. A small percentage of comments did not have any corresponding category or comment type and is indicated as blank. No particular trends were identified for Drawing Errors, since the number of observations was small (less than one percent of the total categories).

Table 2 – Frequency of Comments by Category and Type

	Comment Type					
Category	Drawing Clarity	Error	Plan Note Clarity	Omission	Blank	Total
Coordination	0	17	13	8	0	38
Cross Section	2	25	12	10	0	49
Earthwork	0	27	27	16	0	70
Easement	1	3	9	4	0	17
Environmental	0	5	2	10	0	17
Existing Drainage	**0**	**23**	**51**	**34**	**1**	**109**
Geotechnical	0	25	23	23	0	71
Guardrail	**3**	**71**	**36**	**81**	**1**	**192**
Horizontal Alignment	0	13	18	22	0	53
Maintenance of Traffic	**0**	**59**	**94**	**87**	**0**	**240**
Part-Width	0	3	19	4	0	26
Pavement	**4**	**117**	**80**	**64**	**1**	**266**
Permanent Drainage	1	20	9	18	0	48
Phasing	0	26	29	6	0	61
ROW	0	10	4	18	0	32
Seeding	0	10	7	20	0	37
Signalization	0	6	3	11	0	20
Striping	0	11	8	10	1	30
Structure	**2**	**36**	**35**	**26**	**1**	**100**
Superelevation	0	12	3	9	0	24
Survey/Control	0	19	19	15	0	53
Temporary Drainage	0	4	3	5	0	12
Vertical Alignment	0	9	12	4	0	25
Blank	1	3	9	0	2	15
Total	14	554	525	505	7	1605

A chi-square analysis was conducted to determine whether there are any differences in the frequency of the categories examined among the comment types. This test determines if specific categories have a greater presence in certain comment types. The results indicate that there are statistically significant differences, i.e., there are categories that are more likely to be more prevalent in certain comment types. These categories include Pavement, with greater frequency of occurrence in Errors, Guardrail, with greater frequency in Errors and Omissions, and Existing Drainage, with greater frequency in Plan Note Clarity.

Review Year

The frequency with which reviews are conducted is also of interest, since it can identify the potential personnel needs. The current data can be used to determine the desired level and amount of reviews to be conducted in the future and establish the workload of the reviewers. The data indicates that there were approximately equal numbers within each year. Of the 118 reviews, 45 were conducted in 2010, 47 in 2011, and 26 in 2012. It should be noted that the 2012 data is only up through June, representing a partial number of reviews.

The frequency of the comments within each year was also examined to determine whether there is any trend that could indicate improvements (Table 3). The data indicates that the number of comments has reduced over time (statistically significant). Even though KYTC could not provide any reasoning as to why this trend may exist, it could be indicative of an improvement in the process and efforts to address potential constructability issues earlier in the project development. The greatest reduction over time is observed for Errors (almost 50 percent) while the other two types show smaller improvements (20 percent for Plan Note Clarity and 15 percent for Omissions). This trend is encouraging and could indicate improvement; however, additional years of data will be needed to determine whether this is sustainable and indicative of improved practices.

Table 3 – Frequency of Comment Type by Year

	Comment Type					
Review Year	Drawing Clarity	Error	Plan Note Clarity	Omission	Blank	Total
2010	0	215	179	159	5	558
2011	0	110	142	135	0	387
2012	8	42	51	62	2	165
Total	8	367	372	356	7	1110

The average number of comments per review has also been reduced over time. In 2010, the average review had 12.4 comments, while in 2011 this was reduced to 8.2 and in 2012 to 6.4. Of interest is also the relative distribution of categories within each year (Figure 6). The data is presented in percentages to normalize for the different number of reviews.

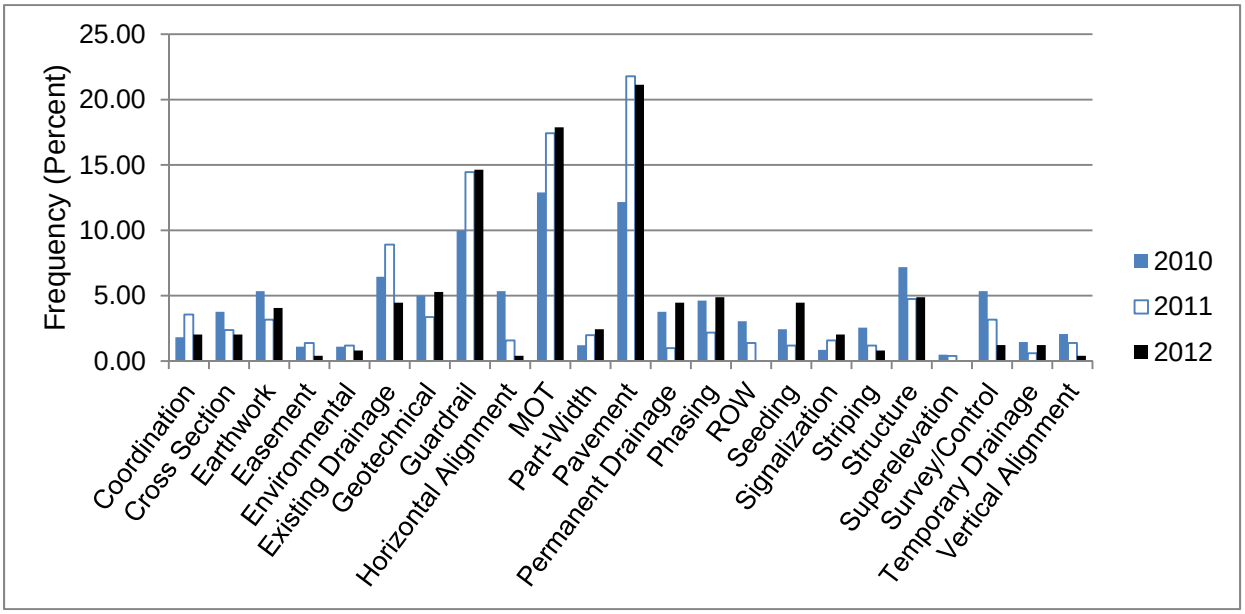

Figure 6 - Category Frequency by Year

These data indicate that there is variability in the frequency of the categories over time. However, a closer evaluation of the data reveals that there is a consistency in the top categories for all years. Table 4 presents the categories that comprise at least 50 percent of the total. A greater number of categories was used in 2010, which is reflective of the larger number of comments completed for each review, thus reducing the corresponding percentages. The most frequent categories are the same in these three years, indicating a consistency of the issues that reviews can identify. This may also indicate an emphasis area for designers to avoid constructability issues and address them in a proactive manner.

Table 4 – Frequent Categories by Year

2010		2011		2012	
Category	Percent	Category	Percent	Category	Percent
MOT	12.90	**Pavement**	21.78	**Pavement**	21.14
Pavement	12.17	**MOT**	17.43	**MOT**	17.89
Guardrail	9.98	**Guardrail**	14.46	**Guardrail**	14.63
Structure	7.18				
Existing Drainage	6.45				
Earthwork	5.35				

It should be noted that similar categories were noted in 2011 and 2012 as those observed in 2010 following the top three noted above.

An analysis of the category types by year and comment type did not reveal any different trends than those observed and discussed in Table 4. For example, there was no consistent pattern as to whether the issues relative to Maintenance of Traffic were Plan Note Clarity or Omission related in any of the three years.

Reviewers

The reviewer who performed the Constructability Reviews for the project has been documented in the database. There were four Reviewers who worked during the 2010-2012 period and each has conducted a different number of Constructability Reviews (Table 5). The large discrepancy in numbers could be attributed to work schedules and availability. However, this may be indicative of personnel needs and the need for a more equitable workload regarding these reviews.

Table 5 – Number of Constructability Reviews by Reviewer

	Year			
Reviewer	2010	2011	2012	Total
1	3	4	--	7
2	--	5	7	12
3	27	8	--	35
4	15	30	19	64

Each reviewer also produced a different number of comments for each review. There are also differences in the comment types as well as the categories identified by each reviewer. Table 6 presents the number of comments by type and provides an indication of the variability of the number of comments by reviewer. It should be noted that these figures do not reflect lack of effort by the reviewer but rather could be viewed as an indication of the lack of consistent templates for conducting the reviews. The large discrepancy in numbers could be attributed to

work schedules and availability. However, this may be indicative of personnel needs and the need for a more equitable workload regarding these reviews. The data also indicates that each reviewer has a different perspective for comment types, which could reflect their specific expertise and background. For example, reviewer 1 has an almost even distribution among the three predominant comment types, while reviewer 3 coded most (43 percent) of the reviews as Errors.

Table 6 – Comment Type by Reviewer

	Comment Type				
Reviewer	Drawing Clarity	Error	Plan Note Clarity	Omissions	Total
1	0	8	7	9	24
2	0	13	18	16	47
3	0	209	140	138	491
4	8	137	207	193	548

An analysis of the comment categories provides additional information that supports the assumption that each reviewer could have their own expertise on subjects and will naturally be more inclined to correct issues in areas where they are comfortable (Figure 7).

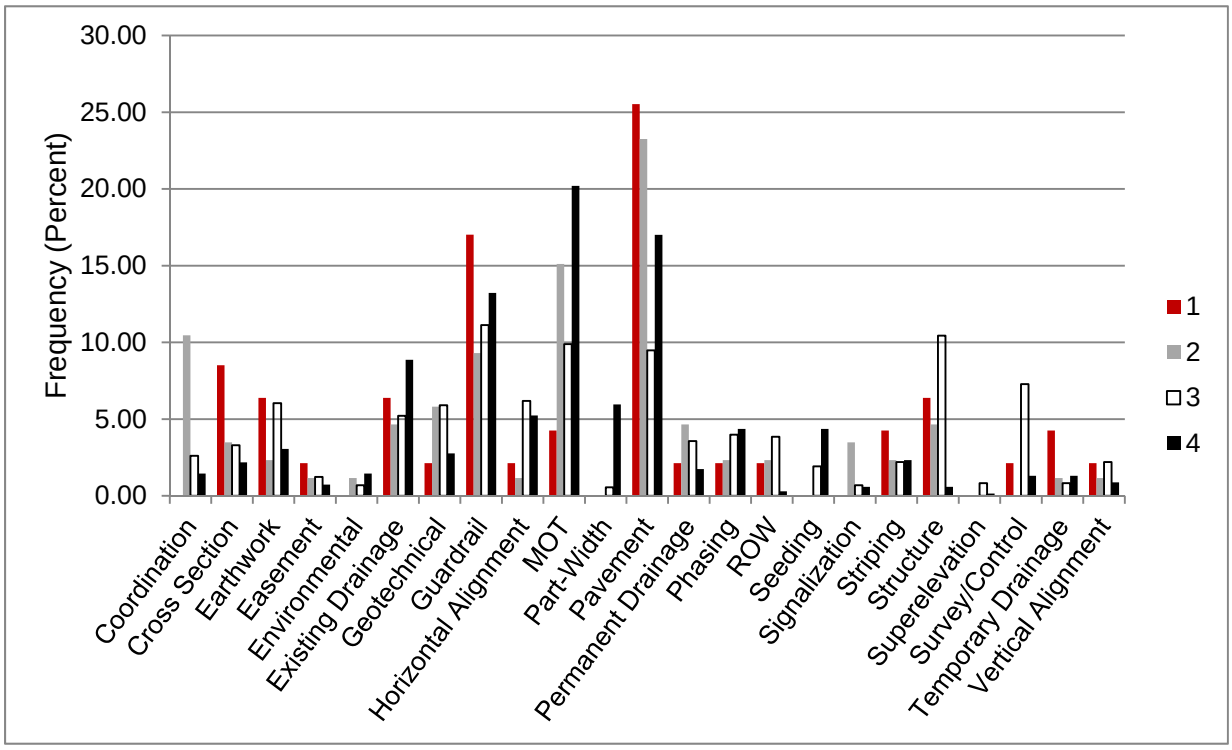

Figure 7 - Categories by Reviewers

A closer evaluation of the data reveals that there is a difference in categories among the reviewers. Table 7 presents the categories that comprise at least 50 percent of the total. A greater number of categories are used by some reviewers, which is reflective of the differences in their number of reviews and comments by review. There are two categories that are present for all reviewers: Pavement and Guardrail. The Maintenance of Traffic is the next category that

is common to three reviewers and is also the next most frequent category for reviewer 1. The data points to a consistency in the top three categories. At the same time, there is variability in the remaining categories that could reflect the reviewer's expertise. For example, Structures is a frequent comment for reviewer 3 while for reviewer 2, Coordination is one of the top categories. The data supports the general assumption that reviewers may have a tendency to inspect areas within their expertise with more emphasis and thus identify a greater number of issues, resulting in more comments in the corresponding category.

Table 7 – Frequent Categories by Year

Reviewer 1		Reviewer 2		Reviewer 3		Reviewer 4	
Category	Percent	Category	Percent	Category	Percent	Category	Percent
Pavement	25.53	Pavement	23.26	Guardrail	11.13	MOT	20.20
Guardrail	17.02	MOT	15.12	Structure	10.44	Pavement	17.01
Cross section	8.51	Coordination	10.47	MOT	9.89	Guardrail	13.23
		Guardrail	9.30	Pavement	9.48		
				Survey/Control	7.28		
				Horiz. Align.	6.18		

The data in Table 7 shows that the structure category appears only for one reviewer as a frequent category, possibly indicating that reviewer 3 has a more extensive expertise in the area of Structural Design. It is apparent that a reviewer should be knowledgeable in all areas and the analysis shows that currently reviewers focus more in their relative area of expertise. It is imperative that reviewers should be trained to review all areas of project plans and they should avoid focusing on what they are more familiar with. Reviewers should be able and know how to review the entire set of plans.

Severity

Each comment was evaluated based on its potential impact on the time and cost of the project if it went undetected. This was accomplished as a subjective evaluation based on the scale and instructions provided in the previous section. The severity levels considered here address only the cost implications, since the time severity was added at a later time, and it was decided to not review the comments again and reclassify them. There were 197 comments that were classified as having a high severity, 655 as medium, and 251 as low. The data indicates that 77 percent of the comments could result in an increase to the project budget, if they were not identified during the review process.

The severity of the comments as a function of the comment type was also examined to determine whether there were any trends that could associate severity with type (Table 8). The data indicates that errors and omissions account for more than 50 percent for each of the severity levels. For high severity comments, these two comment types account for approximately 80 percent of the comments. It is therefore critical to identify these issues during the review process in order to avoid significant change order amounts, which would most likely result in time delays as well.

Table 8 – Frequency of Comment Type by Severity

	Comment Type					
Severity	Drawing Clarity	Error	Plan Note Clarity	Omission	Blank	Total
High	0	50	38	109	0	197
Medium	1	250	233	171	3	658
Low	7	67	101	76	2	253
Total	8	367	372	356	5	1110

Of interest is also the relative distribution of categories within each level of severity (Figure 8). The data is presented in percentages to normalize it for the different number of comments in each category.

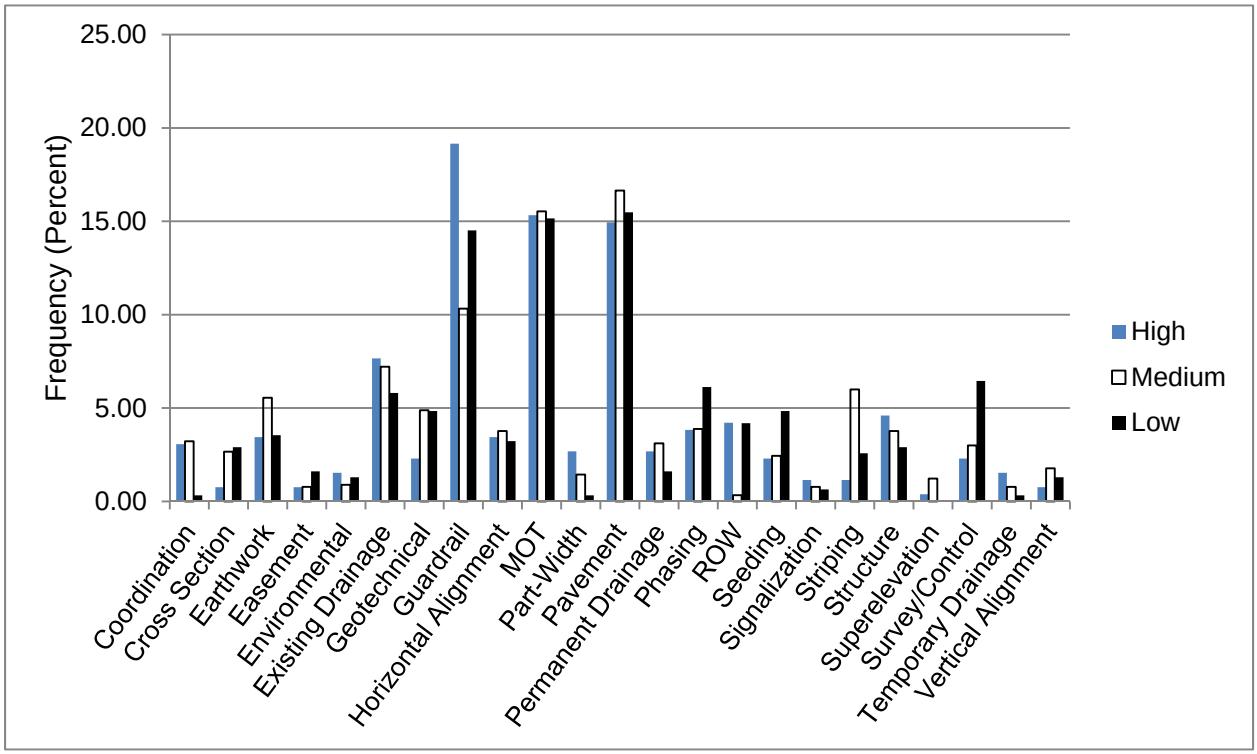

Figure 8 - Category Frequency by Severity Level

The data indicates that, in general, there is variability in the frequency of the categories over the severity level. However, consistency in the top categories for all severity levels is observed. Table 9 presents the categories that comprise at least 50 percent of the total. The most frequent categories are the same in each level, indicating the pervasive issues noted in all variables examined, as well as indicating a consistency of the issues that the reviews can identify. This data also supports the concept that these topics should be emphasized during the design process to avoid constructability issues and address them in a proactive manner.

Table 9 – Frequent Categories by Severity Level

High		Medium		Low	
Category	Percent	Category	Percent	Category	Percent
Guardrail	19.16	Pavement	16.66	Pavement	15.48
MOT	15.33	MOT	15.54	MOT	15.16
Pavement	14.94	Guardrail	10.32	Guardrail	14.52
Existing Drainage	7.66	Existing Drainage	7.21	Survey/Control	6.45
		Striping	5.99		

An analysis of the category types by severity level and comment type did not reveal any different trends than those observed and discussed in Table 2. For example, most of the Pavement issues for medium severity were identified as Errors. On the other hand, there was no consistent pattern as to whether the issues relative to Maintenance of Traffic were related to Plan Note Clarity or Omission for any of the three severity levels.

District

The district in which the review was conducted was also identified in order to determine possible trends in the number of reviews and workload. Figure 9 shows the breakdown for each district and its total number of reviews.

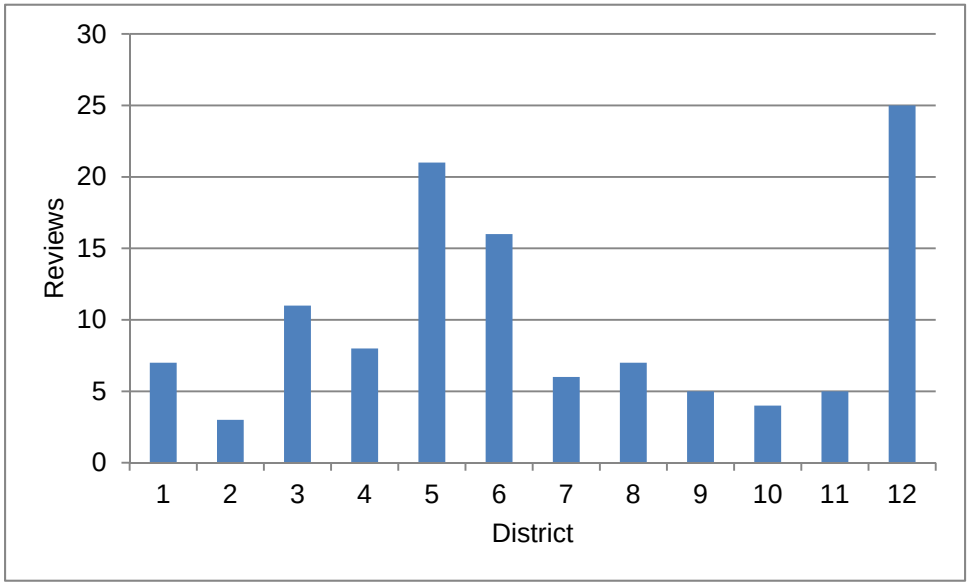

Figure 9 - Number of Reviews by District

The data indicates a large variability in the number of reviews conducted for each district. However, the number of projects within each district is not available in order to provide an understanding of the percentage of projects reviewed or frequency of reviews by district. In this case, it cannot be convincingly concluded that the greater number of reviews conducted in District 12 is reflective of other issues, such as improper designs that could lead to Errors, Omissions or Plan Note Clarity relative to constructability.

A review of the comment type by district was also undertaken to determine specific trends within a district (Table 10).The data indicates that some districts have a greater number of a specific

comment type, which could indicate the need to improve that aspect of the design. For example, District 6 has 50 percent (56 of 111) of the comments noted as Omissions, while District 8 has the same percentage (62 of 124) for Errors.

Table 10 – Frequency of Comment Types by District

	Comment Type					
District	Drawing Clarity	Error	Plan Note Clarity	Omission	Blank	Total
1	0	6	10	13	0	29
2	0	5	8	4	0	17
3	2	17	29	27	0	75
4	3	35	58	29	2	127
5	0	37	66	45	0	148
6	0	27	28	56	0	111
7	0	20	27	20	0	67
8	0	62	22	40	0	124
9	0	14	9	14	0	37
10	0	41	20	22	0	83
11	3	8	9	28	2	50
12	0	95	86	58	3	242
Total	8	367	372	356	7	1110

The analysis of the comment categories did not provide any specific trends, and for most districts the comments received for each category were similar in proportions (i.e., no statistical differences per the chi-square analysis for each category by district).

CONCLUSIONS

When construction expertise is integrated early and throughout the design phases of a project, there is the potential for increased benefits. KYTC has attempted to take advantage of this knowledge by establishing a Quality Assurance Branch which includes the Constructability Review Program. However, in the current state, this effort lacks a systematic method for cataloging the results of the process, analyzing their findings, and yielding direct tools for design engineers to use on future projects. A list of categories has been developed based on review of other state DOT practices, along with a literature review. This list was utilized to develop a database in which existing reviews were entered to be analyzed for trends and tendencies.

The findings from the data reveal several trends and issues. The analysis showed in general that Pavement, Maintenance of Traffic and Guardrail are the most frequent categories observed. These were characterized either as Errors or Omissions, where Errors indicated wrong quantities while Omissions noted absence of the item needed for construction. Plan Note Clarity was also another type of comment that was frequently noted. The data did not reveal any particular trend regarding which of these three types is predominant and all seem to have an equal presence in the existing database.

There were differences in the comment types that each reviewer identified. The data also indicated that each reviewer is likely to review areas within their expertise. Ideally, a reviewer should be familiar with all areas of expertise required for a particular review and be capable of conducting such a review. Given the reality as presented herein, reviewers can be influenced by their unique area of expertise. It is recommended that reviews be conducted either by reviewers competent in all areas of the design or by a team to help achieve a comprehensive and well balanced review. The team reviews would not necessarily have to be conducted in person; they could be completed electronically.

The data for the comment severity indicate that errors and omissions could result in significant cost issues and possible time delays. The same three categories identified above are also present as having a high severity for several comments indicating their significant impact on project cost and time.

The review of the data in each district indicated that there are disproportionate numbers of reviews. This could not be further evaluated, since the total number of projects that should be considered for a review for each district is not known. Trends have been identified by district with respect to the comment type. An effort should be undertaken to examine these in more detail to determine whether they are random.

Recommendations

Constructability Review in Preliminary Design Phase

The comment type Plan Note Clarity was the most frequently observed. Although Plan Note Clarity correction improves constructability of the project plans, the reviewers have the tendency to do more Plan Note Clarity correction than examining the entire project for larger constructability issues. If the plans are reviewed earlier in the design process, the reviewers would have an opportunity to make these types of corrections. According to KYTC's Highway Design Memorandum No. 6-05, Constructability Reviews should be conducted in two stages. The first should be conducted before right of way plans are finalized, while the second is conducted at the end of the final design. The objectives and details for the first review can be found in Appendix A.

It is highly recommended that the reviewers should have the opportunity to review the plans early in the design phase, since this will allow for a better usage of the constructability knowledge of the reviewers.

Constructability Review Teams

The analysis shows that the reviewers tend to review their areas of expertise in more detail. In order to assure that all project plans receive a thorough Constructability Review, a project team should be established. KYTC's Highway Design Memorandum No. 6-05, lays out guidelines for team compositions. As noted above, the first Constructability Review should be conducted before the Right of Way plans are finalized. This review has an option for two different team compositions based upon the budget of the project. The second Constructability Review should be conducted at the end of final design. The teams generally include a facilitator, project manager and two experts in construction. If the project is over $2,000,000 a traffic operations and Right of Way engineer is involved in the review.

These guidelines should be examined and followed more closely. The current system has a single reviewer conducting each Constructability Review. The use of a team of experts to review plans will continue to improve the constructability of the project. The team effort can address all areas and it will not necessitate that a person be familiar with all required areas of expertise. The recommendation for Central Office is to setup the team through the Quality Assurance Branch of KYTC.

Training Workshops

Districts across the state that have a large number of comments for any category should be closely monitored for future trends and possible improvement. Training workshops for such districts targeting the areas with the higher frequency of comments could address constructability issues and help eliminate constructability concerns. The problems can be eliminated from the early stages of the project development once designers become aware of frequent errors they are making in project plans. The Quality Assurance Branch can recommend new topics for these workshops by querying the database and finding which categories have the potential to result in constructability issues.

Constructability Database Availability

The database developed here provides a useful knowledge for all designers, either new to the design world or those who have been designing for years. The database should be available for all persons involved in project development, which include KYTC Districts and Central Office personnel and consultants. Querying topics can help designers minimize construction issues while they are designing the project.

Phase II: Ongoing Efforts

The main objective of the next phase of the project is to quantify the potential benefits from Constructability Reviews. To achieve this, a set of case studies will be identified and reviewed to allow for estimating and quantifying benefits.

The case studies will be selected among projects that have undergone a Constructability Review and have been completed in the past few years. The selection of completed projects was considered appropriate, since all change orders and cost items would have been submitted and recorded. This will allow for an accurate estimation of the impact that each review comment had on the cost of the project, and identify any potential shortcomings of the reviews completed.

A preliminary set of criteria for the selection of the case studies has been developed with the capability to evaluate a wide variety of projects. These criteria include the number of comments in the project, the cost of the project, and the location of the project. The date in this analysis indicated that the average review resulted in nine comments (118 reviews with a total of 1,110 comments). It was determined that the cases to be selected will have at least ten comments to reflect the average number of comments per review. The average construction cost per project for KYTC is approximately $10 million. This figure was deemed appropriate as the boundary condition for project cost and it was decided to include a few projects with costs greater than $10 million as well as a few with lower costs. This will allow for evaluating a variety of project scales and, possibly, scopes. Finally, it was decided that a total of six cases will be reviewed, three in each cost category.

The metrics to be used in the analysis will be determined as part of the next task during Phase II. It is anticipated that these metrics will examine both quantities missed, or with errors, and items that were omitted. For example, if guardrail was omitted from the plans, then the metric to be used will be linear feet of guardrail required for the project and the benefit will be estimated based on the average bid price for guardrail. Metrics will be established for each of the 21 categories identified here that would provide such comparisons and allow for estimating possible benefits as a result of the review conducted. These metrics will be fully developed and submitted to the SAC for review and discussion in order to identify the most appropriate metrics for inclusion.

The next task involves the estimation and quantification of the value and/or cost related to the constructability effort according to the case studies selected for their individual characteristics. Efforts will be undertaken to correlate actions to benefits but this may need to be revisited once the task is underway to determine appropriate value estimating practices.

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APPENDIX A

KYTC HIGHWAY DESIGN MEMORANDUM NO. 6-05

DESIGN MEMORANDUM NO. 6-05

TO: Chief District Engineers
Design Engineers
Active Consultants

FROM: Ken Sperry
Acting Director
Division of Highway Design

DATE: March 17, 2005

SUBJECT: Constructability Reviews for Projects

This Design Memorandum is for guidance in implementing a comprehensive Constructability Review Process for projects. Constructability Reviews (CR) are a means of understanding project elements through the eyes of construction. Constructability is defined by AASHTO as "a process that utilizes construction personnel with extensive construction knowledge early in the design stages of projects to ensure that the projects are constructible, while also being cost effective, biddable, and maintainable." The designer uses sound engineering decision-making in development of the design features, while a Constructability Review allows those with construction expertise to examine the decisions to provide sound advice in construction phasing, traffic control, ease of construction, environmental considerations, and construction scheduling. To obtain maximum benefits from CR, it should be initiated early in the design process, and continue through design and just before the project is let to contract. A valuable tool in CR is the utilization of lessons learned from past projects, which will reduce significantly the need for change orders during construction.

All KYTC projects will be reviewed for constructability issues utilizing the CR process. The extent of the review will depend on the complexity of the project. The Division of Highway Design will handle oversight and support of the program, with primary oversight by the Roadway Design Engineering Branch Manager and Head of the Value Engineering Section. The responsibility for insuring that constructability reviews are conducted in a timely fashion and for gathering of information for delivery to project teams is assigned to the Location Engineer in cooperation with the Project Manager for each project. Participation from Construction personnel is essential as part of the Project Team throughout the life of a project, and these Constructability Reviews are NOT intended to replace or supplant this participation. The CR process is simply a resource to the Project Team to identify issues from a constructability standpoint. Construction's involvement from the earliest stages of a project allows recommendations at times when key decisions are made to address design issues that could be reconsidered in light of constructability issues. Constructability Reviews will typically be conducted in a two stage process, involving two separate Constructability reviews. An outline summary of these two reviews is attached.

At all stages of constructability reviews the Lessons Learned Database should be consulted. The Section Head of the Value Engineering Section of the Division of Highway Design will be responsible for assuring that information is input into the database. Information gathered from Constructability Reviews will be added to this database, along with lessons learned from post-

construction reviews, past VE studies, etc. Minutes of all meetings should be sent to the Value Engineering Coordinator's office in Frankfort for inclusion in the Lessons Learned Database. The Lessons Learned Database is available on the Division of Highway Design's web page, under Value Engineering.

Practices used for the constructability review process are to be consistent in all KYTC districts. CR teams would consist primarily of construction personnel from the Districts, Central Office (as required), and the Location Engineer. Other disciplines (such as Geotechnical , Pavement design, Traffic, etc.) may be considered if desired. Construction personnel from other Districts may be used as needed, depending on the relative complexity of the project. In cases of major or complex projects, the statewide Value Engineering Consultant can be used to conduct Constructability Reviews, along with District Construction personnel. The Statewide VE consultant would provide personnel with extensive construction knowledge to assist the CR team. The use of a statewide VE consultant to do Constructability Reviews will be at the discretion of the Project Team and the Division of Highway Design.

This procedure should be utilized on projects effective with the date of this Design Memorandum. Only those projects that have advanced past Right of Way Plan submittals are exempt.

KRS:RDM:TLV

Attachments

Outline for Constructability Review Process

Purpose: The Constructability Review Process is being implemented as a means of minimizing change orders and identifying design errors and omissions before projects are let. The review is intended to contribute to the project development decision making process at all stages of the project. Constructability Reviews are NOT intended to replace the Project Development Team Process. Participation by Construction, Traffic Operations, Geotechnical and other disciplines are ESSENTIAL.

I. Constructability Reviews Will Be Done on All Projects with Plans

A. Division of Highway Design will oversee the program and provide logistical support.

Options available for administering the program are the following:

1. Branch Manager for Roadway Engineering

   (a) Value Engineering Section
   (b) Plan Processing Section
   (c) Location Engineers

2. Statewide Value Engineering Contract

   (a) Facilitator for Constructability Review Team Meetings if necessary
   (b) Provide "Specialized" expertise for Constructability Review Teams if necessary.

3. Focus for the review are on the following areas:

   (a) Feasibility of alternatives
   (b) Implement lessons learned from previewing projects
   (c) Identify preliminary ROW, Utilities, Railroad and other issues on the project
   (d) Include and evaluate environmental issues
   (e) Evaluate potential waste or borrow sites
   (f) Evaluate traffic and highway capacity issues
   (g) Evaluate need for auxiliary lanes and geometrics involved

II. Constructability Reviews (CR) will be conducted in Two Stages. There will be two separate Constructability Reviews

A. Constructability Review No. 1 (CR-1): CR-1 will be conducted before Right of Way Plans are finalized.

a) Objectives of CR-1

1. Consider findings of a formal VE study if conducted.

2. Provide detailed evaluation of the project design from the perspective of constructability, ROW issues (especially easement and entrances), utilities, railroad issues, maintenance of traffic and opportunities for innovative bidding techniques. Use "lessons learned" database from post-construction review and review of the database for design errors and omissions, to identify common constructability issues.

b) Team Composition for CR-1 (For Projects greater than $2,000,000)

1. Facilitator—Location Engineer
2. Project Manager
3. Two Construction Subject Matter Experts (SME)-Resident expected to oversee Project and Resident from different District with experience on similar type project
4. Traffic Operation (SME)
5. Right of Way (SME)
6. Others as needed dependant upon complexity and characteristics of project

c) Team Composition for CR-1 (For Projects less than $2,000,000)

1. Facilitator—Location Engineer
2. Project Manager
3. Two Construction Subject Matter Experts (SME)-Resident expected to oversee Project and Resident from different District with experience on similar type project or Central Office Construction Liaison for the District.
4. Others as needed dependant upon complexity and characteristics of project

d) Location engineer will prepare a "Constructability Review" report for distribution to the Project Manager

B. Constructability Review No. 2 (CR-2): CR-2 will be conducted at the end of final design and coincide with the submission of "check prints".

a) Objectives of CR-2

1. Ensure that project plans, specifications and details are adequate for bidding.
2. Address final issues of "Constructability and Maintenance of traffic".
3. Review contract time recommendations and any recommendations for innovative contracting.
4. Perform "Quality Assurance" check of at least one major bid item for the project. This essentially involves thoroughly checking a randomly selected major bid item for accuracy.

b) CR-2 Team Composition

1. Facilitation—Value Engineering Section or Location Engineer
2. Project Manager
3. Two Construction Subject Matter Experts (SME)-Resident expected to oversee Project and Resident from different District with experience on similar type project or Central Office Construction Liaison for the District.
4. Traffic Management SME
5. Plan Processing Selection Reviewer

c) The Branch Manager for Roadway Engineering will designate the appropriate individual to prepare a "Constructability Review" report for distribution to the Project Manager.