6-8-2017

Benefits from Constructability Reviews

Nikiforos Stamatiadis
University of Kentucky, nick.stamatiadis@uky.edu

Roy Sturgill
University of Kentucky, roy.sturgill@uky.edu

Kiriakos Amiridis
University of Kentucky, kiriakos.amiridis@uky.edu

Benefits from Constructability Reviews

Digital Object Identifier (DOI)
https://doi.org/10.1016/j.trpro.2017.05.275

Notes/Citation Information
Published in *Transportation Research Procedia*, v. 25, p. 2889-2897.

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 25 (2017) 2889–2897

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

Benefits from Constructability Reviews

Nikiforos Stamatiadis[a*], Roy Sturgill[a], Kiriakos Amiridis[a]

[a]*University of Kentucky, Raymond Bldg., Lexington, KY 40506-0281, USA*

Abstract

Constructability review is a process used during project design to infuse construction knowledge into the design process. There is industry impetus encouraging early construction involvement in project development. State transportation agencies often have to abide by legislation restricting these procurement methods leaving construability review as the only opportunity for early construction involvement. Staffing and budgetary constraints lead to state transportation agencies being very cautious in the practices and processes they implement that seemingly lie outside the main missions of project development and delivery. Without straightforward and documented savings of constructability review processes, these methods may also be eliminated. After streamlining the constructability review process for the Kentucky Transportation Cabinet, an effort was undertaken to estimate monetary benefits from such reviews. Constructability reviews were evaluated at the project level by comparing change order percentages on projects reviewed versus those not being reviewed. This approach showed a clear indication that there are monetary savings associated with constructability reviews resulting in a conservative estimate of 1.25 percent of the project budget. This estimate did not include the additional inherent savings in time, lessons learned or other aspects not readily quantifiable. The second method of evaluating constructability reviews was to quantify and qualify each constructability review comment. A model was developed to estimate the potential monetary gains from the comments indicating the presence of such gains but additional analysis is needed to improve model accuracy.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Constructability review, design, design quality assurance

1. Background

Typical project development follows a phased team process with a central goal of delivering the most appropriate solutions. Past work has documented the significant cost and time benefits of the integration of construction expertise throughout the project development phases and especially the design phases of a project (Gambatese et al.

2352-1465
Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.
10.1016/j.trpro.2017.05.275

2007). The Kentucky Transportation Cabinet (KYTC) has attempted to consistently review design documents for constructability issues before they reach the construction stage through independent constructability reviews and value engineering studies. The existing process, which involves a group of four reviewers conducting individual reviews, 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 (KYTC 2012). Recently, a Constructability Review Database was developed that allows for a systematic cataloging of results from constructability reviews, an analysis of their findings with rating and cost associations, and an ability to develop lessons learned from prior experiences (Stamatiadis et al. 2013).

Current trends of increased need for road improvements and diminished availability of funds necessitate a critical examination of the project development process. State Departments of Transportation (DOTs) have undertaken a variety of efforts and processes to reduce project 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).

Constructability reviews aim to evaluate design options and identify areas where benefits can materialize. Several DOTs have implemented a practice of addressing potential project oversights and minimizing problems during construction (Anderson and Fisher 1997). This practice allows a systematic review of projects during various phases in their development aiming to minimize future disputes and scope changes with construction issues. This is a process typically relying on the expertise of construction engineers and integrated knowledge of techniques, advancements, and experience while trying to avoid future project oversights. Dunston et al. (2002) also demonstrated that the benefit/cost ratio of constructability reviews is greater than two. The findings noted that effective constructability reviews have the potential to decrease 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).

The timing of the reviews within the project development process is another critical issue. Projects approaching the construction phase become less flexible in changing various elements and thus the ability to impact cost and delivery time is diminished. It is therefore important to conduct such reviews in the early stages of design in order to maximize flexibility in plans and avoid potential redesigns. Reviews conducted after the final design and before construction may still identify possible oversights, but the changes at that time would likely result in additional costs and time for the project to be completed. Timing these reviews at the proper time within the design phase, is imperative to allow sufficient time for addressing potential issues.

As noted above, KYTC conducts constructability reviews but 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 significant effort was undertaken to develop a systematic approach and a preliminary system was placed as part of a recent effort (Stamatiadis et al 2013). An analysis of the newly developed database showed that constructability issues are of a dynamic nature and change over time. This was supported by the trends noted among the data reviewed in the three years and showed differences on the issues requiring attention. Reviews conducted by an individual may lead to incomplete evaluations of plans, since the data showed that reviewers have a tendency to focus on comment types and categories that they are more familiar with. Reviews conducted by teams may be an alternative that should be considered to provide more comprehensive reviews. Finally, in the event that team reviews are not feasible, consistency among reviewers is required. The data showed that this could be an issue due to the different areas that individual reviewers focus based on their relative expertise. An area of opportunity in standardizing reviews lies in the uniform use of tools such as checklists.

Many DOTs have not yet embraced alternate procurement methods that incorporate construction knowledge into early stages of design. Constructability review is a method to achieve this while conforming to traditional design, bid, and build procurement. In addition to the issues noted here, DOT staffing and experience levels indicate a need to perform systematic constructability reviews and identify their benefits since resources are limited. This study addresses the benefits from constructability reviews through a comparison of projects with and without reviews as well as a review of case studies aiming to quantify these benefits.

2. Methodology

The main goal in any review process is the documentation of potential benefits from conducting reviews and validation of their usefulness. For this research effort the use of case studies was deemed appropriate in order to determine and demonstrate the potential gains from constructability reviews.

2.1. Case study selection

A detailed and comprehensive set of example projects for case analysis was identified through consultation with the study oversight panel. Projects were selected to include a variety of construction and design aspects as well scope and budget. It was also deemed appropriate to select a small number of cases in order to allow for a timely completion of the study. A list of criteria was developed to select the appropriate cases, including:

- Project Characteristics: Typical issues to be considered were project type, density of surrounding development, estimated construction cost, project designer, highway district, project manager, and project origination. It was understood that the low number of case studies to be considered would not provide results of any significance relative to the effects of these criteria. However, an assumption was made to consider an even distribution of projects with higher estimated construction costs and lower estimated construction costs. Ten million dollars was selected as the threshold for estimated construction cost based on that value being the average estimated construction cost for all projects reviewed.
- Reviewer: This variable was considered in order to allow for adequate distribution across the different reviewers completing reviews. However, the small number of cases would not allow for any significant evaluation and therefore, this was only a minor consideration in the case selection process.
- Project stage: The case studies should be selected among projects that have undergone a Constructability Review in the past few years. The selection of these projects was considered appropriate, since the final design would likely have been completed and the project possibly begun construction and thus allowing for an analysis of possible change orders and cost items. This provided 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.
- Number of review comments: The number of comments per case study plays an important role, in order to determine their impact on the project and thus estimate the value of the constructability review. The assumption is few comments resulting from a constructability review are likely a product of a design with high quality and little room for value added from the review. The threshold of ten comments was used for case study selection, since the analysis of the database indicated an average number of nine comments (118 reviews with a total of 1,110 comments).
- Geographic distribution: Adequate coverage of cases throughout the state is sought in order to avoid any concentration in a specific district. This criterion was relaxed, since all districts were not going to be represented due to the low number of cases.

A structured approach was undertaken in selecting the case studies. First, cases with ten or more review comments were identified. This criterion was utilized to establish a large enough pool of comments for analysis given the small number of cases to be selected. Second, the timing of the review of each case was considered to determine the stage of inspection. Cases selected should have reviews conducted at final joint inspection (i.e., prior to construction where plans are reviewed by the design and construction teams) or check print indicating that the plans were advanced to near completion. This was deemed appropriate, since plans in preliminary design are of limited detail and would not have provided an opportunity to estimate a value for the constructability review comments with any accuracy. Next, the project budget was examined and half of the cases selected had a budget over $10 million and the remainder less than that amount. This threshold was determined as being the cut-off between what would be considered a “large” project for KYTC. The average estimated construction cost for all projects reviewed is $10 million and this value was set as the threshold to be used here.

As an additional selection criterion, the database is comprised of information from two main periods, data collected and entered by researchers during the development of the preliminary database and data entered by the reviewers themselves. An even distribution of cases between self-entered and researcher entered reviews would

allow an evaluation of risk assignment by the researchers versus the risk assignment by the constructability reviewers.

The final criterion used was the level of design process utilized in project development. There are projects, such as those associated with maintenance issues, that do not completely pass through the formal design process and therefore the constructability reviews conducted in such projects may not be reflective of the overall conditions. It was determined that it will be more appropriate to select projects that have been through the entire process.

The process and criteria discussed here were utilized to select the cases shown in Table 1.

Table 1. Selected cases for analysis.

Case No.	Phase of Review	Review Type	No. of Comments	Project Type	Construction Est.
1	Final Joint Inspection	Roadway	18	Major Widening	$19,510,000.00
2	Check Print	Roadway	36	Major Widening	$41,250,000.00
3	Final Joint Inspection	Roadway	11	Safety	$675,000.00
4	Final Joint Inspection	Structure	3	New Route	$12,120,000.00
5	Check Print	Roadway	13	New Route	$12,120,000.00
6	Final Joint Inspection	Roadway	15	Bridge Replacement	$850,000.00
7	Final Joint Inspection	Roadway	13	Bridge Replacement	$400,000.00
8	Preliminary Line and Grade	Roadway	12	Relocation	$45,450,000.00
9	Final Joint Inspection	Roadway	20	Bridge Replacement	$900,000.00

2.2. Identification of benefit metrics

Benefit metrics were established to evaluate the cases and assign values to the corresponding comments. Preliminary evidence and analysis suggested that valuation of the constructability review program could occur both at the project and comment level.

At the project level, projects that were reviewed through the constructability review program were compared to projects that were not formally reviewed. Data for projects from 2007 to the present were compared to projects that were reviewed through the constructability program from 2010 through 2012. The comparison was made by investigating the percentage of cost increase (or decrease) from the as-bid project cost to the final cost inclusive of change order adjustments. Any difference between these two categories of projects (reviewed versus not reviewed) would demonstrate a relationship between the constructability review program and any savings that could be noted.

At the comment level, there were two broad areas of benefit metrics used in evaluation of the comments with this study: quantitative valuation and qualitative valuation. Quantitative valuation was based on identifying the issues and costs associated with the comment if it was not addressed until the project was already under construction. In other words, if the problem, concern, or question were to occur during construction how would it have been addressed. From this analysis, the value of the comment could be determined by calculating the algebraic difference between the costs of addressing the comment during design versus addressing it during construction.

The qualitative valuations of the comments were categorized into three distinct groups (Table 2). These groups are defined by the level of corrective actions required during construction for not addressing the comments in design. The corrective actions might entail additional project communication, additional project documentation, additional project costs, change orders, additional project time, and project disputes or claims.

Table 2. Qualitative value level description.

Qualitative Level	Description of Corrective Actions
Low	Corrective action may require additional project communication or clarification, but can be completed without a change order. Project management staff efforts would be minimal to rectify the situation.
Medium	Corrective action may incur minor project cost or time increases by change order but the overall effects are considered average. The average change order results in a 3.5 percent increase to the project. Project management staff would incur additional documentation and time to rectify the situation.
High	Corrective action will result in large additions to the project in cost and/or time, and would have potential for leading to project disputes or claims. Project management staff would incur excessive amounts of added documentation and time to rectify the situation. May result in additional tension between the contractor and project management staff.

All comments were evaluated qualitatively and only a subset was evaluated quantitatively due to lack of appropriate quantitative data. This allowed for a basic comparison between similar qualitative values and the ability to infer an estimate of what their quantitative value might be.

3. Results

3.1. Identification of benefit project level evaluation

One method of determining the value provided by a constructability review program is a comparison between projects that were reviewed and those that were not. Ideally, this comparison would occur while projects were ongoing. Such analysis and documentation would be cumbersome and time consuming. A perceived method of estimating this comparison is to compare change orders of projects reviewed and not reviewed. While change orders may not capture all changes or problems occurring on a project, the majority of those impacting the project cost would be represented.

To complete this analysis, data regarding projects from 2007 through 2012 was collected. This data included as-bid project cost and cost modifications by change orders. There was also information available to determine if the project was complete or not, and what design item series (an indication of project type and development process) was related to the project. The available constructability review database allowed comparing these datasets in multiple ways and across multiple variables such as reviewer, district, completion status, or item number series. The amount of change orders as a percentage of the as-bid project cost was calculated and reported in Table 3Table in various categories of concern. The Item # is a KYTC mechanism for tracking types of projects and their associated steps though the project development process. Projects with numbers less than 3000 and greater than 7000 will typically go through the entire design process and potentially are reviewed, while all others are traditionally maintenance projects that may not require constructability reviews.

Table 3. Change orders as percent of project budget for project level evaluation

All Projects				
	Project Series			
Reviewed	All Projects	Item#<3000	Item#>7000	Item#>3000, <7000
Yes	3.383	3.794	1.902	No Reviews
No	4.403	4.490	5.932	5.309
Completed Projects				
	Project Series			
Reviewed	All Projects	Item#<3000	Item#>7000	Item#>3000, <7000
Yes	3.012	3.546	0.074	No Reviews
No	4.427	4.781	6.647	4.181
Reviewed Projects				
	Project Series			
Reviewer	All Projects	Item#<3000	Item#>7000	Item#>3000, <7000
1	2.370	3.060	0.682	No Reviews
2	4.611	5.001	2.884	No Reviews
3	2.863	2.589	3.958	0.000
4	0.882	0.882	No Reviews	No Reviews

The data here indicates that projects reviewed through the constructability review program incur a lower amount of change orders (on average 1.25 percent) than projects that were not reviewed. This percentage cannot directly be referred to as savings for projects that were reviewed because it is likely that changes were made based on the constructability review comments adding work or items during design that would have otherwise been added during construction by change order. The KYTC change order procedures indicate that change order items are acceptable at 110 percent of the average unit bid prices. An estimate of the value of the constructability review program for 2010-2012 can be derived utilizing the assumption that the reviews saved this 10 percent premium on the 1.25 percent in change order additions (Table 4). This estimation is extremely conservative as it is likely the reviews saved beyond the 10 percent change order premium. In addition, much of the value in constructability review is not accounted for here such as construction management time savings, designer lessons learned, and schedule delays saved.

Table 4. Estimated savings of the constructability review program by letting year.

Letting Year	Bid Amount for Projects Reviewed	1.25% Estimated Price Reduction	Savings (10% Premium)
2010	$112,060,060.98	$1,400,750.76	$140,075.08
2011	$232,134,684.84	$2,901,683.56	$290,168.36
2012	$88,625,270.91	$1,107,815.89	$110,781.59

3.2. Case study evaluation

As previously mentioned, a second measure by which to estimate the value of a constructability review program is by evaluating the constructability reviews at the comment level. Even though this approach requires several assumptions, it provides a much more discrete analysis of the reviews based on each comment. The assumptions and procedures for evaluating the constructability review comments are discussed in the next sections. A probability analysis is also presented aimed in developing a multivariate regression formula for estimating comment value.

The case study comment evaluation was performed by a research team member with over ten years of experience in construction management with six of those years directly related to the KYTC change order process. This knowledge allowed for a review of each comment utilizing a scenario based analysis where comments were related to similar past project experiences.

Each comment was first evaluated to determine the possibility for a quantitative evaluation. From the 141 comments analyzed, 73 were evaluated quantitatively because they were the only ones with avaialbel quantitiative data. Various approaches were utilized to determine the value of each comment with an underlying objective to determine the impact the problem, issue, or ambiguity would have during construction. The approaches utilized for the evaluation are discussed below.

Two approaches were utilized for estimating the value of comments related to omitted work or bid items. The most straightforward approach was when the bid item was not included. In this case, the KYTC average unit bid prices (AUBP) were used to estimate what costs would have been added to the project at a 10 percent premium, i.e. using a 110 percent of the AUBP. The benefit accrued from the comment was only the 10 percent premium savings that would occur due to correction prior to construction. The second approach involved comments for which omitted work simply meant additional quantity for a bid item already included in the project. Unless the omission affected the current bid quantity by more than 25 percent, by specification, no price adjustment is warranted during construction. In these cases where existing quantities were not changed by more than 25 percent no benefit was accrued for the comment. It can easily be inferred that economies of scale would apply to a quantity increase and therefore the comment does entail a direct benefit to the project; however, it is not quantifiable in this case.

There were several comments where there was a need to replace one set of bid items for another. The comment might require this based on the wrong items being used or simply a switch to a satisfactory, yet more cost effective option. In order to quantify these comments the value of the existing bid items was determined using the quantities and AUBP, then the new items needed were subtracted from this amount at the corresponding quantity and AUBP. The 110 percent premium was not used in these cases as subtracting at normal rate is the true benefit of the comment were it considered at the design stage in these cases.

The final approach taken to determine the value of a comment was for those that involved the simple elimination of bid items. The benefit in these cases simply entailed the quantities eliminated multiplied by the corresponding AUBP rates. If any items also had to be added after the comment eliminations were made, these were added at the normal AUBP rate according to the same reasoning above.

The quantities and values of these 73 comments were computed using the appropriate approach among those noted above. The data indicates that most of the comments resulted in a benefit of less than $2,000 (52 comments of the 73 or 71.2 percent) with only eight comments with benefits over $10,000 (11 percent). However, these 52 comments below $2,000 only account for 4.2 percent of the quantified savings while the eight comments over $10,000 account for 85.3 percent of the calculated savings. Having a majority of the dataset account for the smallest portion of the value determined, makes the values over $10,000 appear as outliers to the data. However, this is most likely due to the small number of cases and comments analyzed. This data variability also affects the regression analysis discussed below.

As previously mentioned, all comments reviewed were assigned a qualitative value according to Table 2. A cross-examination of the qualitative scores by the estimated value indicates that most comments with low values are

also those with a low qualitative level (Table 5). There are few comments with high qualitative level and large benefit value (4 percent). Additional comparison and cross-examinations of the value with the comment types and comment categories did not produce any significant trends.

Table 5. Correlation of qualitative to quantitative analysis of comments.

	Qualitative Level (Percent)		
Value	Low	Medium	High
<$1,000	60	8	0
$1,001-$2,000	5	1	0
$2,001-$5,000	5	9	0
$5,001-$10,000	2	1	0
>$10,000	0	5	4

3.3. Probabilistic and regression analysis

One of the goals of the case analysis was to determine if any trends were evident with regard to comment types, categories, benefits and comment severity. The analysis at the programmatic level discussed above provided an overall estimate for the value and benefits of the constructability reviews. The statistical analysis conducted here aimed at developing prediction models of the benefits of the review utilizing comment attributes. The analysis presented here is based on the 73 quantified comments.

The values obtained for the 73 comments range from $12 to $166,000. The majority of these values are below $2,000 (71.2 percent) as noted above. The significance level for the statistical analyses described next is assumed to be at the 95-percent level, i.e., p-values must be lower than 0.05 in order to be considered statistically significant. The statistical analysis was conducted with the SPSS software. There are various methods and tests to conduct a statistical analysis depending on the nature of the dependent and explanatory variables, i.e., quantitative or categorical. For example, the Analysis of Variance (ANOVA) procedure is utilized in order to analyze the realtionship between a quantitative dependent variable to one or more categorical explanatory variables. Logistic regression on the other hand is used when the dependent variable is categorical. However, the purpose of this study is to develop a predictive model utilizing both categorical and quantitative variables as predictors. Moreover, it is not intended to conduct a statistical test in terms of a distribution fit, but rather to provide a predictive equation to estimat ethe potential benfits from construcatbility reviews. Therefore, regression analysis is considered the most appropriate approach in this case, since there are no other suitable processes that could be used to address both categorical and quantititive variables. Regression analysis allows for a more robust evaluation of the variables of concern and permits their use in a variety of function forms, such as non linear or exponential, in order to allow for the development of a more flexible model with a better fit.

Several attempts were made to develop a regression model in order to predict the possible constructability review benefits utilizing the available variables. Table 6 shows the progression of the models used in this effort and the equation that is considered the best fit for the existing data (Model 4). The data set allowed for six potential explanatory variables, which are: Error Type, Category Type, Severity Type, Quality Level, Number of Comments, and Construction Estimate. The first four variables are categorical and the other two, quantitative. In regression analysis, categorical variables are addressed through the use of dummy variables and coding, since their values are indicative more of a presence than a rank order. Initial trials focused on identifying the variables of significance and upon conclusion of this effort, it was determined that the most statistically significant variable was the categorical variable “Quality Level” resulting in a model with an R^2 of 0.481 (Model 1). Therefore, the “Quality Level” was considered the basic variable of the analysis. The next efforts focused on identifying other variables or their combinations that could enhance the fit of the model, i.e., increase its R^2.

The next variable that entered the model was the “Number of Comments”. Multiple function forms, i.e., linear, logarithmic, quadratic, cubic, and growth, of the variable were used and it was concluded that the exponential function has the best effect in terms of R^2 increase and statistical significance. Specifically, with the inclusion of the exponential function of the “Number of Comments” in the model, the R^2 becomes 0.541 and the p-value of the corresponding coefficient of the exponential is 0.004 (Model 2). After the incorporation of the “Number of Comments” in the regression equation, a richer model in terms of variables was sought. In this case and upon

evaluating several function forms of the variables as well, Model 3 was developed where the "Number of Comments" and "Construction Estimate" are multiplied and raised in the second power. However, the improvement of the R^2 is practically zero (0.001), therefore this regression equation was not considered any further. The final variable tested was that of the "Category Type". Once included in the model, the R^2 increases to 0.602 and all coefficients are statistically significant at the 0.05 level (Model 4).

It should be noted here that the 24 comment categories are regrouped to a smaller number of three categories in order to limit the complexity of the model (Table 7). The same approach was taken for the comment types where Note Clarity and Drawing Clarity were combined to make one type.

Table 6. Models for statistical analysis.

Model	Equation				R^2
1	$Quant\ Value = 93{,}486.667 + b \times Quality\_Level$				0.481
		Low	Medium	High	
	b	-92,331.775	-71,928.761	0	
2	$Quant\ Value = 88{,}612.353 + b \times QualityLevel + 3.392 \times 10^{-12} \times e^{Number\ of\ Comments}$				0.541
		Low	Medium	High	
	b	-91,956.808	-72,741.147	0	
3	$Quant\ Value = 87{,}943.907 + b \times QualityLevel + 0.0067818494 \times (Number\ of\ Comments \times Constr\ Est)^2$				0.542
		Low	Medium	High	
	b	-91,613.982	-72,304.816	0	
4	$Quant\ Value = 108{,}101.091 + b \times QualityLevel + c \times e^{Number\ of\ Comments} + d \times Category\ Type$				0.602
		Low	Medium	High	
	b	-103,112.229	-77,172.621	0	
	c	2.971×10^{-12}			
		Design & Construction	Drainage & Pavement	Other	
	d	-12,653.322	-18,884.604	0	

Table 7. New comment category groups.

New	Original
Design & Construction	Coordination, Cross Section, Earthwork, Guardrail, Horizontal Alignment, Superelevation, Vertical Alignment, Easement , Part Width, Phasing, Seeding, Striping, Geotechnical
Drainage & Pavement	Existing Drainage, Permanent Drainage, Temporary Drainage, Pavement
Other	Environment, Guardrails, ROW, Survey, Structure, Signalization, MOT

The statistical analysis conducted here provides some indication that there is the potential for developing prediction models for estimating the benefit of the reviewed comments based on various attributes of the comment. The limited data used here allows for reasonably good fit models (R^2 0.602) inidctaing that there is indeed some relationship between the comments and their frequency and type and benefits. It should be noted though that there is a need for additional evalaution to further support these models. For now, Model 4 can be used cuatiously and as a general predictor for benefits due to the small number of cases used in its development. The use of the qualitative level in the models, even as a single predictor, indicates that this is a variable with a strong relationship to the estimated value. It should be pointed out that even though this could be cosnidered as a subjective variable, it was determined based on the nature and number of the comments. In addition, the determination of the qualitaty level requires additional review of the comments either by the reviewer or an independent party and this could be problematic and time consuming. As noted above, and even though the model proposed has a relatively high R^2 value, additional work is needed to ensure the accuracy of the assessment in the future and evalaute Model 4 and possibly include any other other significant predictors.

4. Conclusions and discussion

The newly developed Constructability Review database for KYTC has allowed for a systematic method of cataloging the results of the process, analyzing their findings, and yielding direct tools for design engineers to use on future projects. The database is currently in use and provides the reviewers with well-organized database entry where quick analyses and result summaries are available. Critical to such reviews is the documentation of benefits derived from the process and the need to conduct them on all projects. Agencies typically face funding problems and are attempting to address personnel shortages with selective reviews on specific projects. A quantification of the benefits of constructability reviews can provide the needed cost/benefit ratios proving that a larger pool of reviewers could result in greater benefits for the agency by reducing both cost and time of the projects delivered.

The case study analysis indicated that there is a benefit from the constructability reviews and that these benefits can frequently be quantified. The benefits accrued could be of low monetary amount (most comments resulted in less than $2,000 benefit) but there are other intangible benefits such as project delays and scope changes that could not be estimated from the available data. The qualitative analysis of the comments showed that there were few comments with a high severity but those are comments that result in high benefits.

The statistical analysis performed attempted to develop prediction models for the benefits accrued based on various attributes of the comments. One could argue that the low number of case studies and comments reviewed may not allow for a robust statistical analysis. However, the modles developed showed good fit and the propsoed model (Model 4) has a very good R^2 value (0.602). Therfore, this could be viewed as an indication that the available variables could predict the potential benefits from constructability reviews. Obviously, additional case studies and more comments would enhance these models and possibly allow for a more detailed evalaution of the impact of specific comment types on the review benefits. This would allow for the development of models based on comment type, category, severity and qualitative level and could also permit the use of other variables, such project type and cost that were not utilized here. The inclusion of these additional variables will also permit for a possible prioritization of constructability reviews among projects aiming to address first those projects that could have greater benefit potential. It should be noted though that the models developed here show the potential for such predictions and demonstrate an approach for estimating the benefits of the constructability reviews.

The work accomplished here is a major step toward the establishment and expansion of the constructability review process and documentation of its value to transportation agencies. The analysis conducted shows a small but significant benefit of 1.25 percent of savings for projects that were reviewed. Such efforts of documentation should be continued in the future. The development of a Constructability Review database is integral to this effort in order to create uniform data entry of constructability reviews. Such a database can provide the missing link in developing a process that could benefit DOTs and result in reduced project delivery times and costs. Anecdotal evidence indicates that the reviews conducted for KYTC not only provide budgetary benefits but also improve the quality of the constructed projects by defining missing components and correcting errors that could easily lead to increased time and cost for projects. Even though the models developed show promise and can predict the benefits from the reviews, additional work is needed to enhance them in order to create the confidence needed based on additional case studies to more accurately predict of benefits and savings from constructability reviews.

References

Anderson, S. and Fisher, D. (1997) “Constructability Review Process for Transportation Facilities Workbook, ”*NCHRP Report 390, Transportation Research Board.*, Washington D.C.

Gambatese, J., Pocock, J., & Phillip, D. (2007). “Constructability: Concepts and Practices." *American Society of Civil Engineers*, Reston, VA.

Kentucky Transportation Cabinet (KYTC). (2012). "Quality Assurance. " <http://transportation.ky.gov/highway-design/pages/quality-assurance.aspx>(January 31, 2014)

Stamatiadis, N., and Hartman, D. (2011). "Context-Sensitive Solutions Versus Practical Solutions: What Are the Differences?" *Transportation Research Record: Journal of the Transportation Research Board* , 173-180.

Stamatiadis, N., Sturgill, R., Goodrum, P., Shocklee, E.*, and Wang, C.* (2013) “Tools for Applying Constructability Concepts to Project Development (Design)-Final Report,” *Kentucky Transportation Research Center Report KTC-13-14*, College of Engineering, University of Kentucky, Lexington, KY.