THE DEVELOPMENT OF A PARAMETRIC DESIGN TIME ESTIMATING TOOL FOR PRETENSIONED PRESTRESSED CONCRETE BEAM BRIDGES IN IOWA

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ABSTRACT

This paper details the development of an estimating tool for predicting the design time/budget for Pretensioned Prestressed Concrete Beam (PPCB) bridges using historical design time data and regression analysis.

Preconstruction services and the estimation of design time costs are of increasing importance in an era of tight budgets and aggressive project delivery schedules. Traditionally, methodologies for estimating design time have been based on a percentage of bridge construction costs or an estimate based upon a detailed scope of work budget. The first method tends to be a crude approximation while the second method can be very time consuming. An alternative methodology was therefore sought that was efficient, accurate and data driven.

The Iowa DOT developed a data-based model that utilized 45 project designs from 2000 to 2015. Each project was evaluated for distinct parameters including number of spans, span arrangement, pier type, expansion joint type, skew, and construction staging. The parameters were coded into a database along with the design time. A model based upon regression analysis was then produced to predict the design time of future projects by entering the various parameters of the new project.

The result is the development of a tool that can rapidly estimate the design time required for new PPCB bridge projects for the State of Iowa.

Keywords: PPCB, Design Cost, Design Time

INTRODUCTION

From the fiscal years 2001 to 2014 the Iowa DOT has constructed on average twenty-six new or replacement Pretensioned Prestressed Concrete Beam (PPCB) bridges yearly on the primary roadway system. Design of new and replacement bridges are accomplished both by in-house final design services and by the use of consultant design services. Each year on average Iowa DOT in-house final design services produce twelve PPCB bridge designs while consultant design services average production of 13 PPCB bridge designs. A distribution of the designs is shown in Figure 1 – PPCB Designs per Fiscal Year by DOT and Consultant Designers. A spike in the number of designs in fiscal years 2001 and 2002 is attributed to a Iowa DOT effort to finish several corridor projects in the State of Iowa. Since that time the Iowa DOT has shifted focus of the state's investment in transportation to maintaining the current transportation system with less emphasis on new corridor development or capacity expansion.

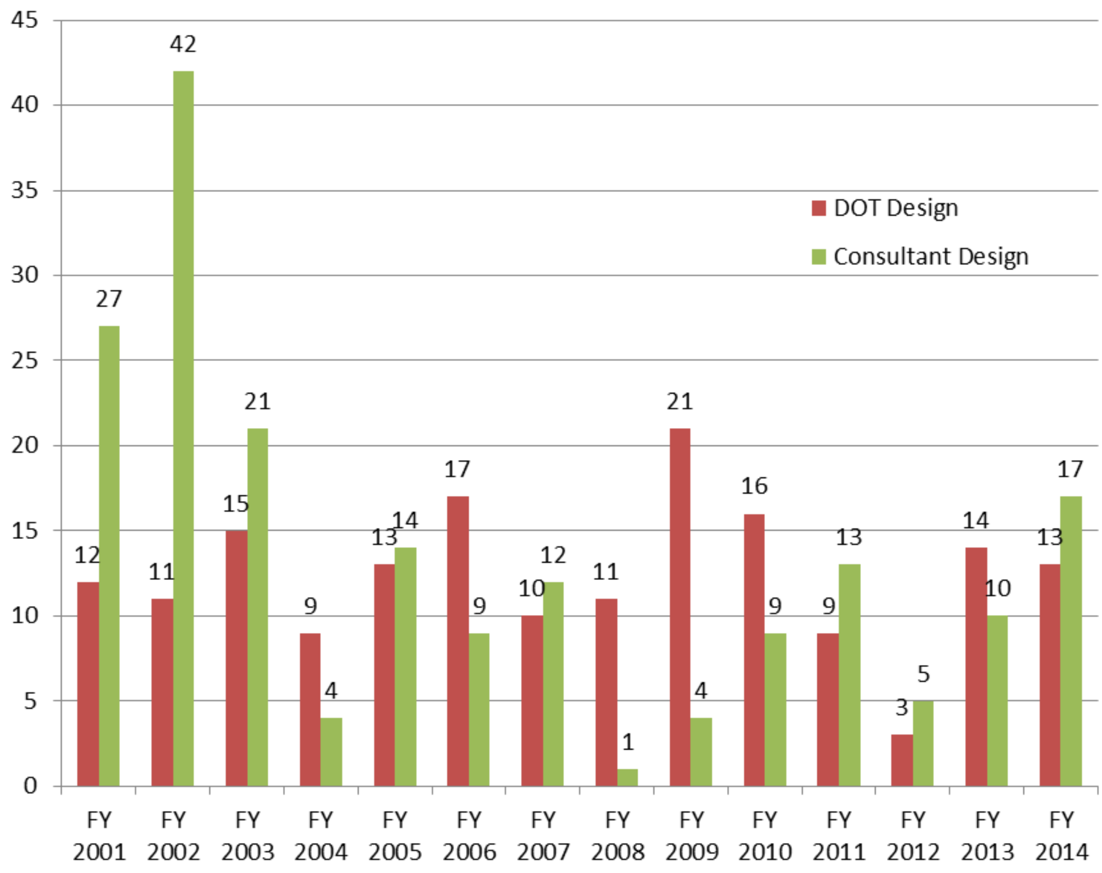

Figure 1 – PPCB Designs per Fiscal Year by DOT and Consultant Designers

PPCB bridges are by far the most prevalent type of bridge selected by the Iowa DOT for new and replacement bridges followed by steel bridges and then Continuous Concrete Slab (CCS) bridges. A breakdown of bridge type constructed per fiscal year is shown in Table 1 – Iowa Primary System New and Replacement Bridges by Type per Fiscal Year.

Table 1 – Iowa Primary System New and Replacement Bridges by Type per Fiscal Year.

	Bridge Type			
Fiscal Year	PPCB	CCS	Steel	Total
FY 2001	39	7	9	55
FY 2002	53	3	13	69
FY 2003	36	3	12	51
FY 2004	13	3	10	26
FY 2005	27	1	14	42
FY 2006	26	4	13	43
FY 2007	22	7	6	35
FY 2008	12	2	9	23
FY 2009	25	10	8	43
FY 2010	25	7	2	34
FY 2011	22	8	7	37
FY 2012	8	0	6	14
FY 2013	24	2	4	30
FY 2014	30	4	5	39
Total	362	61	118	541
Average	26	4	8	39

Following the financial crisis of 2007-2008 the state has had a significant reduction in force at the Iowa DOT. While engineering reductions were not as severe as other areas such as maintenance forces at the Iowa DOT, the size of the two final bridge design sections was reduced 14%. All the eliminated positions from final bridge design were engineers. Workload at the Iowa DOT has not decreased in a corresponding fashion and in fact increased temporarily due to the federal stimulus program called the American Recovery and Reinvestment Act of 2009 and a state transportation stimulus program in 2009 known as I-JOBS that was an infrastructure investment initiative intended to help strengthen the Iowa economy according to the Iowa DOT[1]. A longer-term increase in workload has just taken effect as the State of Iowa raised fuel taxes for the first time since 1983 with a 10 cent per gallon increase in state fuel tax effective March 1, 2015. The increase in revenue from the increase in fuel tax will be allocated to highway program spending and not to Iowa DOT operations. In fact, part of the new legislation requires to the Iowa DOT to further find an additional $10 million in operational efficiencies. There is also a national emphasis that on reducing project delivery timeframes for transportation customers that is likewise felt at the Iowa DOT. The pressure on the Iowa DOT to reduce operational expenses, and to reduce project delivery timeframes under a growing workload requires new and innovative business practices to streamline and be efficient.

Balancing workload for final bridge design between in-house design and consultant design to meet desired production schedules is a complex task. There are various factors contributing to the complexity including:

- Structures design projects with long work hour durations and a relatively linear critical path.
- A high volume of work with a small Iowa DOT management and engineering staff.
- The time it takes to formulate and execute a consultant contract for structural design work adds to the project development timeline.
- Dependency on predecessor deliverables such as preliminary engineering, geotechnical reports and environmental clearances.
- Unforeseen projects superseding planned work such as bridges damaged by over-height loads and earth slide repairs.
- Limited accuracy of work effort estimates for design.

The Iowa DOT Office of Bridges and Structures evaluates every design that is necessary to produce using a work hour estimate to resource level in-house design. Averaging over 150 designs each year including bridges, reinforced concrete box culverts, contracted bridge repairs, sign support structures and other miscellaneous structures the Iowa DOT Office of Bridges and Structures needs an efficient method of estimating work hours required to complete projects. See Figure 2 – Designs per Fiscal Year by DOT and Consultant Designers for a breakdown of designs by consultant and Iowa DOT designers per fiscal year and the total amount of designs.

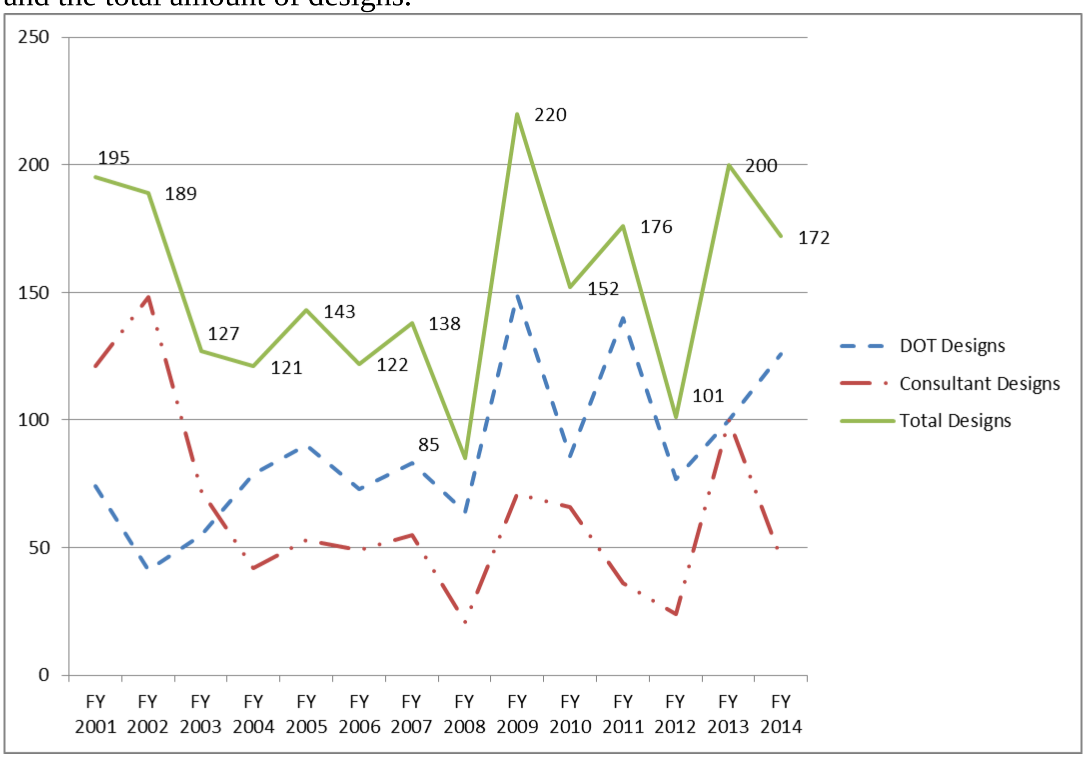

Figure 2 – Designs per Fiscal Year by DOT and Consultant Designers.

There are two typical methods for estimating work effort needed for final bridge and structure design. One method is to use a percentage of the estimated construction budget to estimate the work effort required. A second method is to prepare a detailed work break down structure for a project and estimate hours of effort necessary for each task.

Developing an estimate of design time from a construction cost estimate of the structure is a fairly risky proposition. There are several shortcomings to this methodology. The first is the fact that the design time estimate is based on a construction cost estimate. This amounts to heaping uncertainty upon uncertainty. Complexity of a project typically will drive design cost but there are many factors that drive construction cost that clearly have no correlation to project complexity such as timing of the letting, local and national economic conditions, materials and energy cost at the time of the letting, contractor bonding capacity and availability of contractors to bid the work. Larger project size in terms of a construction cost estimate tends to drive down the percentage of design cost allocated to the project. Use of a consistent percentage of the construction cost to estimate the design costs can lead to an over estimation of design cost on large construction cost projects. However, on small construction cost projects there is a risk of greatly underestimating the design costs that can be a large percentage of the small construction cost projects. General guidelines have existed in the industry for very rough estimates of the percentages to use in relation to construction costs estimates. Finally the design cost needs to be converted to a work hour effort estimate which is dependent on the skills, qualifications and ultimately the hourly compensation of the staff selected to complete the project.

A detailed scope and work hour budget breakdown is a much better approach to estimating design time on a specific structural design project. However it is not practical or even possible with the amount of in-house Iowa DOT management time that would need to be dedicated to that type of effort. Projects that utilize consultants for design have a detailed scope, work break down structure and estimate of hours for each task prepared by the consultant project manager. The Iowa DOT does not have a corresponding project manager available to independently prepare a detailed scope, work break down structure and estimate of hours and thus evaluates the consultant proposal by comparison to similar historical project data. With a wealth of historical project data available to Iowa DOT engineers, an alternative parametric data driven methodology was sought to quickly estimate design hours estimates.

A DATA DRIVEN APPROACH

The Iowa DOT has consistently collected a significant amount of data about projects for various business purposes. Personnel timesheet data is collected on a project number and design number basis and coded to function codes. Function codes indicate the type of work being undertaken such as preliminary design, final design, construction administration and so on. The function code list is exhaustive. Design numbers are only used by the Iowa DOT Office of Bridges and Structures and a unique number is assigned to a single structure. For example, on a corridor grading and paving project there may several reinforced concrete box culverts that would each be assigned a unique design number but let together under one project number. The design number concept allows the Iowa DOT to isolate a very specific structure from a data tracking standpoint with a unique identifier. Time spent on final design is charged on a design number basis allowing individual tracking of the design time spent on a specific structure. While this personnel timesheet data has been collected since before 1999, only recently in 2010 a custom query was created to allow managers to efficiently access reports of time charged to design numbers.

The Office of Bridges and Structures maintains a detailed database called PC-Bridge Information System (PC-BRIS) regarding the specific aspects of each design number (structure). There are a total of 94 data fields in the database to identify specific characteristics of the work undertaken. For a PPCB bridge the most important data fields include the geometrical properties of the structure such as length, width, skew, number of spans, number of beams in the cross section, and curve information. Additional characteristics defined include abutment type, abutment foundation type, pier type, expansion joint type, and beam type. The database also tracks the design methodology such as Standard Specification versus the LRFD Specification. The primary purpose of the PC-BRIS database has traditionally been twofold. First, the database helps designers locate projects with similar characteristics in order to save design and detailing time by adapting and reusing details when appropriate. Second, the PC-BRIS database allows for an efficient method to answer data type questions that occasionally are posed to the Office of Bridges and Structures, for example, "how many designs let in 2015 used a 120 foot Bulb Tee C Beam?"

A concept was developed to approach design time estimating using historical data in a more refined approach than simply looking for comparable projects and using the durations of the comparable projects for future estimates. The concept developed was to use regression analysis to evaluate the relationship between a dependent variable and several independent variables (parameters or project characteristics). The dependent variable in this case is the final design time estimate and the independent variables are the characteristics of the PPCB bridge. The first challenge in the task was to identify the characteristics of the PPCB bridge that drive the design time required.

DESIGN TIME PARAMETERS

The Iowa DOT maintains a significant collection of bridge standards in order to efficiently implement the highway program. Many of the standards are used in local systems projects by County and City engineers but they may also be used both by DOT engineers and consulting engineers designing projects on the primary system. One of the important characteristics of the design was thought to be how extensive the use of standards was in the design. Standards generally can be characterized as either working standards or signed standards. Working standards are plan sheets that are substantially prepared but require some engineering and information to be updated on the plan sheet in order to include them in a plan for letting. Signed standards are standards that are complete and can be called for in a design without modification. Signed standards are simply listed on the title sheet of the plans for letting and the contractor obtains them through the Iowa DOT Electronic Reference Library (ERL).

PPCB bridge designs for the primary system typically do not use signed standards but may consist of many working standards depending on the project. The Iowa DOT has working standards for PPCB shown in the Iowa DOT LRFD Bridge Design Manual[2] and summarized in Table 2 – Standard I and Bulb Tee PPCB for HL-93 Loading.

Table 2 – Standard I and Bulb Tee PPCB for HL-93 Loading .

Beam Shape	Span Range, feet	Depth, inches	Maximum Spacing, feet
A	30.00 to 55.00	32	7.5
B	34.17 to 67.50	39	7.5
C	30.00 to 80.00	45	7.5
D	35.00 to 110.00	54	7.5
BTB	30.00 to 105.00	36	9.25
BTC	30.00 to 120.00	45	9.25
BTD	50.00 to 135.00	54	9.25
BTE	60.00 to 155.00	63	9.25

At the initial development of the parametric design time estimating tool the characteristic of a standard versus non-standard bridge was approached indirectly through span arrangement. At the Iowa DOT typically a standardized bridge design been considered as a three span bridge as this is the most common bridge superstructure arrangement. For the coding in the database PPCB bridges were identified as 3 span, less than 3 spans and greater than three spans. An additional question was asked with respect to span arrangement as standard or not standard. A standard span arrangement for a PPCB bridge would be a symmetrical bridge with end spans of 80% to 90% of the center span.

Additional characteristics thought to contribute to design time were pier type, expansion joint type, skew and construction staging. Skew and construction staging was indicated either as being present on the design or not being present. There were several options to select from for pier type including pile bent pier, frame pier, tee pier and no pier. Expansion joint had three options given to select from that it was thought may contribute to variations in design time. Those options were integral (no joint), finger joints and strip seals. A screen shot from the data input form is shown in Figure 3 – PPCB Data Input Fields.

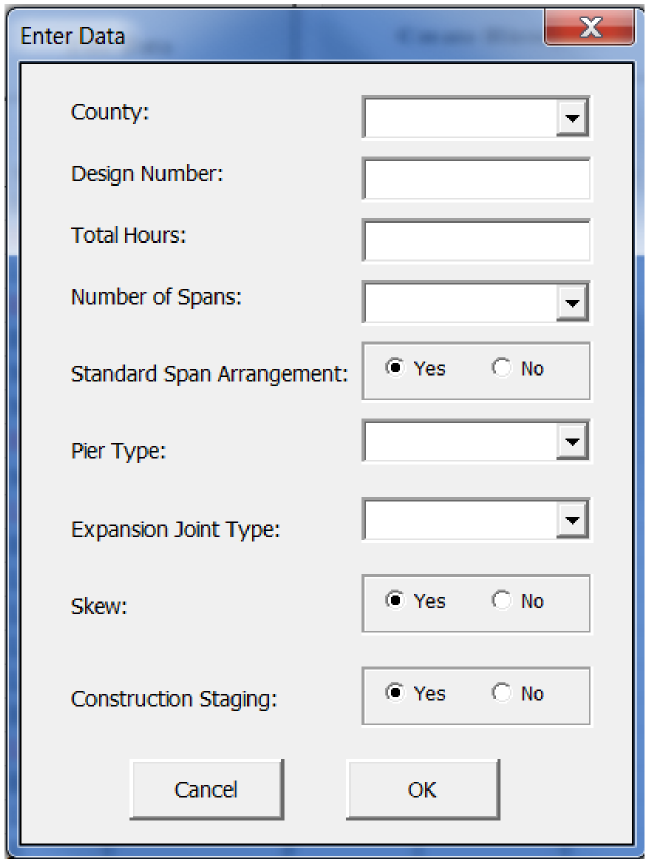

Figure 3 – PPCB Data Input Fields

With a collection of 45 PPCB design projects developed by Iowa DOT Final Design Section 2 entered into the database regression analysis could be conducted. Quickly it was learned an option for eliminating data points from the regression analysis had to be added. Some project data for various reasons was abnormal and should not be considered. For example, one design excluded from the regression analysis was designed and detailed in-house by the Iowa DOT but the plan checking was contracted out to a consultant so the project contained no hours for the design check. Of the 45 projects in the database six were excluded from the regression analysis after being determined to be abnormal for one reason or another.

REGRESSION ANALYSIS

Once the data had been collected and outliers eliminated, the regression analysis was conducted. It is beyond the scope of this paper to discuss the inner workings of regression analysis as ample material on the matter is available. However, to put things in perspective, a loose but informative analogy is to imagine strategically placing a bucket to catch a ball after it has traversed an unknown trajectory. In order to know where to place the bucket, certain parameters might be considered: angle of incline, initial velocity, etc. If historical observations of the landing locations are made, regression analysis can be employed to determine the bucket size and location required to catch the ball.

In the case of preconstruction services, the location of the bucket is analogous to the final design time prediction while the bucket's size is analogous to the time range over which that prediction is valid. More uncertainty in the data would warrant a larger bucket. The same is true of the percentage of time one would aim to catch the ball. For this analysis, the 95% confidence interval was used. That is to say that based on the sample data, one can be 95% sure that any given confidence interval of design time will indeed contain the true population average, or "catch the ball".

In short, the overall purpose of performing a regression analysis is to create a model that will estimate a dependent variable (the response) from one or more independent variables (the predictors). This model comes in the form of Eq. (1) below. On the left side of this equation is Y which is the response variable – design time. The right side of the equation comprises three basic components: the intercept denoted by the variable "a", the coefficients or "b" terms, and the X-scores which are the "X" terms. Both the intercept and coefficients are determined from the data while the X-scores are user inputs that allow for future prediction.

$$Y = a + b_1 X_1 + b_2 X_2 + \cdots \tag{1}$$

Every regression analysis will contain a single intercept. The intercept represents the value of the response variable if all predictor variables are set to 0. The amount of additional terms is dictated by the number of predictors analyzed. These terms are used to introduce the change in response imposed by each predictor. The coefficients represent an incremental change in response for each increment in X. Since the data for the design time predictions are exclusively binary, i.e. a bridge is either skewed or not skewed, the X-scores for this analysis are always zero or one. One, for example, might indicate a bridge with skew while zero would indicate a bridge without skew.

Before delving into the results of the analysis, it is informative to first make observations with respect to the data set in question (Appendix A). A histogram of design time for all 39 PPCB bridges considered in the analysis is shown in Figure 4. Six additional projects were excluded from the analysis as explained in Appendix A. The data show a significant deviation at the 500-750 hour bin range from what would otherwise be a skewed-right bell distribution. A similar but less extreme example of this also occurs at the 1000-1250 hour bin range. These seemingly sporadic increases in bin frequency may be a result of the fact that the predictors are not all entirely random. For example, the Iowa DOT has found that integral abutments minimize construction and maintenance costs and therefore are preferred over incorporating expansion joints into the bridge. Therefore one can expect to see more bridges with integral abutments than without in Iowa. If it is determined that the incorporation of expansion joints significantly impacts the time it takes to design a PPCB structure, one could expect to observe "pockets" of data as seen here.

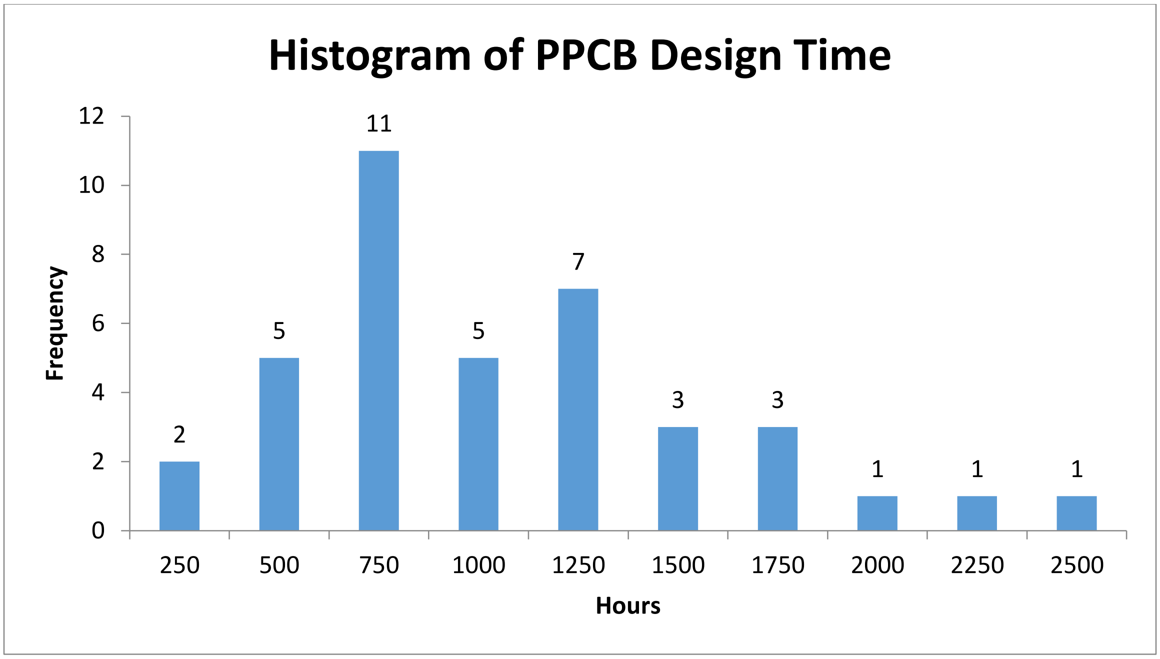

Figure 4 – Skewed-right histogram showing design time for all 39 PPCB Bridges considered in the regression analysis. Six projects were excluded from consideration (See Appendix A).

Table 3 below outlines the frequency of observations for each predictor considered in the regression analysis. Finger jointed and strip seal expansion joints were observed in 2 and 3 bridges of 39, respectively. A larger data set with more observations of this kind would be ideal in future generations of the design time prediction tool.

Table 3 – Shows the frequency of observations for each predictor considered in the regression analysis. Six projects were excluded from consideration (See Appendix A).

Predictor		Observations	Percentage of Total
Number of Spans	3	16	41%
	Less than 3	14	36%
	More than 3	9	23%
Standard Span Arrangement	Standard	11	28%
	Non-Standard	28	72%
Pier Type	Frame	12	31%
	Pile-Bent	4	10%
	Tee	16	41%
	No Pier	7	18%
Expansion Joint Type	Integral	31	79%
	Finger Jointed	2	5%
	Strip Seal	3	8%
Skew	Skew	31	79%

	No Skew	8	21%
Construction Staging	Construction Staging	6	15%
	No Construction Staging	33	85%

The initial regression analysis resulted in a relatively weak correlation coefficient (Multiple R) of 75% as shown in Table 4 below. Many analyses of this sort aim for a correlation coefficient closer to 95%. Also shown in the table are the coefficients of each predictor and their corresponding probability values. Probability values are important in regression analysis because they indicate the strength of any given predictor in the model. A low probability value would suggest that a change in the predictor would yield a change in response.

Table 4 – Initial results of the PPCB Bridge design time regression analysis, n = 39. Six projects were excluded from the analysis (See Appendix A).

Predictor	Coefficient, hours	Probability Value
Intercept	263	0.36
Less than 3 Spans	83	0.75
More than 3 Spans	107	0.67
Non-Standard Span Arrangement	-37	0.85
Frame Pier	896	0.00
Pile-Bent Pier	472	0.18
T-Pier	572	0.06
Finger Jointed Expansion Joint	1017	0.01
Strip Seal Expansion Joint	534	0.06
Skew	-126	0.49
Construction Staging	627	0.01
	Multiple R	75%

It is common in regression analysis to use probability values to determine which terms to keep in the model and which to discard. Naturally, the inclusion of a weak predictor in the model could significantly deteriorate the model's accuracy and utility. In order to accomplish the removal, one must first choose a significance value α which acts as a threshold for removing terms. If any of the probability values determined in the analysis exceed the significance value, the worst offender is removed first and the analysis is repeated. This process is iterated until all remaining terms have a probability value lower than the threshold.

The resulting regression after removing terms at the 0.05 significance level is shown in Table 5. The final model corresponding to this regression is shown in Eq. (2). Variables removed from the analysis included number of spans, standard span arrangement, pile-bent pier, and skew. After removing these terms, the correlation coefficient for the final regression model actually decreased slightly to a value of 72%. It is likely that the initial model was assigning values to these weak variables to make for more overall correlation. Incorporating these variables, however, would be an artificial means of increasing the model's correlation and would negatively impact the accuracy of the final model.

Table 5 – Final results of the PPCB Bridge design time regression analysis, n = 39. Six projects were excluded from the analysis (See Appendix A). Number of spans, standard span arrangement, pile-bent pier and skew were not considered due to their inadequate probability values (See Table 3).

Predictor	Coefficient, hours	Probability Value
Intercept	394	0.00
Frame Pier	685	0.00
T-Pier	382	0.02
Finger Jointed Expansion Joint	1020	0.00
Strip Seal Expansion Joint	536	0.03
Construction Staging	547	0.01
	Multiple R	72%

$$Y = 394 + 685X_1 + 382X_2 + 1020X_3 + 536X_4 + 547X_5 \qquad (2)$$

The model's need for refinement becomes clear when one considers the individual coefficients produced from this output. It is unlikely for example that the design of a frame pier alone would add 685 hours of design time to a project. There are probably other factors contributing to this design time increase. Identification and inclusion of these additional factors will be key in the future accuracy of the design time estimation tool. In addition, there is a relative lack of data for the amount of predictors considered in this analysis. A larger data set could also considerably strengthen the final model.

In fact, it is the current lack of data that largely forms the basis for the need of a design time estimation tool of this sort. All of the analysis discussed in this section can be performed quickly and easily within the tool following the addition of future data. For instance the regression analysis is executed by simply clicking a button and choosing which parameters should be considered. A screenshot of the regression analysis dialog is shown in Figure 5. Once the analysis is complete, the user is prompted to run the analysis again with different parameters. Just as before, this process may be repeated until the user is satisfied with the model.

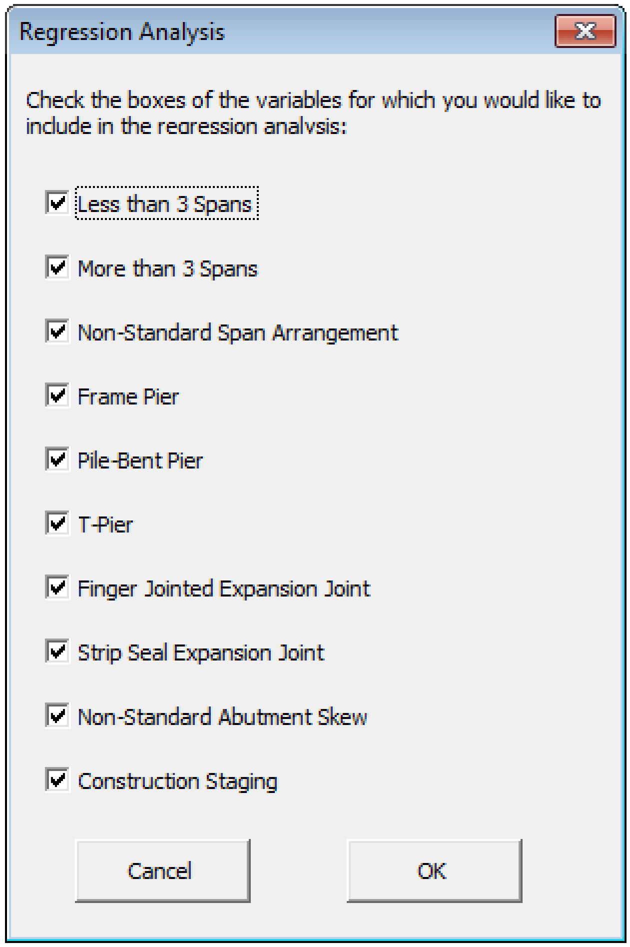

Figure 5 – Dialog for the regression analysis command

One last feature included in the design time estimation tool is the ability to make future predictions based on user inputs and a previously executed regression analysis. This feature provides an overall design time estimate along with a 95% confidence interval for the estimate. A screen shot of the estimation tool input screen is shown in Figure 6 while an example output can be found in Table 6.

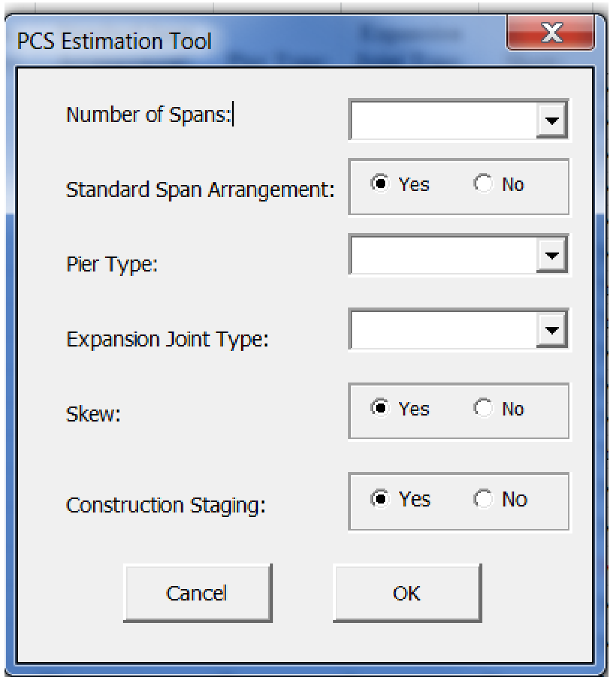

Figure 6 – Data input dialog for the design time estimation tool.

Table 6 – Example time prediction from the design time estimation tool.

Expected Value	Lower 95% Estimate	Upper 95% Estimate
2650 hrs.	1860 hrs.	3430 hrs.

FUTURE WORK AND LIMITATIONS

The initial database only contains data from one Iowa DOT Final Design Section over a fifteen year period which is a limited data pool. Additional work should be done to add the second Iowa DOT final design section data to the database. In addition, consultant data for PPCB bridges should be added to the database. A characteristic to indicate whether the project was consultant design or design in-house could be added to the characteristics of the PPCB bridge design for the regression analysis.

The parametric design time estimating tool for PPCB bridges in Iowa was based on initial assumptions on the characteristics that contributed in a significant way to design time needed for a project. Since the initial development some additional characteristics have been identified that can contribute significantly to design time and should be further evaluated for inclusion in the data. New characteristics to consider include bridge aesthetics, deep foundation type (e.g. drilled shafts, driven piling), accelerated bridge construction techniques, deck area, and barrier rail type. The list of additional characteristics to be considered is not an exhaustive list but is a starting point for future development.

One of the concerns about development of a tool like the parametric design time estimating tool for PPCB bridges in Iowa is that there are factors that the tool does not take into account such as individual engineer and technician experience, changes in design specification requirements that impact design time, changes in design technology and software or possibly even changes in the design result deliverables. Some of these concerns that are limitations of the tool will likely never be addressed such as individual engineer and technician experience where others will require adaptation of the tool over time and an effort to keep the data fresh and relevant. For example, the Iowa DOT is just beginning an investigation into providing 3D structural design plans to contractors. Depending on the outcome of the investigation there could be a radical change in the way plans are delivered with a yet to be determined effect on the design time required to produce those new plans. It would be hard to use the existing data to predict design times for future projects and the database would likely need to add a new 3D characteristic and build a new relevant data set over time in order to be useful.

Preliminary work has been done to expand the parametric design time estimating tool into other types of Iowa DOT structures projects such as continuous concrete slab bridges, reinforced concrete box culverts and retrofit barrier rails. Rapid parametric estimation tools for additional project types will increase the Iowa DOT's ability to effectively resource level and assign work.

CONCLUSION

The parametric design time estimating tool for PPCB bridges in Iowa has been demonstrated to be a feasible tool for rapidly providing estimates of design time with confidence levels. The quality of the design time estimates will be dependent on continued refinement of the parameters and enlarging the data set in the database. The design time estimation tool needs to be adaptable in the future in order to remain relevant as changes occur in the design process and even potentially in the design deliverables.

ACKNOWLEDGEMENTS

The authors would like to thank Ronald J. Meyer, P.E. Iowa DOT Office of Bridges and Structures, Consultant Coordinator for access to compiled data regarding all Iowa DOT bridges and projects produced from fiscal years 2001 to 2014.

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2. Iowa Department of Transportation, Office of Bridges and Structures. LRFD Bridge Design Manual, 2015.

Appendix A – Iowa DOT PPCB Bridge Data (2001-2015 Final Design Section 2)

County	Design #	Total Hours	Num. Spans	Std. Spans	Pier Type	Expansion Joint Type	Skew	Staging
Benton	106	603.1	3	No	Pile Bent	Int. Abut.	Yes	No
Black Hawk	111	1901.7	3	No	Tee Pier	Int. Abut.	No	Yes
Black Hawk	215	819.5	>3	No	Tee Pier	Int. Abut.	Yes	No
Buchanan	113	*225	3	Yes	Pile Bent	Int. Abut.	Yes	No
Cass	113	628.7	<3	No	No Pier	Int. Abut.	Yes	Yes
Cass	408	*1565.1	3	Yes	Tee Pier	Strip Seal	Yes	No
Cass	508	609.2	3	No	Tee Pier	Int. Abut.	Yes	No
Cedar	105	2368.2	>3	No	Tee Pier	Frame Pier	Yes	No
Cedar	205	1222.7	>3	No	Tee Pier	Frame Pier	Yes	No
Chickasaw	102	*66	3	No	Pile Bent	Int. Abut.	Yes	No
Clay	109	1727.5	>3	No	Tee Pier	Strip Seal	Yes	No
Des Moines	302	*3	<3	Yes	No Pier	Int. Abut.	Yes	No
Jefferson	309	320.7	3	Yes	Pile Bent	Int. Abut.	Yes	No
Jefferson	603	521.5	<3	Yes	No Pier	Int. Abut.	Yes	No
Jefferson	706	1027.3	<3	No	Frame Pier	Int. Abut.	Yes	No
Lee	110	590.4	<3	No	No Pier	Int. Abut.	Yes	No
Lee	210	1244.3	<3	No	Frame Pier	Int. Abut.	Yes	No
Lee	810	1157.1	3	No	Frame Pier	Int. Abut.	Yes	No
Lee	2210	*590	<3	No	No Pier	Int. Abut.	Yes	No
Lucas	102	959.2	3	Yes	Pile Bent	Int. Abut.	Yes	No
Mahaska	306	385	<3	No	No Pier	Int. Abut.	No	Yes
Mills	108	696.1	3	Yes	Frame Pier	Int. Abut.	Yes	No
Mills	208	1044.5	>3	No	Tee Pier	Strip Seal	Yes	No
O'Brien	303	1386.1	<3	No	Frame Pier	Int. Abut.	Yes	No
Osceola	505	1003.7	<3	No	Frame Pier	Int. Abut.	Yes	No

* Project not included in analysis. See Table of Outliers below for comments

County	Design #	Total Hours	Num. Spans	Std. Spans	Pier Type	Expansion Joint Type	Skew	Staging
Plymouth	504	1653.1	3	Yes	Frame Pier	Int. Abut.	Yes	No
Plymouth	604	1463.6	<3	No	Frame Pier	Strip Seal	Yes	No
Polk	205	512	<3	No	No Pier	Int. Abut.	No	No
Polk	1010	757.5	<3	No	Frame Pier	Int. Abut.	Yes	No
Pottawattamie	109	1123.2	3	Yes	Tee Pier	Int. Abut.	No	No
Pottawattamie	113	2035	>3	No	Tee Pier	Int. Abut.	Yes	Yes
Pottawattamie	114	1345.2	>3	No	Tee Pier	Int. Abut.	Yes	Yes
Pottawattamie	209	875	<3	No	Tee Pier	Int. Abut.	Yes	No
Sac	113	611.2	3	No	Tee Pier	Int. Abut.	No	No
Sac	610	635.8	3	Yes	Frame Pier	Int. Abut.	No	No
Scott	514	490.8	<3	No	No Pier	Int. Abut.	Yes	Yes
Tama	101	203.1	>3	No	Tee Pier	Int. Abut.	Yes	No
Tama	108	1540.4	3	Yes	Frame Pier	Int. Abut.	No	No
Van Buren	106	*3530.5	>3	N	Tee Pier	Strip Seal	Yes	No
Wapello	106	479.5	3	Yes	Tee Pier	Int. Abut.	Yes	No
Wapello	116	236.8	3	Yes	Tee Pier	Int. Abut.	Yes	No
Warren	114	550.9	3	No	Tee Pier	Int. Abut.	Yes	No
Warren	312	917.7	>3	No	Frame Pier	Int. Abut.	Yes	No
Washington	110	641	3	Yes	Pile Bent	Int. Abut.	No	No
Worth	301	317	<3	No	No Pier	Int. Abut.	Yes	No

* Project not included in analysis. See Table of Outliers below for comments

TABLE OF OUTLIERS

County	Design #	Comments:
Buchanan	113	No hours billed to design check
Cass	408	Multi-discipline project
Chickasaw	102	Unreasonable design time (outlier)
Des Moines	302	Unreasonable design time (outlier)
Lee	2210	Replica of Lee 110
Van Buren	106	Unreasonable design time (outlier)