Updating the Bridge Construction Cost Database

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Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Research Report

KTC-22-12/SPR21-606-1F

Updating the Bridge Construction Cost Database

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Adopting a comprehensive suite of methods to track, analyze, and maintain data on bridge construction costs can help state transportation agencies identify and implement strategies to mitigate the influence of factors which escalate project costs. This report discusses how the Kentucky Transportation Cabinet (KYTC) should approach updating, maintaining, and analyzing its bridge construction cost data. Based on a review of practices introduced at other agencies and interviews with public and private industry stakeholders, the report catalogues practical strategies for improving estimating procedures and tracking cost data as well as the most important cost drivers of bridge construction. Analysis of KYTC data on average unit bid prices for eight key bid items on bridge projects found that prices went up for every item between 2015 and 2021. Steel reinforcement and epoxy coated steel reinforcement displayed the most consistent linear upward trend, while greater variability was noticeable in prices for Class A and AA concrete and foundation preparation. This analysis substantiated observations by interviewees that contractors submit higher bid prices when they perceive greater risk associated with a work item. Recommendations for process improvements at the Cabinet focus on agencywide rollout of AASHTOWare Estimation, conducting post-construction reviews, establishing contract durations that reasonably accommodate the completion of all work, and performing more in-depth geotechnical investigations.</td></tr>
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Executive Summary

Although the Kentucky Transportation Cabinet (KYTC) tracks bridge construction costs, it needs a more systematic approach to data collection and analysis as well as an updated database solution. This report lays out strategies KYTC can implement to update cost data, modernize database throughput, identify cost anomalies, and analyze price variability. These strategies were developed through a review of practices used at other state departments of transportation (Ohio, Iowa, Florida, Virginia) and applications for developing cost estimates and tracking cost data (e.g., AASHTOWare TRACER and Project Estimation). Several agencies rely on proprietary applications, which often take the form of Excel-based tools and web-based apps. A thorough review of factors that impact bridge construction costs is also presented (see p. 16).

To catalogue cost drivers on bridge construction projects, researchers interviewed stakeholders in the contracting industry, KYTC staff members from district offices and the Central Office, and assistant state bridge engineers in Missouri and Pennsylvania. Table E1 lists important cost drivers interviewees spoke of and indicates whether they increase or decrease construction costs.

Table E1 Cost Drivers and Impacts on Construction Costs

Cost Driver	Impact on Cost
Compressed project schedule requirements	Increase
Insufficient work area (i.e., lay down area, staging area) for contractor materials and equipment	Increase
Standardization of structure design components	Decrease
Contract documents and design inconsistencies or contradictions	Increase
Insufficient or inappropriate bid items for contract work — overuse of incidental work items	Increase
Optimize span length to minimize need for cofferdams and dewatering	Decrease
Complicated traffic management requirements and work phasing (e.g., partial width construction of structures)	Increase
Consistent overall volume of bridge construction work let per year	Decrease
Unanticipated geotechnical site conditions	Increase

Using KYTC data from2015 through 2021, researchers analyzed variability in average unit bid prices (AUBPs) for eight critical bid items to detect key trends and evaluate concepts interviewees discussed. Prices for all items increased over the study period, with steel reinforcement and epoxy coated steel reinforcement exhibiting the most statistically robust upward linear trends. Although prices for Class A and AA Concrete rose as well, trendlines were not as linear as those for reinforcement steel. Foundation Preparation is the bid item that displayed the most volatility. Evaluation of AUBPs validated the contention of interviewees that contractors submit higher bids when there is more perceived risk associated with a particular work item. Analysis also identified items which account for the most expensive changes post-award — included among these are structural steel, concrete, structure removal, foundation, and predrilling for piles.

Based on the review of approaches used in other states, perspectives offered by interviewees, and analysis of the Cabinet's AUBPs for key bid items, researchers developed short- and long-term recommendations for improving bridge cost estimates, mitigating the effects of key cost drivers, and strengthening the bridge construction process.

Chapter 1 Introduction and Background

Historically, the Kentucky Transportation Cabinet (KYTC) has tracked, compiled, and reported bridge construction costs by reviewing construction letting results. But a more systematic approach and comprehensive database are needed. This project sought to improve the Cabinet's ability to monitor and apply bridge construction cost information by (1) updating cost data, (2) modernizing database entry and data mining tools, (3) identifying and explaining outlier costs and spikes in pricing, and (4) investigating what factors and relationships influence price fluctuations. KYTC staff can use the tools developed as part of this research to improve bridge construction estimates and find savings opportunities.

Division of Structural Design personnel need bridge construction cost data to support multiple processes and bridge cost estimates at different stages of asset management. For example, they prepare conceptual estimates that inform decisions made by project managers (PMs). As each bridge construction project progresses through project development, estimates are gradually refined, eventually including fine-grained data on individual work items. For KYTC Division of Structural Design staff, however, bridge construction cost tracking does not end when the contractor breaks ground. They also compile construction cost and project summary data each year and report this information to the Federal Highway Administration (FHWA).

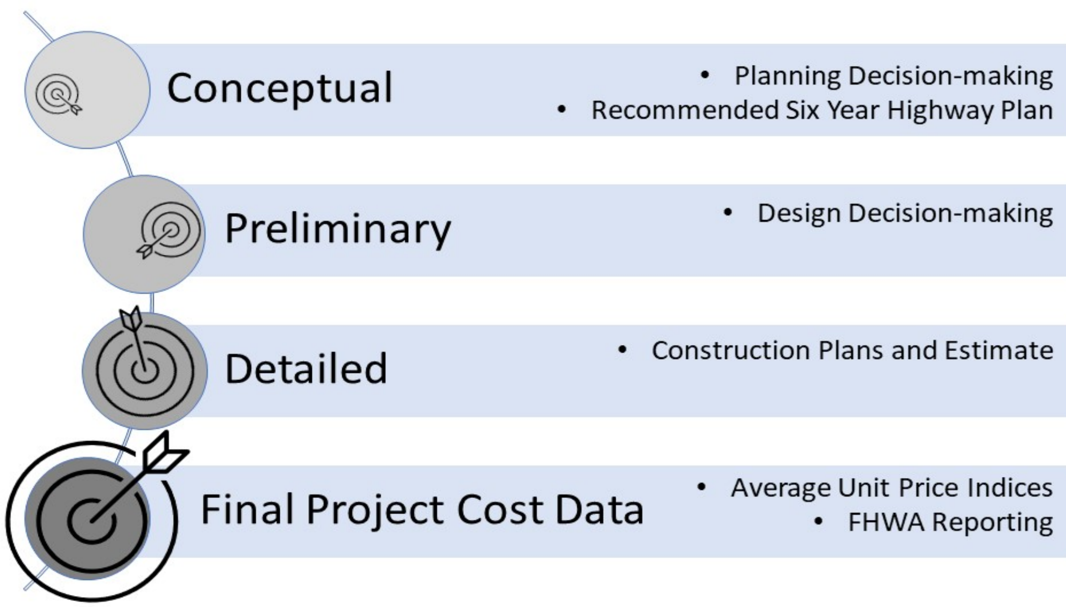

Figure 1.1 Stages and Degrees of Accuracy for Bridge Construction Cost Estimates

This report offers practical solutions KYTC can adopt to track, analyze, and maintain data on bridge construction costs, and to identify and implement strategies to mitigate the influence of factors which escalate project costs. Table 1.1 summarizes the report's contents.

Table 1.1 Report Structure

Chapter	Content
2	• Reviews estimation tools used at other state DOTs

Chapter	Content
	• Discusses software applications for compiling, updating, and analyzing bid data
3	• Summarizes KYTC's current approach to estimating bridge construction expenses
4	• Presents findings from interviews with private and public sector industry stakeholders • Identifies bridge construction cost drivers and provides recommendations for mitigating key risks
5	• Analyzes average unit bid prices for eight bridge construction
6	• Offers recommendations for improving KYTC's approach to estimating bridge project costs, maintaining cost data, and mitigating the effects of cost drivers

Chapter 2 Literature Review and Other State Practices

2.1 Conceptual Bridge Cost Estimating Tools and Data Requirements

Engineers typically prepare conceptual estimates with very little scoping or design information. Estimates can be prompted by foreseeable deterioration in bridge conditions or driven by regional development, political actions, or corridor projects. Conceptual estimates include significant contingencies to cover known and unknown risks. Many state departments of transportation (DOTs) develop conceptual estimates using data on anticipated bridge deck area, historical costs, and very limited design information (e.g., structural type, number of spans).

Ohio DOT Conceptual Estimating Tool

The Ohio DOT uses an Excel-based workbook tool to prepare conceptual and preliminary budget estimates for agency projects (Ohio Department of Transportation, 2013). In the *Structures* tab, the workbook provides item costs per square foot for different bridge projects (e.g., new bridges, rehabilitation, removal). Figure 2.1 shows the new bridge portion of the *Structures* tab. It lets users estimate the cost of constructing a new bridge based on bridge deck area, number of spans, and bridge size range.[1]

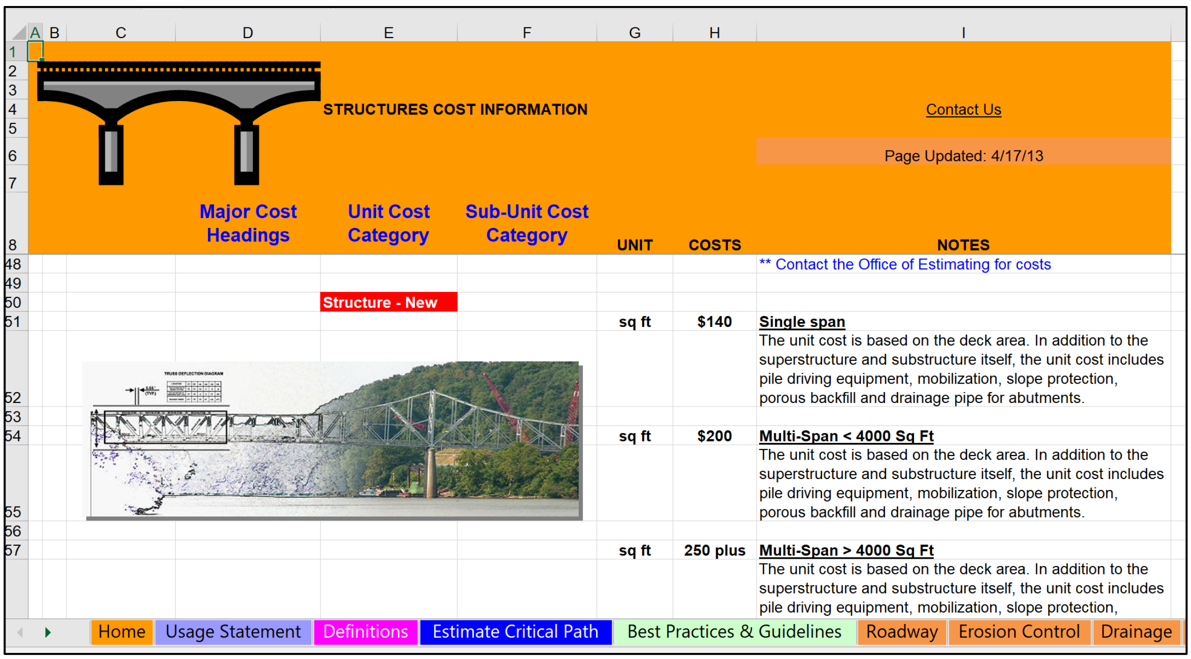

Figure 2.1 Ohio DOT's Conceptual Cost Estimating Tool

Iowa DOT Typical Bridge Costs

Iowa DOT's *Bridge Design Manual* has a table of that lists costs per square foot for items used on for typical bridges (Table 2.1). Estimates based on unit prices are adjusted according to complexity, staging, and other applicable costs using the amounts listed in the table (Iowa Department of Transportation, 2017). Contingencies are estimated as a percentage of total cost. Percentages are determined based on the planning/design stage:

- B0, Bridges and Structures Bureau concept, 20%
- B1, Bridges and Structures Bureau layout, 15%
- B2, structural/hydraulic design plans to Design Bureau, 5%

[1] The Excel workbook is available at: http://www.dot.state.oh.us/Divisions/ConstructionMgt/Estimating/Item%20Master%20Bid%20History%20List%20Links/May%202013%20ODOT%20Procedures%20for%20Estimating.xls

- D0, predesign concept, 15%
- D2, design field exam, 15%

Table 2.1 Iowa DOT Preliminary Costs for Typical Iowa Bridges

Cost Item	Unit Cost
New continuous concrete slab (CCS) bridge	$90/ft^2$
New pretensioned prestressed concrete beam (PPCB) bridge	$100/ft^2$
New bulb tee (BT) bridge	$105/ft^2$
New rolled steel beam three-span standard bridge	$105/ft^2$
New continuous welded plate girder (CWPG) bridge	$130ft^2$
Complex bridges: variable width, urban area such as De Moines, construction over traffic	Add $5/ft^2$ for each item
Staged bridges	Add 10%
Cofferdam for pier construction	$25,000/pier
Detour bridge 40-foot span, 3 panel 32-foot width	$40,000/span
Bridge removal	$7.00/ft^2$
Bridge widening, including removal and staging	$200/ft^2$
Bridge aesthetics	Add 3%
RCB Culvert (CIP), in close proximity or corridor projects	$600/yd^3$
RCB Culvert (CIP), individual projects or extensions	$650/yd^3$
Mobilization	10%
Contingency	B0 = 20% D0, B1, D2 = 15% B2 = 5%

Florida DOT

The Florida DOT *Structures Manual* lists item costs per square foot (Florida Department of Transportation, 2014). The agency typically completes between 100 and 200 bridges each year. Bridges 20 – 45 feet long are generally designated short-span bridges. Bridges 45 – 150 feet long are medium-span bridges, and those over 150 feet are long-span bridges. Table 2.2 lists presents cost ranges (per square foot) for each bridge type.

Table 2.2 Florida DOT Bridge Cost Ranges

Bridge Type	Low (per ft^2)	High(per ft^2)
Short Span Bridges		
Reinforced Concrete Flat Slab Simple Span	$115	$160
Precast Concrete Slab Simple Span	$110	$200
Reinforced Concrete Flat Slab Continuous Span	NA	NA
Medium and Long Span Bridges		
Concrete Deck / Steel Girder — Simple Span	$125	$142
Concrete Deck / Steel Girder — Continuous Span	$135	$170
Concrete Deck / Prestressed Girder — Simple Span	$90	$145
Concrete Deck / Prestressed Girder — Continuous Span	$95	$211
Concrete Deck / Steel Box Girder — Span range from 150 ft. to 280 ft (for curvature add a 15% premium)	$140	$180
Segmental Concrete Box Girders — Cantilever construction, span range from 150 ft. to 280 ft.	$140	$160
Moveable Bridge — Bascule Spans and Piers	$1,800	$2,000
* Increase the cost by 20% for phased construction		
Bridge Demolition		
Typical Bridge Removal	$35	$60
Moveable Span Bridge (Bascule)	$60	$70

Bridge Type	Low (per ft^2)	High(per ft^2)
Widening		
Bridge Widening Construction	$85	$160

Data Required for Conceptual Cost Estimates
The DOTs mentioned in this section estimate conceptual bridge costs based on bridge deck area. Their estimating tools indicate bridge costs per square foot are impacted by several factors:

- Project type (new construction, rehabilitation, removal, widening)
- Structural type (reinforced concrete, precast concrete, steel, movable)
- Number of spans (single vs. multiple)
- Bridge size (total length, span length)
- Delivery timeline (phased/staged construction or not)

Agencies that want to develop (or improve) a bridge cost database to facilitate planning and conceptual design work need to collect data on these parameters for bridges that have already been completed. This will provide a reference when developing future estimates.

2.2 Preliminary Bridge Cost Estimating Tools and Data Requirements

AASHTOWare Project TRACER
AASHTOWare Project TRACER is a parametric cost estimating tool used to plan and budget for transportation construction, renovation, and demolition projects during the predesign and preliminary design phases. The software bases cost estimates on quantities or work units (e.g., tons of structural steel, cubic yards of excavation). For projects in their early stages, TRACER supplies default values for most quantities based on a few very basic specifications. RSMeans supports default project cost data. As the project matures and more information becomes available, users can override and replace default values to create a progressively more accurate estimates of quantities. TRACER produces location-specific cost estimates that include general conditions, overhead and profit, risk allowance, and escalation. It can generate consistent estimates for users agencywide and is relatively easy to navigate (American Association of State Highway and Transportation Officials, Inc., 2012). It provides three built-in models for estimating bridge construction costs: (1) Construct Bridge Cost Model, (2) Renovate Bridge Cost Model, and (3) Demolish Bridge Cost Model

Virginia DOT Project Cost Estimating System (PCES)
The Virginia DOT's Project Cost Estimating System (PCES) collects and stores cost estimates for projects in the agency's Six Year Improvement Plan (SYIP) and Secondary Six Year Improvement Plan (SSIP) (Virginia Department of Transportation, 2018). PCES was developed in-house and implemented statewide in 2003 (Kyte, et al., 2004). It lets project managers generate, update, and view cost estimates for projects that have been scoped and includes a web-based application for preliminary estimation of bridge costs (only accessible by VDOT employees). Users enter bridge size (length, width, and skew) to generate an initial estimate and can select cost modifiers to adjust the initial estimate based on specific bridge design. Any portion of the estimate can be entered manually.

For external users, Virginia DOT has developed an Excel-based Bridge Cost Sheet that performs the same function as the web-based application but is not dynamically connected to the agency's project database. Upon inputting bridge dimensions, the worksheet generates an initial estimate (Figure 2.2). It then works through a series of cost modifiers (Figure 2.3). At the end of the worksheet, users manually enter additional cost items or adjustments not included in the built-in modifiers (Figure 2.4). Final results are displayed as the total estimated cost for the bridge and cost per square foot of deck area. Screenshots are from the *PCES User's Manual* (Version 7.1).

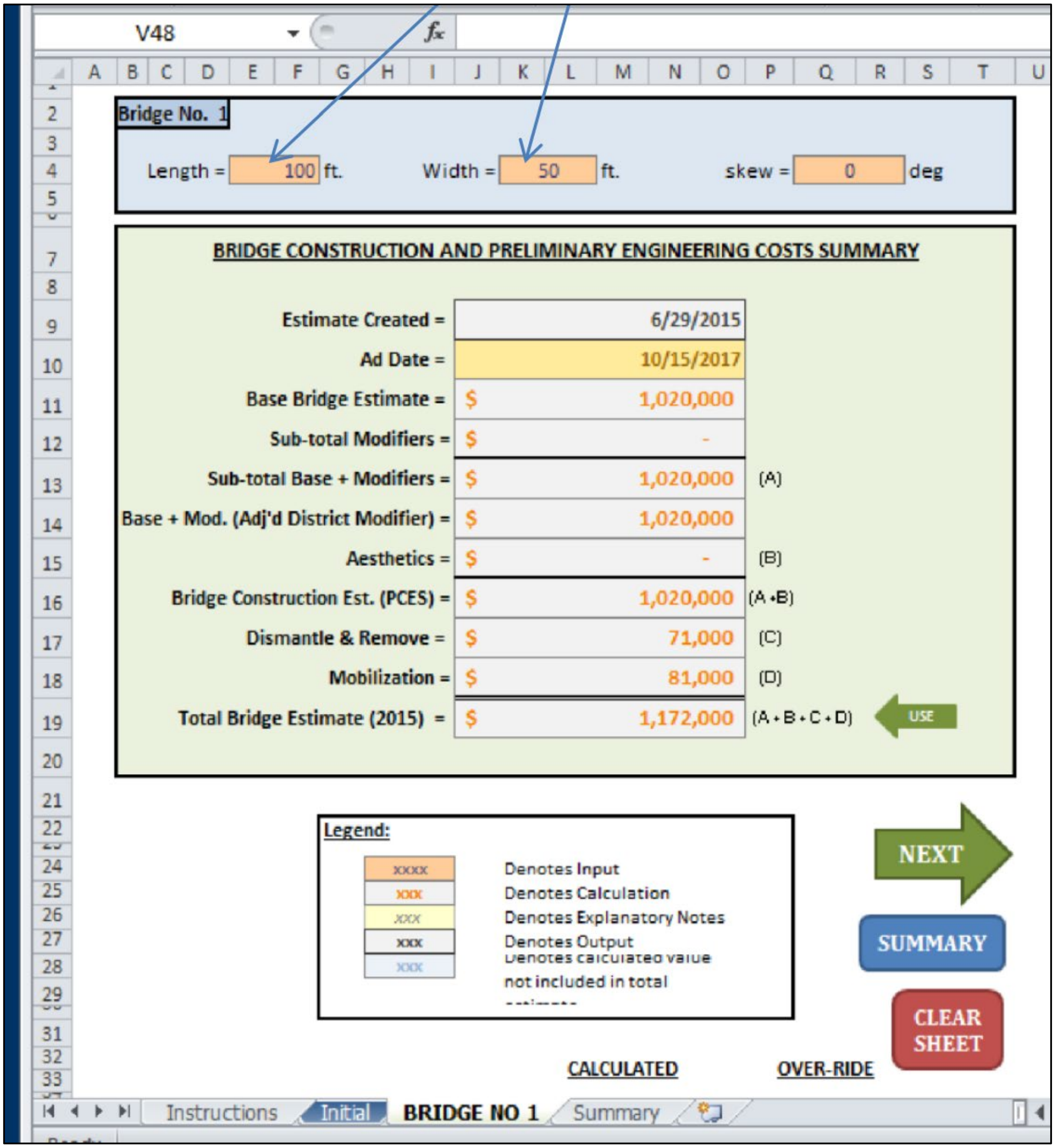

Figure 2.2 VDOT PCES Input and Initial Estimate

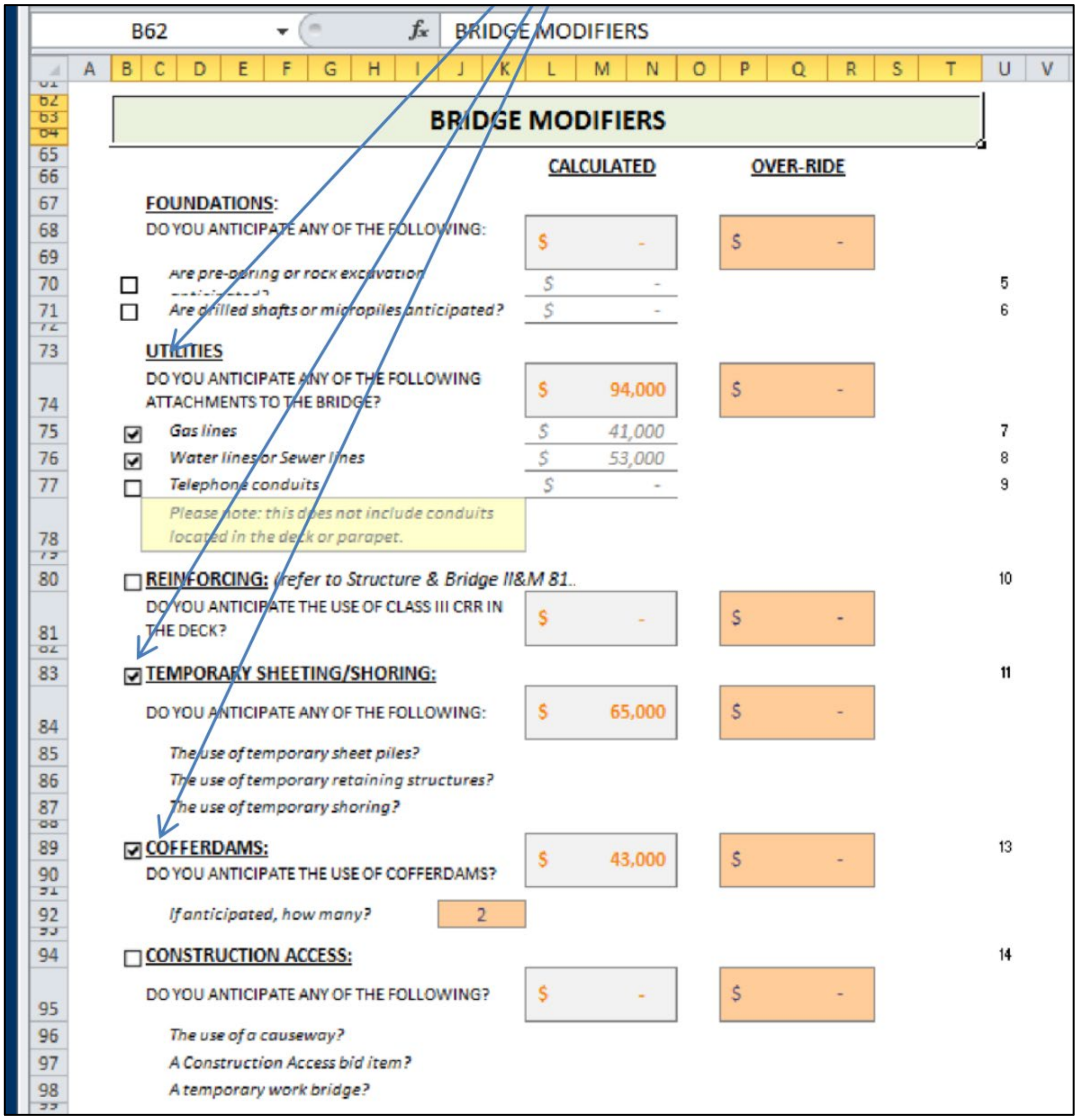

Figure 2.3 Virginia DOT PCES Modifiers

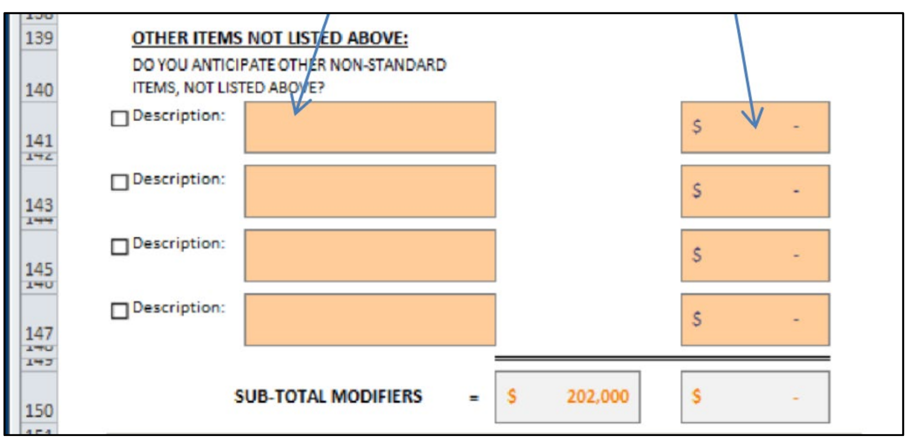

Figure 2.4 Virginia DOT PCES Additional Input

Florida DOT Bridge Development Report

At the Florida DOT a *Bridge Development Report* is submitted when structural design is about 30% complete (Florida Department of Transportation, 2018). The report is used to select the most appropriate structure type for the project site. Since it is critical to select a cost-efficient, context-adapted design, when staff complete a *Bridge Development Report* they must develop preliminary cost estimates for alternatives.

An Excel-based tool is available for generating preliminary estimates.[2] The process applies after completion of the preliminary design, which includes member selection, member size, and member reinforcing. This process develops estimates for the superstructure and substructure. Costs for all other items (e.g., mobilization, operation costs for existing bridge(s), removal of existing bridge or bridge fenders, lighting, walls, deck drainage systems, embankment, fenders, approach slabs, maintenance of traffic, load tests, bank stabilization) are excluded from the estimate.

Estimators begin by using average unit material costs provided in the worksheet to develop an estimate based on the preliminary design (Figure 2.5).

Bridge Development Report Cost Estimating **Effective 01/01/2020**			
Step One: Estimate Component Items			
Utilizing the cost provided herein, develop the cost estimate for each bridge type under consideration.			
A. Bridge Substructure			
1. Prestressed Concrete Piling, (furnished and installed)			
Size of Piling	**Cost per Lin. Foot [1]**	**Quantity**	**Cost**
18" w/Carbon-Steel Strands (Driven Plumb or 1" Batter) [2]	**$90**		
18" w/Carbon-Steel Strands (Driven Battered) [2]	**$125**		
24" w/Carbon-Steel Strands (Driven Plumb or 1" Batter) [2]	**$100**		
24" w/Carbon-Steel Strands (Driven Battered) [2]	**$140**		
30" w/Carbon-Steel Strands (Driven Plumb or 1" Batter) [2]	**$150**		
30" w/Carbon-Steel Strands (Driven Battered) [2]	**$210**		
18" w/CFRP or Stainless-Steel Strand (Driven Plumb or 1" Batter)	**$135**		
18" w/CFRP or Stainless-Steel Strand (Driven Battered)	**$160**		

Figure 2.5 Florida DOT's Bridge Development Report (Step 1: Estimate Component Items)

Components and unit costs are updated each year. The current version of the Excel-based too includes the following components:

- Bridge Substructure
  - Prestressed Concrete Piling, (furnished and installed)
  - Steel Piling, (furnished and installed)
  - Drilled Shaft (Total in-place cost)
  - Cofferdam Footing (Cofferdam and Seal Concrete)
  - Substructure Concrete
  - Substructure Reinforcing
- Walls
  - Retaining Walls
  - Noise Wall
- Box Culverts
  - Box Culverts
- Bridge Superstructure

[2] Available at: http://www.fdot.gov/structures/structuresmanual/currentrelease/bdrbridgecostestimate.xlsx

- Bearing Type
  - Bridge Girders
  - Cast-in-Place Superstructure Concrete
  - Concrete for Precast Segmental Box Girders, Cantilever Construction
  - Superstructure Reinforcing
  - Railings and Barriers
  - Expansion Joints
- Miscellaneous Items
  - Bridge Deck Grooving and Planing
  - Detour Bridges
  - Approach Slab

After preparing an estimate based on unit costs, it is modified the cost to account for site context:

- For construction over open water, floodplains that flood frequently, or other similar areas, costs are adjusted upward 3%.
- For construction over traffic and/or phased construction, costs for affected units of the superstructure and/or substructure are adjusted upward 20%

Last, the estimator reviews the total estimate on a cost-per-square-foot basis and compares it to historical cost ranges for similar structure types. Cost ranges are updated in the Excel worksheet every year. The process should produce a reasonably accurate cost estimate. However, if a site has idiosyncrasies that will affect bridge construction the estimate needs to account for them. If the estimate is outside the historical cost ranges, the variance requires justification.

2.3 Detailed Construction Cost Estimating Tools

A construction estimate or Engineer's Estimate is usually completed before letting, after the final bridge plans are signed. These are usually bid-based estimates based on actual pay items and quantities from the final bridge plan and historical unit prices adjusted for location, quantity and project specific parameters. State DOTs relay on several tools and methods to facilitate the task.

AASHTOWare Project ESTIMATION

AASHTOWare Project Estimation is a web-based application designed to deliver accurate, reliable cost estimates for construction programs. It is widely used among state DOTs. Individual agencies can tailor the software to their needs. Pay items included in the bridge project scope must be added into the software for pricing. Users can either manually add pay items, import them as a list, or import them from other AASHTOWare applications. The software can query bid histories for each pay item for projects with similar characteristics to identify an appropriate unit price.

Two methods are available in the application to generate a pay item unit price — average bid price and regression. Agencies differ in their preferences. For example, according to the Connecticut DOT's user manual, if the selected bid history catalog has 2 – 14 occurrences of the same item, the unit price is the average of those prices, and no project-specific factors are accounted for. If the selected bid history catalog includes 15 or more occurrences of the same item, unit price is computed using regression based on several factors (quantity, location, letting date, work type). Other factors that affect bidder prices (e.g., schedule constraints, difficult site conditions) are not accounted for. With both methods, users can decide whether to exclude outliers and which outliers are omitted (Connecticut Department of Transportation, 2019). The application has several limitations:

- It does not generate estimated prices for lump sum items.
- It does not generate estimated non-contract costs (e.g., utilities, state police). Those are estimated according to agency procedures.
- It does not generate estimated prices for unit-based items unless the item was used in at least two previous construction contracts in the selected catalog.

Iowa DOT iPDWeb Project Cost Estimating for Bridges

Iowa DOT's iPDWeb is a web-based estimating application. Project estimates are generated at several project development milestones. For detailed bridge estimates, the application functions similar to AASHTOWare Project Estimation as it builds a list of pay/bid items and applies historical unit price. Figure 2.6 shows a list of bid items that has been imported before unit prices are applied. Users can manually enter unit prices for each bid item or use a suggested price. When using suggested price, the application searches the historical bid database for the selected bid item and recommends a unit price using regression analysis. Users can view more details on bid price history for the selected bid item (Figure 2.7) and decide whether to accept the recommended unit price or adjust it. Filters can be applied to bid price history to limit reference points to only the most similar bridge projects (Figure 2.8).

iPDWeb allows lump sum items and recommends a percentage of total cost. Estimates in iPDWeb are done in present day dollars — not adjusted for inflation. Nor do they include contingency or risk. Inflation, contingency, and risk are managed at the program level (Iowa Department of Transportation, 2018).

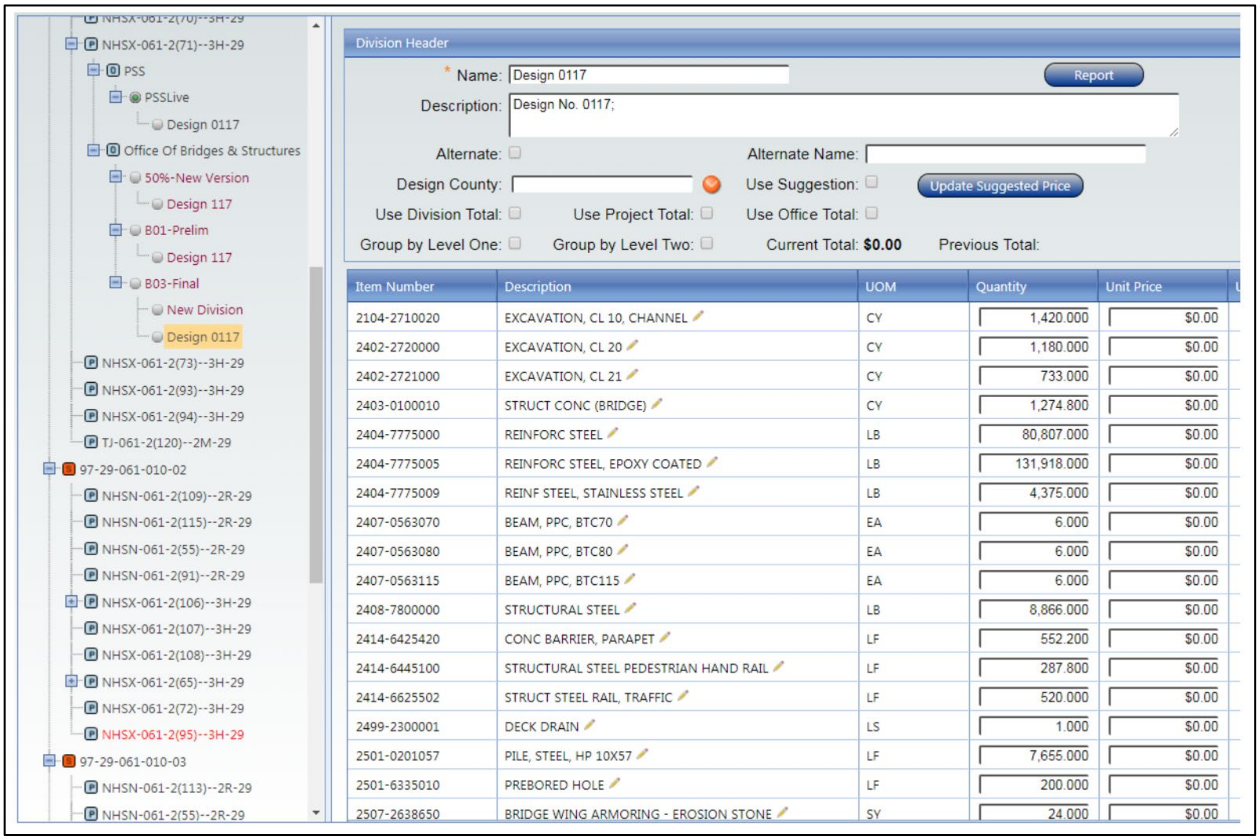

Figure 2.6 Iowa DOT's iPDWeb Estimating Tool Bid Item List

Project Number	Work Type	Route	Bid Date	Quantity	Unit	Let Unit Price	Unit Price (Todays $)	Excl.
IM-NHS-080-1(378)4--03-78	2014-BRIDGE NEW - STEEL GIRDER	I- 80	10/17/2017	2,171.10	CY	$300.00	$305.09	
IM-NHS-080-1(380)4--03-78	2014-BRIDGE NEW - STEEL GIRDER	I- 80	10/17/2017	185.80	CY	$350.00	$355.94	
IM-NHS-080-1(379)4--03-78	2014-BRIDGE NEW - STEEL GIRDER	I- 80	10/17/2017	913.30	CY	$350.00	$355.94	
NHSN-020-2(143)--2R-81	2023-BRIDGE REPLACEMENT - PPCB	US 20	09/20/2016	638.20	CY	$375.00	$366.55	
NHSN-020-2(143)--2R-81	2023-BRIDGE REPLACEMENT - PPCB	US 20	09/20/2016	638.20	CY	$375.00	$366.55	

Figure 2.7 Iowa DOT's iPDWeb Estimating Tool Bid History Details

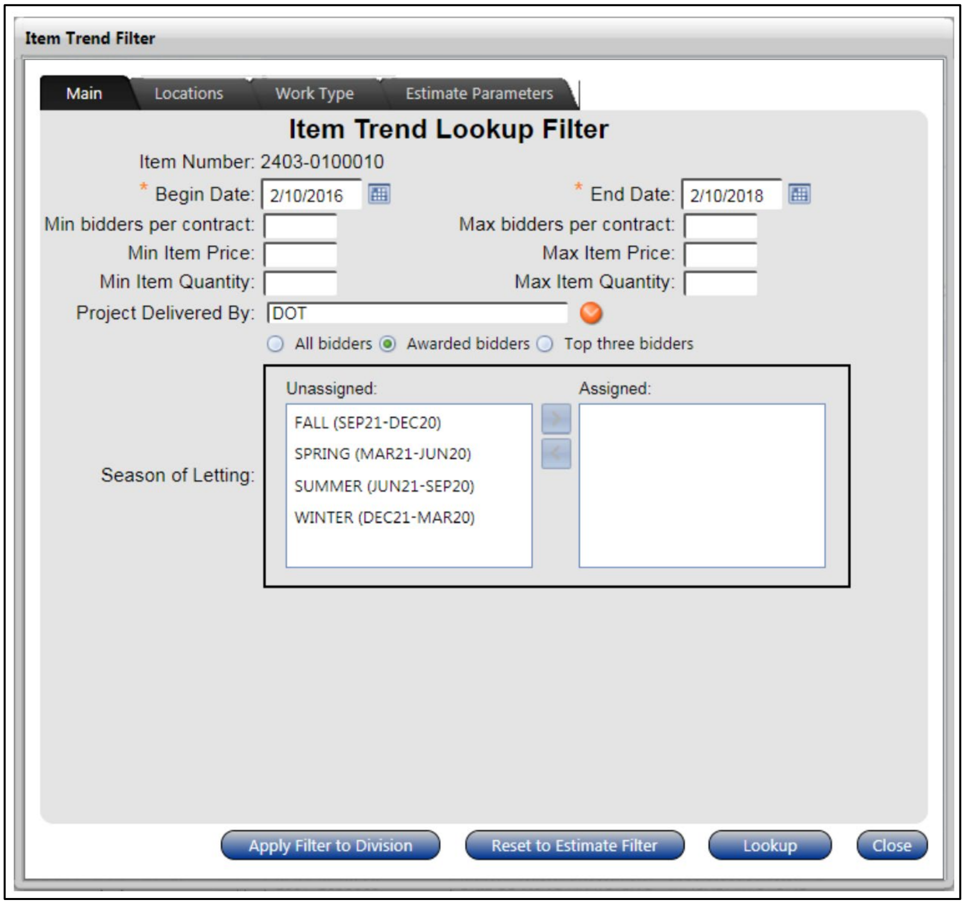

Figure 2.8 Iowa DOT's iPDWeb Estimating Tool Bid History Filter Screen

Cost-Based Estimating for Prioritized Work Items

The purpose of cost-based estimating (i.e., scratch estimating) is to estimate the cost of a work item (material, equipment, and labor) plus the contractor's overhead and profit. Compared to historic bid-based estimating, preparing cost-based estimates requires significantly more effort, time, and skill. However, they can help agencies and estimate reviewers better understand how much a project should cost. Only high-cost impact items that represent a substantial percentage of the total project estimate should be considered for cost-based estimating (Pennsylvania Department of Transportation, 2018). The Pennsylvania DOT recommends the following sequence of activities to estimate cost of a work item:

1. Identify Items for Cost-Based Estimating Approach.
2. Collect Data-Investigate, in detail, identified items to be estimated. Review Plans, Specifications, and Special Provisions and Contingencies.
3. Define and List Work Associated with Identified Items.
4. Review construction schedule information.
5. Determine material requirements.
6. Determine equipment requirements.
7. Determine labor requirements.
8. Time (Establish anticipated progress rate).
9. Compute base cost of labor, materials and equipment.
10. Add overhead.
11. Add profit.
12. Compute unit price.

2.4 Publicly Available DOT Cost Databases

Missouri DOT Unit Price Book

The Missouri DOT maintains a Unit Price Book for all coded pay items. The book includes district-specific unit prices based on cost data from all bids received within a year (Missouri Department of Transportation, 2020). Figure 2.9 shows the 2019 Unit Price Book for Missouri DOT's Northwest District.

MoDOT — 2019 UNIT BID PRICES — Northwest District

PAY ITEM	DESCRIPTION	UNIT	AVERAGE QUANTITY	#OF BIDS	AVERAGE PRICE	HIGH BID	LOW BID	TOTAL QUANTITY
2013000	CLEARING AND GRUBBING	ACRE	1.15	100	4533.73	28000.00	500.00	114.80
2022010	REMOVAL OF IMPROVEMENTS	L.S.	1.00	200	20619.33	162488.45	800.00	200.00
2024043	REMOVAL OF MISCELLANEOUS ACM (NON-FRIABLE)	S.F.	12.00	3	113.46	125.00	100.00	36.00
2031000	CLASS A EXCAVATION	C.Y.	1281.76	126	14.57	250.00	4.25	161502.00
2035000	UNCLASSIFIED EXCAVATION	C.Y.	386.00	6	16.54	24.00	7.00	2316.00
2035500	EMBANKMENT IN PLACE	C.Y.	3429.18	95	17.74	500.00	4.00	325772.00
2036000	COMPACTING EMBANKMENT	C.Y.	852.77	97	5.26	90.00	0.10	82719.00
2037075	COMPACTING IN CUT	STA.	7.84	48	989.90	6800.00	335.00	376.30
2061000	CLASS 1 EXCAVATION	C.Y.	82.44	88	68.46	300.00	16.00	7255.00
2063000	CLASS 3 EXCAVATION	C.Y.	186.04	51	30.82	534.60	3.00	9488.00
2063300	CLASS 4 EXCAVATION	C.Y.	828.00	5	29.20	65.00	13.00	4140.00
2063500	CULVERT CLEANOUT	EACH	6.88	16	2290.27	25000.00	500.00	110.00

Figure 2.9 Missouri DOT 2019 Unit Price Book

New York State DOT As-Bid Bridge Cost

The New York State DOT publishes ja database with as-bid prices for bridges completed between 2005 and 2019.[3] It contains the following information for each project:

- Project ID Number
- Bridge ID Number
- Contract Number
- Letting Date
- County
- Description
- Low Bid Estimate
- Cost per Shoulder Break Area (sq ft)
- Structure Type
- Superstructure Type
- Abutment Type
- Total Wingwall Length > 65 ft
- Piles
- Maintenance & Protection of Traffic
- Total Width (ft)
- Number of Spans
- Total Length (ft)
- Skew

2.5 Factors Affecting Bridge Costs

If an agency is using historical cost data to estimate project costs, at each stage of the estimating process it is important to recognize factors that impact cost and adjust estimates accordingly. A bridge cost database is useful for storing data that can be used to gauge how these factors will influence bridge costs. Factors to consider include (Washington Department of Transportation, 2019):

[3] The database is available at: https://www.dot.ny.gov/divisions/engineering/structures/repository/manuals/2005_to_2019_lettings_pub.xlsx

- Structure Type
    - Type, size, and location of a bridge or wall influences cost.
    - Common structures with conventional details are near the low end and middle portion of the cost range.
    - Unique or complex structures are near the high end of the cost range.
- Location of Project Site
    - Projects in remote areas or with limited access are generally near or above the high end of the cost range.
- Size of Project Contract
    - Small projects tend to be near the high end of the cost range while large projects tend to be near the low end of the cost range.
- Foundation Requirements
    - Water crossings requiring pier construction within the waterway are generally very expensive.
    - Scour mitigation can increase costs.
    - The earlier foundation information is available, the more accurate the estimate will be. Unusual foundation requirements or changes to foundation type should be done as soon as possible to update the estimate.
- Project Sequencing
    - Projects with staged/phased construction, detours, and/or temporary construction are more expensive.
- Time of the Year (Pennsylvania Department of Transportation, 2018)
    - The month in which project work is scheduled to begin affects the construction estimate. It is best to start projects in early spring and/or finish them before cold weather sets in.
    - If the project cannot be completed before cold weather, rates of progress must be adjusted downward and the construction estimate revised upward.
    - Added costs (e.g., winter overhead, heating of materials, winter damage) must be factored into the construction cost estimate.
- Maintenance and Protection of Traffic
    - Construction in high-volume traffic areas add substantially to project duration and construction estimates.
    - Similar projects in low-volume traffic areas generally have shorter contract times and lower construction estimates.
- Project Risk and Contingency
    - Bridge projects are generally considered medium/high risk for estimating purposes.
    - Contingencies are usually added to estimates as percentage of total bridge cost.
    - Contingencies are between 15% and 20% for conceptual estimates, 5% and 15% for preliminary estimates, and around 5% for detailed estimates (Georgia Department of Transportation, 2020).

2.6 The Accelerated Bridge Construction (ABC) Movement and Bridge Cost

The FHWA promotes accelerated bridge construction (ABC) techniques through its Every Day Counts initiative. According FHWA, “ABC is bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the onsite construction time that occurs when building new bridges or replacing and rehabilitating existing bridges” (Federal Highway Administration, 2019).

Many DOTs are implementing ABC techniques and have seen positive outcomes on numerous bridge replacement and/or rehabilitation projects. ABC techniques often carry high initial costs, which deters some agencies from more widespread implementation (Hadi, et al., 2016). Recent studies have shown that ABC may lower bridge construction costs by reducing construction duration, which cuts indirect cost and general conditions (Orabi, et al., 2016). But existing data are insufficient to draw statistically reliable conclusions about whether applying ABC lowers bridge construction costs. Several DOTs (e.g., Utah, Massachusetts, Washington, Colorado, Wisconsin, Iowa, and Pennsylvania) have decision models for selecting bridge projects eligible for ABC. More data are needed to clarify the impact of ABC on bridge construction costs. Once available, these data could help agencies revise bridge cost estimating processes.

Chapter 3 Overview of KYTC's Existing Bridge Construction Cost Estimating Program

Reliable construction estimates aid decision making and planning efforts. Estimate requests originate from many sources and have different purposes. Estimate levels of precision and turnaround times vary. KYTC's Division of Structural Design website[4] offers a 2017 pricing summary that aids construction estimate development for a range of structures.

Staff primarily rely on datasets maintained in an Excel spreadsheet to prepare estimates. Contract-specific bid tabulations are retrieved from public-facing Division of Construction Procurement website offerings (as PDFs). Low-bid pricing details are manually entered into the workbook and categorized. The Division of Structural Design database thus includes changes to bid quantities that occur prior to letting through project addenda. Each structure's cost is a manual compilation and summation of plan quantities and the successful low bidder pricing.

Structure attributes and context relevant to pricing data (e.g., span length, pier height, beam type, and foundation type) may be added but must be referenced to other sources, including individual project plans and structure plans. The Division of Structural Design uses the following categorizations and data filters to contextualize data:

- Drawing Number
- Construction Letting Dates
- Construction Letting Call Number
- Averages are calculated after removing highest and lowest values
- Fiscal Year
- Fill height in feet (<5, 5-10, 10-20, >20) and width (4 ft to 20 ft) for culverts
- Construction contract identification (CID)
- Six Year Plan Item Number
- District
- Structure Designer (Consultant or Department)
- Structure degree skew
- Structure deck area
- Span length for single span or maximum length for multiple span structures

Cost tracking data are sporadically updated in spreadsheets and analyzed (e.g., intermittent reviews of construction indices). However, analysis is a cumbersome process. Updating source data is also time-consuming. Individual projects must be tracked using at least four identifiers: SYP Item Number, Letting Call Number, Contract ID (CID), and Structure Number. Multiple structure numbers must be tracked within a single CID and call number when more than one structure is included in the construction contract, further complicating data management. In these cases, bid items may or may not be grouped into one quantity for contractual purposes, as is often the case for Class A Concrete (Item Code 8100) and Steel Reinforcement (Item Code 08150) — items that can be used for structures or the fabrication of small pipe culvert headwalls. Thus, drawing accurate conclusions about cost trends from low-bid pricing is especially difficult.

The existing database references the Turner Building Construction Cost Index[5] and prorates it according to the increase in KYTC's reported average unit bid prices for monitored items. However, this has not occurred since 2017.

KYTC's existing database cannot create construction project schedules or track progress. Establishing the duration of a construction project contract begins during project development and continues through plan processing and into construction management. Contract duration calculated outside of the Division of Structural Design.

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[4] https://transportation.ky.gov/StructuralDesign/Pages/Structural-Resources.aspx
[5] https://www.turnerconstruction.com/cost-index

Along with providing a basis for construction estimates, the existing system used to compile data facilitates a portion of KYTC's reporting requirements to FHWA. Specifically, the Cabinet reports bridge projects completed in each calendar year. This information is sourced in a manner similar to data for construction estimates. Thus, improving data tracking systems can boost the accuracy of external reports.

The existing spreadsheet's tracking capabilities do not capture changes in project bid quantities made via change orders, contract time extensions, quantity overruns and underruns, or contract items added after the contract award and notice to proceed. These data are important because they reveal design errors, omissions, opportunities for process efficiencies, and innovative fabrication and construction solutions.

Data in the spreadsheet are developed into *per square foot* (of superstructure) formats that are useful for conceptual construction estimates (e.g., recommendations for Kentucky's *Six-Year Highway Plan* and early design estimates.) Extracting unit price estimates is left to Division of Structural Design staff. External users (e.g., District staff, consultant engineers, county and local government engineers) only have direct access to the 2017 reference sheet. Rules of thumb for per-square-foot formats are derived from these data and shared with KYTC project managers and Division of Structural Design personnel at the district level.

Chapter 4 Stakeholder Interviews

We interviewed 13 regional industry representatives, six (6) KYTC staff members from three districts and the Central Office, and the assistant state bridge engineers in Missouri and Pennsylvania. We conducted all interviews virtually. Interviewees shared their observations about factors that influence cost during construction contract bid letting (based on bid package information only) and following the award (based on site conditions and throughout construction phase). Table 4.1 lists cost drivers identified by interviewees. The following sections present detailed observations from interviewees.

Table 4.1 Bridge Construction Cost Drivers Noted by Interviewees

Cost Driver	Effect on Bridge Construction Costs
Compressed project schedule requirements	Increase
Insufficient work area (i.e., lay down area, staging area) for contractor materials and equipment	Increase
Standardization of structure design components	Decrease
Contract documents and design inconsistencies or contradictions	Increase
Insufficient or inappropriate bid items for contract work — overuse of incidental work items	Increase
Optimize span length to minimize need for cofferdams and dewatering	Decrease
Complicated traffic management requirements and work phasing (e.g., partial width construction of structures)	Increase
Consistent overall volume of bridge construction work let per year	Decrease
Unanticipated geotechnical site conditions	Increase

2.1 KYTC Interviewee Perspectives

Contract Time

Interviewees observed that compressed schedule requirements (too few working days or not long enough time prior to completion date) increase construction costs, which translates into higher bids. Adequately long project schedules (enough to allow the contractor flexibility within their workload) reduces prices.

Working Area

Difficult site access and tighter restrictions on a contractor's working area around a structure increase bid prices. Contractors forced to make accommodations for their own staging area (e.g., lay down area) or stage materials and equipment in inconvenient locations perceive greater risk and increase bid prices accordingly. This is especially true when a contractor's workload is stable or they expect KYTC to advertise a high volume of work in their preferred region.

Utility clearances can result in delay cost and direct cost. For example, time extensions may be granted via change order if utilities are not cleared. Environmental restrictions and railroad coordination requirements can further restrict working areas and increase construction costs. Interviewees commented that environmental clearances for Bridging Kentucky projects were insufficient for construction activities. Working areas can be further restricted by prohibitive terrain (e.g., steep grades, floodplains). Construction is also more expensive when the existing bridge cannot be used to move equipment and materials. In these cases, detour length impedes contractor movement, increases costs, and impacts the public.

Standardization

Standardizing structure drawings lowers construction costs. One challenge on Bridging Kentucky has been materials supply. Plans for these projects mixed and matched steel and box beams, which drove up costs. On a project with highly specific foundation repair work in Mason County, bids came in well above the engineer's estimate. This example was offered as evidence of the relationship between standardization and cost. Interviewees recommended keeping the footings for each structure the same since varying footing type requires contractors to manage different equipment types. Standard bridge designs, especially for smaller bridges, reduce construction costs and potentially design costs.

Plan Quality

More in-depth review of plans prior to letting — even simple review — will catch costly errors. Interviewees provided several examples. One project's design intended to provide additional contract working days for seasonal flood conditions, but the note was not included in the proposal document. District Section Office staff learned of the provision during the preconstruction meeting and had to adjust project management accordingly. Interviewees noted that plan errors are often brought to light between the project's advertisement and when bids are opened because contractors ask questions. Often, inaccurate structure quantities increase costs post-letting. Existing piles hampering new construction result in delay cost and higher construction costs.

Incidental Work Items

Fewer work items should be lumped together using plan notes that describe work as incidental to related tasks. Interviewees pointed out this can increase bid costs and inflate average bid item costs. One suggestion was that cofferdams should always be a separate bid item rather than incidental to other work.

Cofferdams

Interviewees agreed that lengthier bridge spans can serve long-term asset management better than short spans that experience scour. Additionally, longer spans are typically simpler to construct, since cofferdams might not be needed. Bridge length can save or increase cost based on practical aspects of construction and maintenance.

Partial Width Construction

Partial width and complicated work phasing always result in higher construction costs than structures constructed full width. Traffic control designs should be developed in coordination with construction staff.

Market Capacity

Competition for projects affects construction pricing more than other factors. Interviewees felt Bridging Kentucky drove prices up once the market was saturated once local contractors reached their capacities. They also noted that winning bridge replacement contractors sometimes hired a competitor to complete work that was above their capacity. Interviewees believed contractors were forced to plan for liquidated damages as they prepared bids because they understood the volume of work was too much to complete with internal resources. The program was viewed as giving contractors an upper hand in pricing — a consistent level of competition would have meant more stable, lower pricing.

Geotechnical Risk

Costs increase when bidders deem geotechnical information inadequate and perceive heightened risk. When the rock elevation encountered during construction differs from the elevation on a geotechnical report, mass concrete placement and/or piling length changes introduce additional costs. If a redesign is needed, schedule delays follow. If the proposed friction piling capacity does not match field capacity, redesign and material changes are necessary and costs rise. KYTC staff acknowledge geotechnical field investigations are difficult. Borings are often inaccurate because the underlying geology can change dramatically over short distances (especially in the vicinity of streams and river crossings). Increased coring will help to lower construction costs.

General Notes from KYTC Staff and Recommended Innovations

Interviewees familiar with AASHTOWare Estimation see its potential for improving construction cost estimates. Linear regression is used, and staff recommend the software for Division of Structural Design processes. However, price spikes affect output unless the user understands how to target spikes and evaluate context. Estimation may be improved, however, and automatic data transfers between the software components of AASHTOWare saves time and eliminates error in manually copying data.

KYTC's bid-item structure does not distinguish between different uses of concrete. This should be adjusted to provide more clarity to data users. A similar issue occurs with the current structural steel bid item. Since truss and plate girder types have very different costs (trusses are more expensive to build than plate girders), using two separate bid items (both in pounds) would provide sufficient granularity to support decision making. Volatility in materials and labor costs over the past few years has been profound. Material supplies affected scheduling, which also drove up costs for Bridging Kentucky.

Users must be careful when working with bridge inspection data from files. Detour lengths in bridge inspection files should be verified and sufficiency ratings used in concert with engineering judgement. Construction estimates based on bridge deck area for replacement projects are always higher than the existing bridge since the deck area is typically wider. This is especially true for county bridge replacements. Interviewees could readily access Division of Construction Procurement Average Unit Bid Price data for their own bridge construction cost estimate needs.

Staffing issues affect costs for industry and KYTC. Staff turnover prevents the relationship building that facilitates effective construction project management. Reduced KYTC staffing levels and the associated knowledge losses can affect project costs. Payment processing delays were cited as an example of a project management issue that increases risk for contractors and translates into higher costs on future projects. The low availability of CDL drivers and experienced laborers is a cost driver for industry.

Interviewees offered several recommendations to boost cost savings:

- Increase the use of aluminum or concrete precast (e.g., Con/Span brand) culverts to save on time and labor
- Increase construction staff involvement in decision making during project development
- Adopt alternate bid methods – with bridge design variations (steel and concrete), especially on smaller bridges
- Use carbon fiber reinforcement
- Transition to stainless steel reinforcement
- Increase the use of bid item supplemental descriptions to provide context for bid items
- Develop a concrete index (similar to KYTC's diesel fuel and asphalt adjustment policy)

Table 4.2 Projects Noted for Unnecessary and/or Avoidable Structure Cost

CID	Item No.	County	Project Description	Note
191247	2-1080.00	Henderson	Spottsville Bridge, STP BRO 5053 (031)	Varied footing types, including spread footing inside a cofferdam that was sacrificed as formwork. Traffic control design not useful
195140	12-10039.00	Letcher	Sand Lick Creek/Caudill Town Road (BKY) 121GR19D140 - STP BRZ	Had metal beams with a metal mesh as reinforcement - unusual (costly) design
211020	12-301.20	Floyd	FD04 SPP 036 0680	Better pre-letting review could have avoided issues identified by bidders

4.2 Industry Perspectives

Contract Time

Interviewees from industry were adamant that contract time impacts project costs. A compressed schedule also ratchets up construction costs. If KYTC adopts a shorter contract term to minimize traffic disruptions, interviewees suggest this should be addressed separately from the overall contract term. The time of year letting occurs is less impactful than scheduled completion dates and number of working days provided. Projects built during the winter always carry higher costs.

Lead time on projects is important for contractors' work. One interviewee explained cost escalation using the example of labor costs. Because building a structure demands a lot of labor, hourly unit costs for time-and-a-half overtime is high relative to grade and drain construction, where equipment is often matched with one operator. Interviewees acknowledged that compressed schedules are a less influential cost driver when the volume of projects let is low and competition high.

Lead times for materials and fabrication are quite impactful. Contractors are better able to manage their work and crews when given more lead time. December – March lettings are ideal because they give the fabricator time to plan ahead of the season.

Working Area

Since bridge construction requires a lot of equipment, limited space on the jobsite decreases production and adds cost. Insufficient room to construct bridges and restricted laydown areas are costly. When a laydown area is not available, contractors may seek agreements with property owners use area within right of way. This can damage pavement and result in repairs. Space to lay down material and keep a tool trailer are important considerations. Clearances and permitting should be sought for the true area needed for the work being done. Restrictions on working area that introduce problems include:

- Environmental restrictions
- Overhead and underground utilities (interviewees cited examples of projects with overhead utilities that were relocated to a place where they still obstructed crane movement)
- Railroad proximity
- Stream location and prohibitive site geography (e.g., steep, flood zone)

Interviewees said that Bridging Kentucky attempted to keep its first projects within existing right of way — an area described as a postage stamp by one interviewee, with dimensions of 55 ft. x 85 ft. Stockpiling material onsite was impossible, negatively impacting productivity. Quantifying these costs is difficult but should not be overlooked.

Standardization

Interviewees felt Kentucky's level of standardization helped minimize costs, while the simplicity of designs (compared to adjacent states) results in streamlined and economical projects. The use of concrete beams was cited as especially commendable. Interviewees observed that some consultant structure designers severely overdesign, which increases costs. Using simpler designs to replace county bridges is always a good idea because they are the most economical. Cross-frame design offers an opportunity for standardization-type savings. Even if bolt holes must be adjusted, standardizing this component through design produces savings during fabrication and field installation. Shop-bolted cross frames are also economical.

Interviewees cautioned that extraordinary formwork always increases cost. Using repeatable structure component shapes is more efficient and saves money. Step-ins and specialty forming carry higher costs than straight walls. For example, a proposed design for a stem wall on a pier that is narrower than the cap is time-consuming to form. Modifying the design to match the stem wall to the pier cap width reduces saves on time and expense.

Interviewees contended that designs with additional materials quantities (e.g., steel reinforcement tonnage, concrete volume) lower overall cost and time requirements because the labor time is streamlined and minimized. Designers should be mindful not to spend money on construction costs to save a yard of concrete. For example, labor hours are expensive when used to form up a complicated element, when higher concrete volume may be cheaper due to fewer additional labor hours. Longer spans may be a better option if a shorter span increases the contractor's risk of dealing with high water, specialized abutments, dewatering, and delay cost. Drill rig stability (for pre-drilled piles) may require a lot of site work that could be mitigated with longer spans. Moreover, longer beams can be more economical to fabricate, depending on the bed size available. Prefabrication site capacity should be maximized, because prestress strands are bed length, regardless of beam length.

Plan Quality
Interviewees recommended increased oversight and accountability during project development. Design errors in reinforcement (bill of reinforcement as well as dimensions) are prolific, and accountability (of the bridge designer) needs to be addressed. Interviewees asserted that errors in reinforcement steel quantities are always short. This could be a result of contractors not finding it as necessary to bring overages to attention of KYTC — contractors do not benefit from correcting an overage because it would reduce payment. If those errors occur in a design-build contract, corrections are taken back to the designer, and they would be held accountable. This is not the case with design-bid-build contracts.

Incidental Work Items
KYTC can save money on by ensuring bid documents clearly communicate project details. Stating explicitly the basis for contractor payments and tracking work quantities lowers project costs. Incidental work is always higher risk and therefore increases cost. Cofferdams and other incidental work are included in bids, though this might not be conspicuous in typical unit prices. Creek crossings or site work needed to facilitate a project are other examples of costs that often go overlooked but are directly attributable to design decisions.

For Bridging Kentucky, many items were made incidental to others using plan notes. For example, an inadvisable number of work items was made incidental to the lump sum foundation preparation. Structure granular backfill was made incidental to paving. Since bidders included incidental work costs in paving, paving quantity overruns were more costly than they would have been otherwise.

Cofferdams
Costs go up whenever a cofferdam is needed. These costs are reflected in bid item unit costs for structure excavation common and foundation preparation, depending on project pay quantities. Breastwall abutments are usually not less expensive than a pile cap or drilled shafts when related cost factors are considered. Spread footings on rock may be less economical than piling, especially when a cofferdam is needed for the construction. Cofferdam bracing sometimes interferes with abutment construction, requiring multiple pours and impacting schedule and labor hours. Like cofferdams, foundation shoring is a complicated activity. Contractors consider associated work costs, but they are not directly paid within the bid item structure. If drilled shafts are simpler than a lot of foundation shoring, that configuration should be strongly considered.

Partial Width Construction
Interviewees regarded phased bridge construction as cost prohibitive. When project work occurs under traffic it introduces additional safety risks to employees, Cabinet inspection staff, and the traveling public. Traffic control measures for an open adjacent roadway add significant expense.

Market Capacity
Large swings in KYTC's letting volume for the statewide bridge program produce erratic cost variations. Greater consistency in work volumes benefits the industry, lowers costs, and improves quality. When Kentucky's bridge construction program is lean, more competition drives down pricing. But when local bridge contractors are near capacity, bids increase. Bid price volatility occurs when the program is feast or famine. Interviewees also noted that work volumes are impacted by state government administration changes.

Bridging Kentucky propelled a lot of projects to letting initially, but that pace not been sustained. Once contractors were loaded with work, they could not responsibly bid on new project bundles. However, bundling 5-6 bridge projects regionally is an effective way to bring down costs. Supply chains and material costs remain affected by the COVID-19 pandemic and climbing fuel prices.

Geotechnical Risks
Interviewees consider good geotechnical information as deeply important for efficient bridge construction. When construction reveals geotechnical site features that conflict with geotechnical information in plans, the result is costly schedule and design adjustments. Contractors build risk (cost) into their bid estimate when geotechnical

information appears insufficient or possibly incorrect. For example, bearing pile lengths can be underestimated when rock elevations are lower than expected. Interviewees recommended more subsurface exploration to increase the credibility of the geotechnical information offered in bid documents and to lower bridge construction costs.

General Notes from Industry and Recommendations

Interviewees said Cabinet staff make timely decisions when unforeseen site conditions appear. Decision making is most effective when it occurs onsite and inspectors are educated about contract requirements.

KYTC staff must increasingly prioritize maintenance (operations) tasks over construction. Section Engineers' relationship with contractors on projects impacts cost indirectly — this should not be overlooked, though it may be difficult to quantify. Adversarial relationships in the field lead to delays and higher project costs. Good relationships keep costs down and bolster site safety. When outside agencies are involved (e.g., US Army Corps of Engineers) their decision-making processes impact the project schedule negatively.

Throughout the industry, interviewees noted that the materials approval process is cumbersome and expensive. Third party materials sampler/testers on KYTC projects have lacked understanding of required testing/sampling procedures. Quality control at the plant (e.g., aggregate moisture tests) requires staffing and that increases costs compared to projects that have fewer requirements. Costs include maintaining certifications and conducting lab testing. Staffing levels are low for everyone (KYTC and industry), and this poses challenges for schedule and cost. Training is an important for creating quality finished projects that are cost-efficient and perform well throughout their design lives.

Interviewees highlighted construction materials whose fabrication and shipping schedules place them on the critical path for most projects. On projects with compressed contract schedules, their use should be minimized:

- Guardrail attached to bridge beams
- Atypical bearing pads (e.g., steel bearings or bridge specific types)
- Steel intermediate diaphragms (reliant on shop drawing approval process)

The Indiana DOT manages its construction letting process well, maintaining information that bidders can access easily.[6] Like KYTC, bidder questions and agency answers are posted online. But the agency also lists questions that have not been answered yet. Bid prices are not listed for unawarded projects. This keeps pricing confidential until award, which is important if a project is let again. Indiana DOT also alters the contract number by adding a suffix *a*, *b*, or *c* when a project is let again.

Other cost-savings recommendations provided by industry stakeholder are listed below.

- Heavy skew or curve is always undesirable for schedule and cost.
- Pile driving hammer size restrictions in Geotechnical notes are usually too light.
- Standard H-pile splicing is more economical (faster) in the field than pipe pile.
- Steel girder length of 140 ft. is optimal. Greater lengths introduce splices and require expensive shop labor.
- Side-by-side box beams standardized with a 5-inch deck is the most economical configuration.
- The cheapest piers are solid, multi-column designs with hammerhead caps.
- Bolts and shopwork are less expensive than welds and fieldwork.
- Expedited schedule needs may be best addressed using a deadline tied to maintenance of traffic or completion milestones.
- Structure plans reference inches and grading plans use tenths of a foot. This creates confusion for some subcontractors.
- Kentucky's decision to move away from painting weathering steel was judicious.
- Direct tension indicator washers are more expensive up front but could have costs offset.

[6] See https://www.in.gov/dot/div/contracts/letting/index.html

- Satellite phone is an added cost required on projects with no cell coverage.
- The West Virginia DOT and Indiana DOT have used a Class M and 24-hour concrete mix design that can be batched at a ready-mix plant and includes microsilica.
- Send KYTC staff to trade shows and let them be creative. Contractors see benefits from this investment in their own staff.
- Designers should make site visits and visit fabricators to grasp savings opportunities proposed by interviewees.
- Buried approach slabs could be a good solution to the bump at the end of the bridge — typically, a 17 in. deep, 25 ft. long slab that rests on a ledge on the end bent diaphragm. This bridges the area of natural settlement. Expansion joints have not been used as often in recent designs, so bridge expansion is not actively managed like it used to be.
- The 1.25 HL 93 Design vehicle is specific to Kentucky. Other states use a lighter vehicle that is expected to reduce construction costs.
- Chemical admixtures may offer KYTC opportunity to extend structure life-cycles and/or reduce maintenance costs. New admixtures are promising, including internal cure and internal sealants. Some efforts are underway in pursuit of a 100-year concrete mix. If an admixture could protect reinforcement steel from moisture, it would cut down maintenance and repair costs.
    - Penetron looks promising to reduce permeability. (https://www.penetron.com/)
    - Indiana DOT is testing admixture "element 5" that assists shrinkage, waterproofing, and curing. (http://www.specificationproducts.com/rcsproducts/rcs-internalcure/)
    - Carbon footprints are becoming more of an industrywide focus. CarbonCure is an admixture that offers means of harvesting CO2 and using it to replace cement in the mix. (https://www.carboncure.com). This admixture pushes the carbon back to free lime, thereby increasing strength.
- Field staff lack direction on converting payment when measured units are not payment units. This relates to items like granular embankment, which is tracked using truck weight tickets tonnage, but for which the standard bid item payment unit is cubic yards.

4.3 State DOT Perspectives (Missouri and Pennsylvania)

Contract Time

Missouri and Pennsylvania DOT staff agreed that unreasonable construction deadlines increase bids. Limiting working hours drives up costs by at least 10%. A Missouri River bridge superstructure replacement project estimated at $15-20 million exemplified the issue. The first letting received no bids because the original contract time was compressed to nine months. Qualified contractors deemed the schedule impossible.

Working Area

Interviewees identified several cost drivers related to available working areas:

- Demands by proximal railroads increasingly create project delay and cost.
- Projects without nearby DOT-approved materials suppliers (e.g., concrete ready-mix batch plants, quarries) are more expensive to construct. Material supplies are influenced by regional availability and demand in similar industries (e.g., railroad).
- Ready access to both sides of a project lowers cost and should be provided if possible.
- Environmental permitting requirements drive the overall construction cost up.

Standardization

Pennsylvania DOT attempts to standardize structure design wherever possible. The agency developed software that optimizes costs related to beam spacing design. The Missouri DOT is developing standard designs for a 55-foot bridge for use in the state's flat lands. These details include options for some small skews. Tables go from 25 ft. to 120 ft., including prestressed I beams, box beams, plate girders, fascia beam design, interior, and sometimes a third beam design. But this is costly because the bed is used more efficiently when the strand pattern and beam sizes differ. Any standardization and formwork simplification is cost-efficient.

Plan Quality

Plan quantity errors increase costs, whether the error appears in the original design or shop drawings. If the contractor or supplier makes an error in designing temporary hangers, the already-critical review process will be further delayed.

Cofferdams

Groundwater and unforeseen springs can increase the cost of dewatering a bridge construction site.

Partial Width Construction

Staged construction (i.e., partial width or phased) yields sub-optimal outcomes due to all the necessary joints. This approach also drives up costs. When road closures are needed, agencies should invest the time and effort to develop a good public information campaign. Missouri successfully used a series of closures to work on portions of an interstate through St. Louis in 2008. Efficiency and savings were realized, and the public responded favorably. The Pennsylvania DOT prefers to build structures with enough girders to ensure half-width maintenance activities can be conducted, but agency officials remove traffic through construction closure whenever possible.

Market Capacity

Spreading out bid lettings for bridge construction helps increase competition and lower costs. Pennsylvania DOT strives to maintain a consistent letting volume for its bridge replacement program and publishes an anticipated schedule. Publicizing the schedule keeps precast yards from being overwhelmed with upticks in work. Metered lettings are also more feasible for internal staff who prepare lettings. The agency also bundles bridge projects to get lower prices. It uses alternative bids (steel/concrete) and allows bridge redesign. This can include fewer girders to a point.

Geotechnical Risks

Interviewees agreed that geotechnical issues drive up costs and offered specific examples and promising solutions:

- Incorrect original friction pile bearing estimates demand expensive field adjustments to the piles to achieve bearing requirements. Pennsylvania DOT studies past projects for insights into the number of core borings most likely to prevent cost overruns.
- Pennsylvania DOT typically extends drilled shafts by 4 ft. to accommodate slight differences in rock elevation. Site conditions that vary more than that introduce greater expense.

General Notes from Other DOTs and Recommendations

- Due to significant karst topography, Pennsylvania DOT sometimes uses grout tubes. The agency has begun using micropiles frequently, even installing them through old bridge abutments. Drilled shafts are a preferred foundation design.
- Pennsylvania DOT is studying the low-bidder system to see if qualifications-based selection for bridge construction will offer improvements. Legislation would be necessary to move away from low-bid selection.
- High bridge skew increases costs.
- Missouri DOT tried alternate bid options (i.e., concrete beams versus steel girders.) Out of seven recent lettings, steel received the low bid twice. The alternate bid system apparently increases competition enough to regulate cost.
- Missouri DOT's online plans room may offer some ideas: https://www.modot.org/modot-online-plans-room.
- Missouri DOT uses precast panels to save on deck construction.
- Integral end bents allow Missouri DOT to avoid joints.
- Interviewees recommended being mindful of ways to minimize maintenance costs.
- Tybot is an automated robot for tying steel reinforcement. Ironbot also automates the placement of reinforcement. These are interesting options to reduce labor costs. https://www.constructionrobots.com/
- Pennsylvania DOT has coordinated with contractors when dividing larger bridge projects. Pre-construction meetings were held, and the work was split up into manageable contracts.

- Good industry relations improve designs and cut costs. Multiple annual conferences support industry communication and relationship building.
- Pennsylvania DOT is testing smart glasses for fabrication inspection. Consultant inspections are responsible for nearly all fabrication approvals. https://proceedix.com/devices/smart-glasses
- Context capture is another innovation to consider, though file sizes are presently cumbersome. https://www.bentley.com/en/products/brands/contextcapture
- Surphaser 3D scanner has potential. http://www.surphaser.com/index.html
- Pennsylvania DOT trained a technician in phased array ultrasonic testing. The method offers unprecedented visibility of defects. Specifications were adjusted to allow more inclusions because this method identifies so many that were previously missed.

Chapter 5 Data Review

5.1 Average Unit Bid Price – Structures Items Evaluation

We evaluated average unit bid prices (AUBP) for eight bridge construction bid items across a seven-year study period (2015 – 2021):

- Steel Reinforcement
- Steel Reinforcement – Epoxy Coated
- Concrete Class A
- Concrete Class AA
- Remove Structure
- Foundation Preparation
- Structure Excavation – Common
- Structure Excavation – Solid Rock

Taken alone, AUBP analysis cannot speak to overall cost drivers in bridge construction. Nonetheless, it gave us the opportunity to explore observations and concepts from our interviews. The prices of all eight items went up during the study period. Steel Reinforcement and Epoxy Coated Steel Reinforcement exhibited the most statistically robust trends (Figures 5.1 and 5.2)

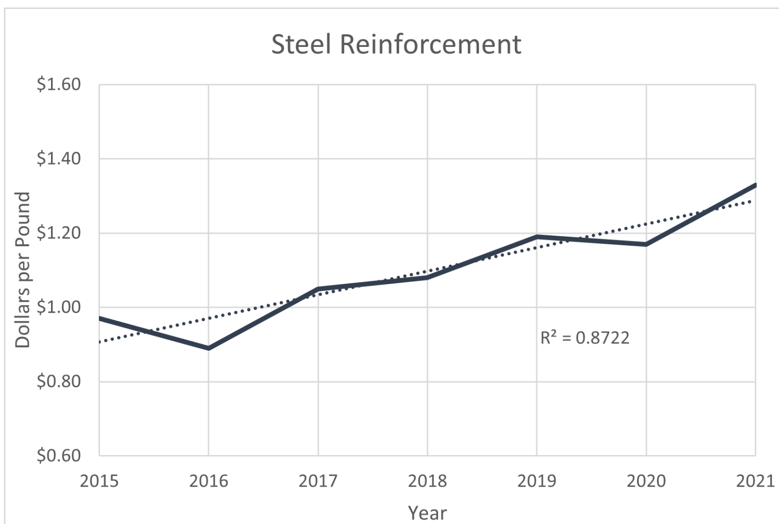

Figure 5.1 AUBP for Steel Reinforcement (2015 – 2021)

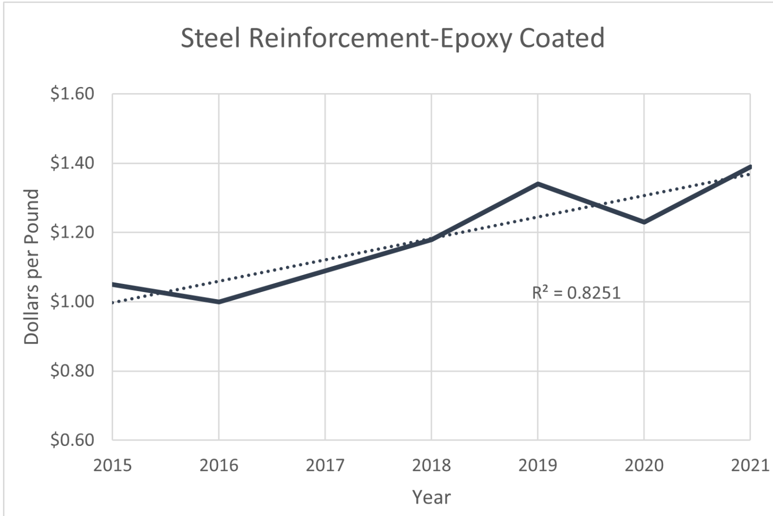

Figure 5.2. AUBP for Epoxy Coated Steel Reinforcement (2015 – 2021)

Pricing for Concrete Classes A and AA followed patterns similar to Steel Reinforcement (black and epoxy coated), although no strong trendline was evident (Figure 5.3). Price increases for superstructure materials in 2019 (Concrete Class AA and Steel Reinforcement-Epoxy Coated) were more pronounced than for their substructure counterparts (Concrete Class A and Steel Reinforcement). Concrete Class A and (black) Steel Reinforcement bid items may also be used for materials installed but unrelated to structures (e.g., headwalls.)

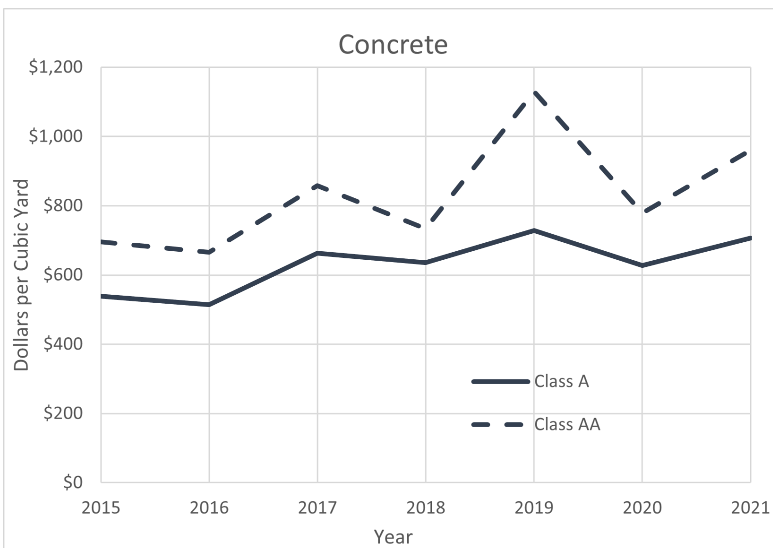

Figure 5.3 AUBP for Concrete Class A and Class AA (2015 – 2021)

We can get a handle on how bidders perceive risks associated with project-specific details by looking at lump sum-type pay items embedded with incidental work and weighting them by geotechnical uncertainties. Perceived risk from incidentals and unknown site conditions relates directly to bid pricing, with higher perceived risk resulting in higher bids. Mobilization, Clearing and Grubbing, Remove Structure, and Foundation Preparation are examples of lump sum bid items. KYTC construction inspection staff approve contractor payments for these bid items using fractions of lump sum, or each spread over multiple pay estimates. Because Remove Structure and Foundation Preparation only pertain to structure construction projects, annual statewide AUBP comparisons offer evaluation of historic bridge-specific construction pricing. Remove Structure pricing increased in four out of six years (Figure 5.4).

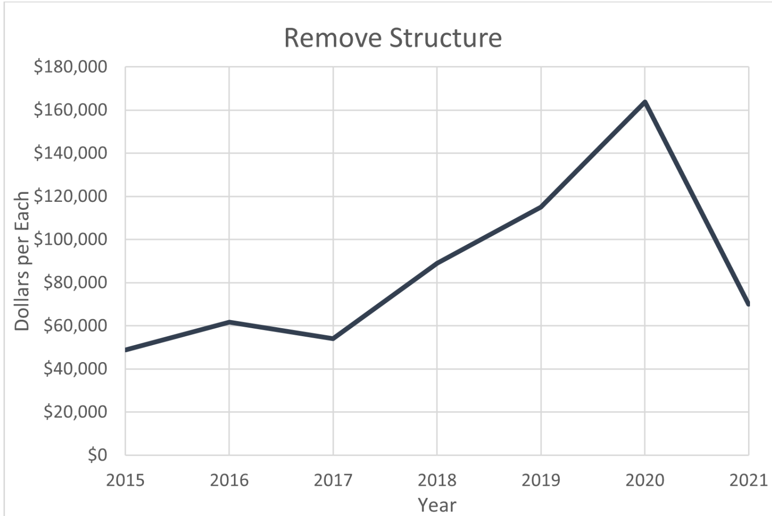

Figure 5.4 AUBP for Remove Structure (2015 – 2021)

Of the bid items we performed AUBP analysis on, pricing for Foundation Preparation showed the most pronounced fluctuations. (Figure 5.5). AUBP for Foundation Preparation fell in 2016 and 2017 — the only item showing a multi-year price decrease during the study period. Pricing for this item did not surpass 2015 costs until 2019, when prices for all six bid items steeply increased.

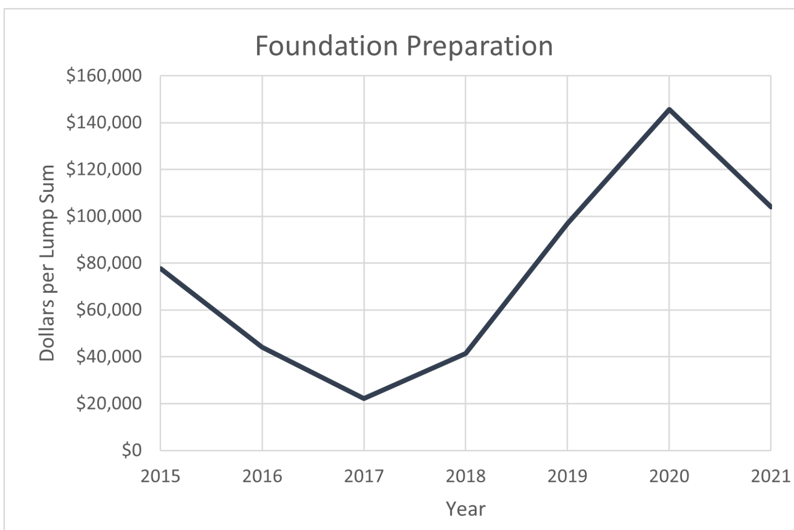

Figure 5.5 AUBP for Foundation Preparation (2015 – 2021)

Pricing trends for Remove Structure and Foundation Preparation become more telling when viewed in the context of a threefold spike in total contract occurrences — the number of KYTC construction contracts with these items of work in 2018 and 2019. Figures 5.6 and 5.7 capture the magnitude of this single-year increase in the number of contracts with the two bid items. The secondary y-axis plots AUBP. For Foundation Preparation, the pricing spike closely followed an uptick in bridge construction projects in 2019. Pricing averages for both items remained high in 2020, although the contract volume spike disappeared. In 2021, average pricing for these items dropped sharply, but contract volume showed a modest recovery.

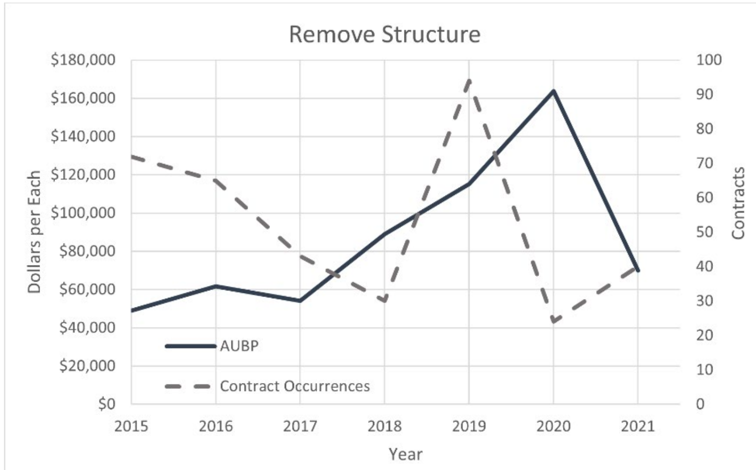

Figure 5.6 AUBP for Remove Structure and Contract Occurrences (2015 – 2021)

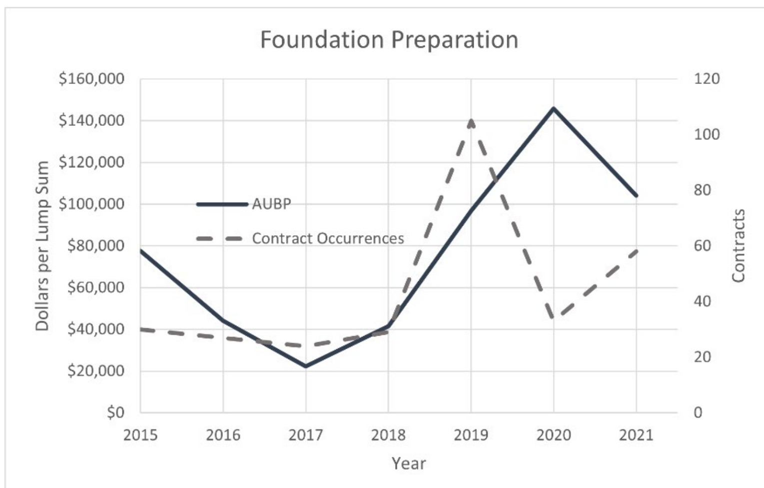

Figure 5.7 AUBP for Foundation Preparation and Contract Occurrences (2015 – 2021)

Structure Excavation bid items (Common and Solid Rock) are tracked in cubic yards, but also relate to subsurface geotechnical risks faced by contractors. Unlike Foundation Preparation, prices dropped quicker for these two bid items (Figures 5.8 and 5.9).

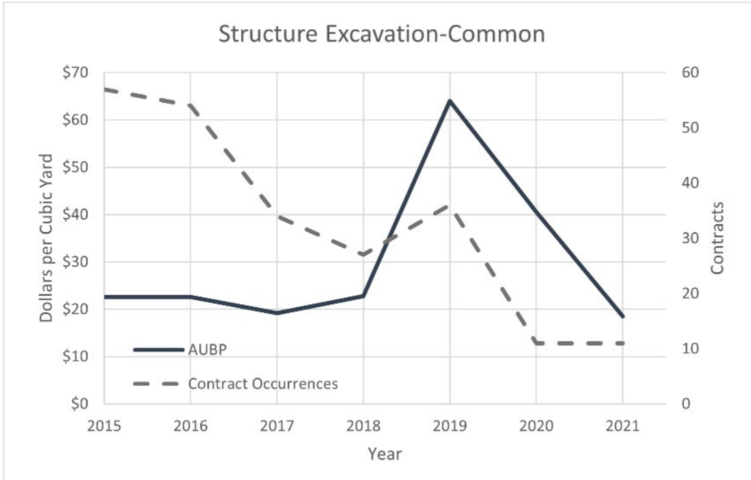

Figure 5.8 AUBP for Structure Excavation-Common and Contract Occurrences (2015 – 2021)

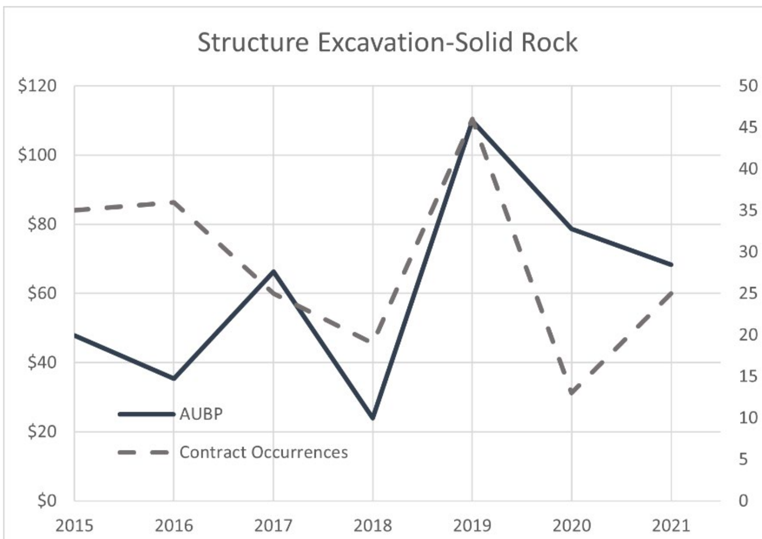

Figure 5.9 AUBP for Structure Excavation-Solid Rock and Contract Occurrences (2015 – 2021)

Statewide, AUBP for the eight bridge-related bid items drastically increased concurrently with 2019's tripling of bridge projects let to construction.

5.2 Bid Item Price Mining and Analysis – Post-Letting Dataset

We next analyzed detailed KYTC bridge construction project data for 185 structure-related bid item codes for contracts issued between 2015 and 2021. Kentucky's standard bid item codes list relates to work tasks found in the *Standard Specifications for Road and Bridge Construction*. The full dataset included the *Six-Year Highway Plan* (SYP) contains information on Number, Federal/State Project Number, County, District, Contract Identification Number (CID), Bid Quantity, Net Change Order (CO) Quantity, Unit Price, Quantity Paid (to date), and Project Paid Off Date for all projects let during this period.

Bid Quantity, Net Change Order Quantity, and Quantity Paid (to date) relate to project adjustments in different but important ways. For example, an original bid quantity may have been overrun or underrun at the direction of KYTC field staff without a change order. We referenced paid-off date to contextualize project status and determine if quantity that has been paid to date represents the final quantity.

To compare original bid quantities to final quantities paid for projects and contextualize the data, we used the ratio of the proportion of the pay volume (converted to dollars with unit pricing) to the overall project contract dollar amount. For example, an adjustment that increased the original contract amount of steel reinforcement by 5,000 lb. may significantly increase the original bid item amount buy only represent a small percentage of the project cost. We focused on the highest dollar changes (net negative or positive) targeting the most impactful anomalies through both a statewide (full dataset) and project-level lens.

Bid items changed from original quantities were compared using conversion to overall dollar amounts. Our list of projects with the most expensive changes for structure-related bid items may be used for case studies, if KYTC wants to pursue this route. Items listed in Table 5.1 account for the most costly single project changes post-award for KYTC during the study period.

Table 5.1 Items Responsible for the Most Expensive Changes Post-Award

Bid Item Code	Description
08160	Structural Steel
24520EC	PPC I-BEAM HN 48-49
08100	Concrete – Class A
08104	Concrete – Class AA
02731	Remove Structure
21420ED	DRILLED SHAFT-66 IN (COMMON)
08634	PRECAST PC I BEAM TYPE 4
08003	Foundation Preparation
08039	PRE-DRILLING FOR PILES

To further categorize the dataset, we used contract identification numbers (CID) to separate project types. The CID's first two digits indicate calendar year the project let to construction bids, while the third digit represents the program in which a project originated:

1=Project Development (Plans, Specifications, and Estimate (PS&E) process held)
2=Maintenance Program
3=Rural Secondary Roads
4=Highway Safety Improvement Program
5=Bridging Kentucky Program
9=Design Build Projects

For example, a CID of 195000 is a Bridging Kentucky project let in 2019. CID nomenclature provides additional depth to the pricing study (Figure 5.10). As evident in the data for 2019, some project prices spiked. This appears especially pronounced among CIDs taking the form of 195XXX (captured in the blue oval).

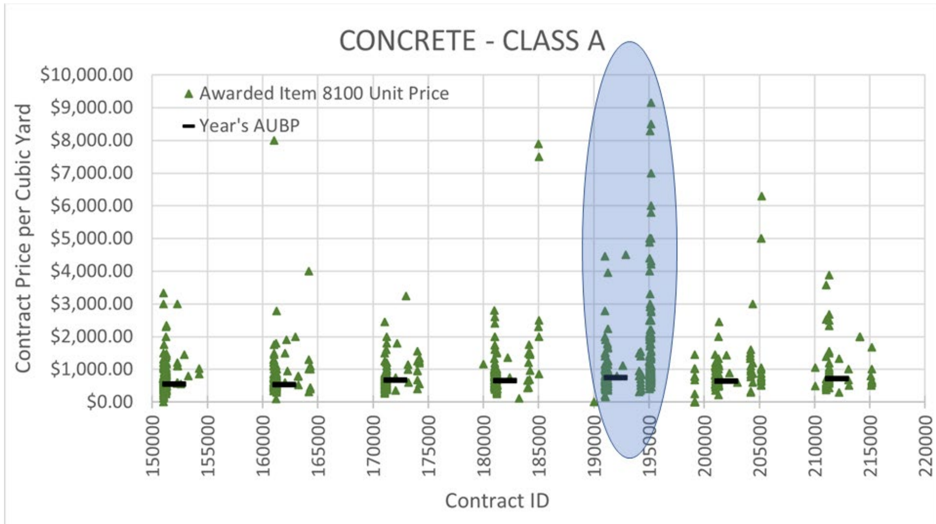

Figure 5.10 Awarded Bid Item Price for Concrete – Class A per Year with AUBP per Year

Chapter 6 Recommendations

- KYTC's implementation of AASHTOWare Estimation for project development workflows is underway — staff in the Divisions of Construction Procurement and Structural Design have been introduced to it. Customizing the software will let Division of Structural Design staff tap directly into construction project details. Because KYTC is already an AASHTOWare client, Estimation provides the Cabinet an ideal option to track and analyze bridge costs.

- Before AASHTOWare Estimation is fully deployed among Division of Structural Design staff, we recommend data mining through Crystal Solutions queries. Periodic data queries can efficiently support FHWA reporting requirements. Building Crystal Solutions queries with the help of Division of Construction technical support staff requires minimal effort and can inform project development for bridges until AASHTOWare Estimation is fully functional.

- Milestone date entries in AASHTOWare can facilitate the Division of Structural Design's tracking responsibilities. Entries can also be queried. Relevant examples include the date a structure opens to traffic or its inspection date. Screening projects based on the date they opened to traffic fosters efficient reporting without having to navigate multiple data sources or manual data entry.

- AASHTOWare includes supplemental description fields that can be used to track critical project details. We recommend using these to monitor information on structures. Selective use of these data fields already provides critical context for individual bid items (e.g., total estimated acreage for clearing and grubbing, structure identifiers (location or number) for Remove Structure bid items). Coordinating with the Divisions of Construction and Highway Design on judicious use of supplemental description fields will benefit staff across multiple divisions. These fields can also be used by Division of Structural Design staff to track bridge deck area.

- Staff should conduct post-construction, structure-focused project reviews. The Division of Highway Design's post-construction review process offers a useful model. Project selection could be supported through Crystal Solutions reports that itemize mass quantity changes or formal change orders tied to structure-related work items. Informal post-construction projects review are recommended when formalized meetings are impossible to coordinate. KYTC will also benefit from individual project case studies, like those identified by interviewees.

- Interviewees agreed that mismatched project contract duration is a major cost driver. KYTC's process for developing contract durations and types (e.g., working days, calendar dates) should be evaluated for improvement opportunities.

- Performing benefit-cost analysis of more in-depth geotechnical investigations (e.g., increased coring during preconstruction) will inform risk-based decision making on how unforeseen site conditions affect structure foundations. This study will be especially useful if the analysis considers the effects of region and context (i.e., urban, suburban, rural).

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