Montana Department of Transportation July 2017
RESEARCH PROGRAMS

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Top-down Construction Cost Estimating Model Using an Artificial Neural Network

http://www.mdt.mt.gov/research/projects/const/cost_est_neural_network.shtml

Introduction

This two-year study was aimed at improving the quality of early construction cost estimates. It sought to exploit cutting-edge advancements in data mining and acquisition to develop data-driven estimating models using artificial neural networks (ANN) and multiple regression techniques. It also aspired to provide a flexible approach to the development of construction cost estimates at the earliest stages of a typical MDT project's development. These tools were combined with a top-down estimating approach to solve the fundamental problem: achieving improved cost certainty in early planning and design stages before quantities are available(i.e. the classic unit price bottom-up estimate).

The issue of accurate estimating is essentially tied to the efficient use of available public capital. Early estimates developed during the planning phase often turn into project budgets before the final scope of project work is adequately quantified. States with small populations and large amounts of highway lane miles to service must use funds appropriated for design, construction and maintenance as wisely as possible. To do so, requires that early estimates of project costs are not overly inflated, potentially preventing precious federal-aid funding from being obligated on other projects. Worse yet, if the budget overage is found late in the fiscal year, the incremental overage can be lost to the state by Federal Highway Administration (FHWA) year-end reapportioning. The other side of the coin is a concept called "optimism bias" where engineers unintentionally underestimate project cost and keep the project "alive" by making unrealistically optimistic assumptions in the project's estimate and schedule.

A previous MDT research project furnished a bottom-up conceptual estimating procedure that appears to be risk-adjusted but utilizes extremely small sample populations. That study found that MDT sees a 46% growth in construction cost from programming to construction completion. Montana's small population and huge area makes it imperative that MDT squeeze every last penny out of its federal and state highway funding to provide as much service as it can afford. So, reducing cost growth from the early estimate is a priority. To do so, requires that the uncertainty associated with future costs be reduced and that means better conceptual estimates. It also requires a shift in fiscal philosophy from the normal decision criterion of "minimize construction costs" to a new one of "maximize construction cost certainty." This shift is in line with current FHWA policy which changed the old mantra of "better, faster, cheaper" in 2010 to "better, faster, smarter." The words "better" and "faster" in the old saying are fundamentally at odds with the term "cheaper," expressing an unrealistic attempt to optimize the three concepts. The change to "smarter" brings the three into harmony and essentially expresses the notion that public agency engineers should strive to use every dollar available in a given project's appropriation to deliver the best project the department of transportation (DOT) can afford rather than trying to make the final project as cheap as possible. Current deteriorated state of the nation's highway system can be traced to the focus on "cheap" rather than "better and faster."

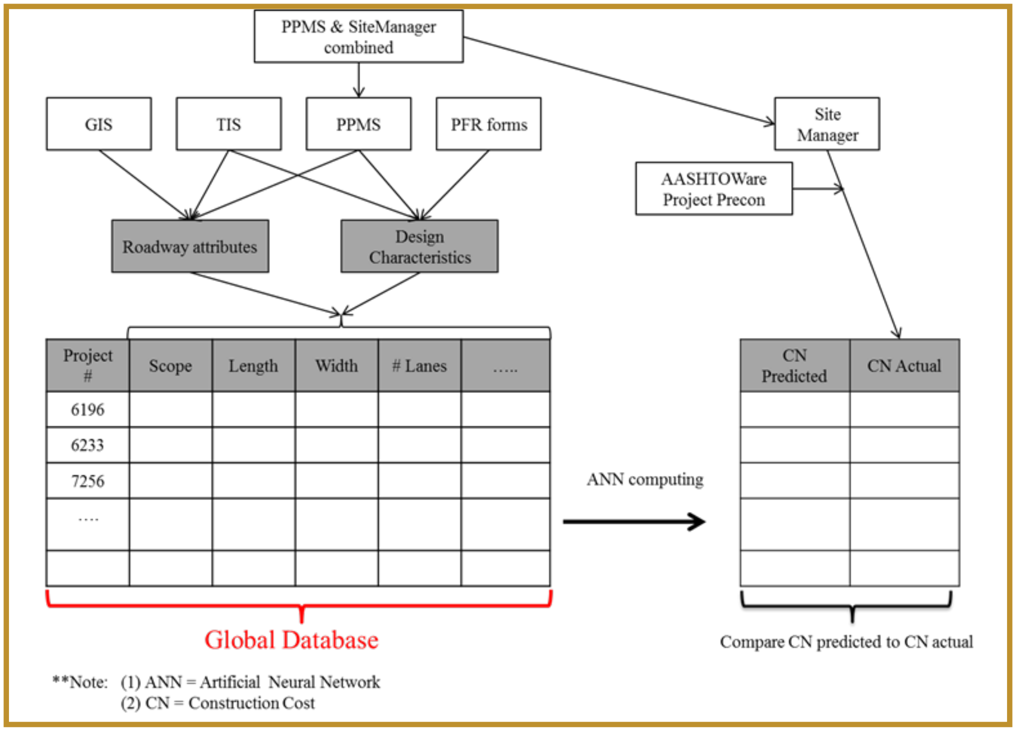

Figure 1: Incorporating databases to form a 'global database' for predicting construction cost with the model

What We Did

Data-driven top down early cost estimating models provide a means to better quantify the scope of work in dollar terms because it uses as-built construction costs from the MDT Program and Project Management System (PPMS) and SiteManager® construction cost databases rather than the product of "guess-timated" quantities of work generated early in the design process and bid tabulation as-bid unit prices used in conceptual bottom-up estimates (see Figure 1). The medium of sophisticated statistical analytics and machine learning furnishes the technical processing in a manner that facilitates increased cost certainty by focusing the estimates on those input variables that have the greatest influence on the bottom-line cost. An artificial neural network methodology, as well as a multiple regression estimation model was developed to compare prediction accuracy of proposed estimating approaches to those achieved under MDT's current practices. Four separate estimation equations were provided to predict agency costs under three broad project work types. Together these groups of work account for more than 80 percent of the agency's construction program.

Due to the critical nature of input selection for the cost estimation methodologies, the study allocated considerable effort to the proper identification of project and attributes variables that are often readily available at the early stages of an agency project. Upon conducting an extensive review of MDT's budgeting and cost estimating efforts, the research team identified 27 project characteristics that were used as input to MDT estimates. A survey of 31 agency experts identified the most salient project attributes with the dual-objectives of low effort and high impact on estimate accuracy, and with that as a base, the team was able to propose a rational method for top-down variable selection as seen in Table 1 and Figure 2. Selected variables were

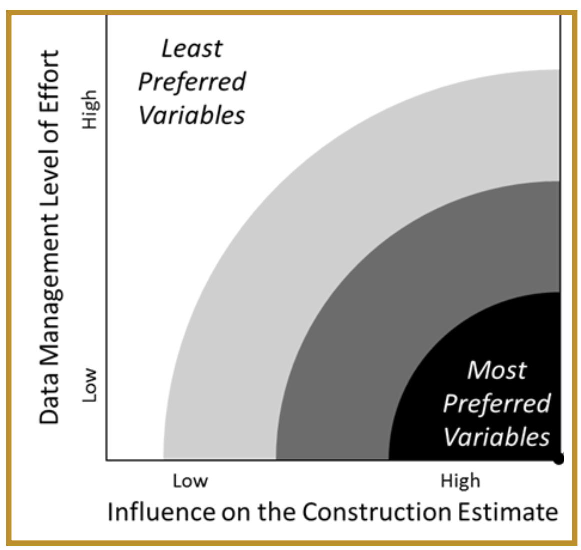

Figure 2: Selecting construction project variables for construction cost estimating model

Table 1: Input variables that were recognized at MDT through inverviews

	Design related attribute		Roadway information attribute
1	Design AADT	19	Urban or rural project
2	Design speed	20	Construction on Native American Reservations
3	Start and end stations, length and width	21	Site topography
4	Intersection signalization and signage	22	Existing surfacing conditions and depths
5	Horizontal and vertical alignment	23	Number of intersections in project
6	Extent of changes to the existing intersections	24	Number of bridges in the project scope
7	Typical section		**Construction Administration attribute**
8	Curb, gutter and sidewalk	25	Traffic Control - closures or detours
9	Bridge type and complexity	26	Environmental permitting requirements-wetlands
10	Volumes of excavation and embankment	27	Letting Date
11	Geotechnical - subsurface and slope recommendations	28	Context sensitive design issues, controversy
12	Bridge deck area	29	Contract time
13	Hydraulic recommendations and culverts		
14	Storm drain extents		
15	Bridge span lengths		
16	Foundation complexity of the bridge		
17	Right-of-way acquisition and costs		
18	Extent of utility relocations and costs		

further tested in their explanatory power of construction costs through the application of two cost estimating methodologies; multiple regression and artificial neural network methodologies. Both methods are shown to provide sizeable improvements over the agency's current levels of prediction accuracy for its construction costs. Potential accuracy gains are also demonstrated to depend on project work types. The comparison of mean absolute percentage errors across different estimating methods confirms that the potential benefits from the proposed methodologies are expected to rise as the project level complexity and uncertainty increase. Bridge reconstruction and replacement projects, for instance, are expected to gain the most in estimating accuracy since these two groups seem to exhibit considerably higher levels of deviation from the MDT's preliminary cost estimates.

To facilitate MDT's implementation of the suggested methodology developed, a cost estimation methodology was also presented in an MS Excel® spreadsheet format. This achieves two goals. First, it provides an accessible tool to make top-down cost predictions for agency planners during the budgeting stage based on MDT's historical project data. Second, it furnishes a process through which the proposed model can be improved as new project information becomes available. Ultimately, the insights gained from this study are expected to contribute to a better formulation of the agency's early cost estimation and budgeting efforts.

What We Found

The top-down estimating methodology decreased the mean average percent error for bridge projects when compared to the current estimates made in MDT Preliminary Field Review (PFR) reports used during the project programming, budgeting and development process. Estimating error was reduced as much as 18% in bridge replacement projects and 11% in bridge reconstruction projects (See Figure 3). This marked increase in cost certainty at an early stage of project development will mean that MDT will need to tie up smaller amounts of funding as contingencies, releasing it to be

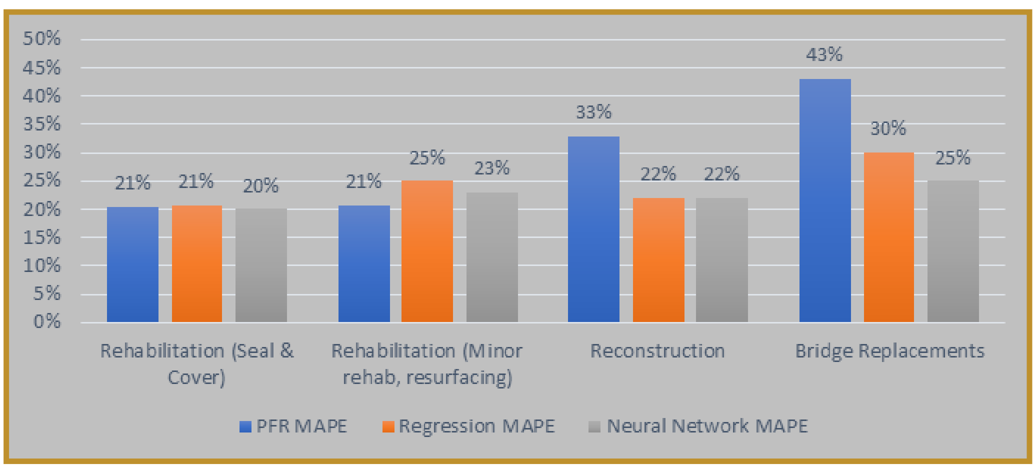

Figure 3: Prediction accuracy of multiple regression, neural network cost estimating methods, and MDT estimates (PFR)

Note: MAPE = Mean Average Percent Error

applied to completing more projects without an overall budget increase. This is definitely a "smarter" way to conduct project development. The same improvement was not observed in pavement projects since the number of input variables are significantly fewer than in a bridge estimate. Nevertheless, over time the reduction in system errors due to increased consistency of how early estimates are produced along with the use of as-built rather than as-bid data should improve estimating quality in all project types.

The significant aspect of the research is that the improvement in estimating error was achieved by building models that contained the minimum number of input variables selected based on their predictive impact on the estimate and minimizing the level of effort by MDT engineers to quantify them. For example, the two types of bridge projects and the rehabilitation (seal and cover) projects only used six input variables apiece. Figure 4 shows the relationship between the ANN model's predicted construction cost and the actual construction costs of the MDT projects in the research database.

What the Researchers Recommend

Cost estimating equations for this project were developed through the consolidation of high-level project information that is readily available during the project inception phase with the projects' final construction costs based on their contract award information. Due to the constantly evolving nature of project scopes during the project development stage, the ease of updates to early cost estimates as scope changes occur will be critical for the efficient implementation of the proposed methodologies. As such, the integration and timely update of early project information on MDT project management systems is a logical next step in further improving the initial model specifications provided here. Further, tailoring MDT project management systems with an emphasis on capturing project information essential to the accuracy of early estimating practices is expected to increase the confidence levels of agency's budgeting efforts notably.

Finally, identifying those projects that experienced considerable variances from funding to the award stage and the analysis of such unexpected deviations from baseline budgets will ensure the calibration of the estimation equations as MDT's dynamic planning needs continue to evolve.

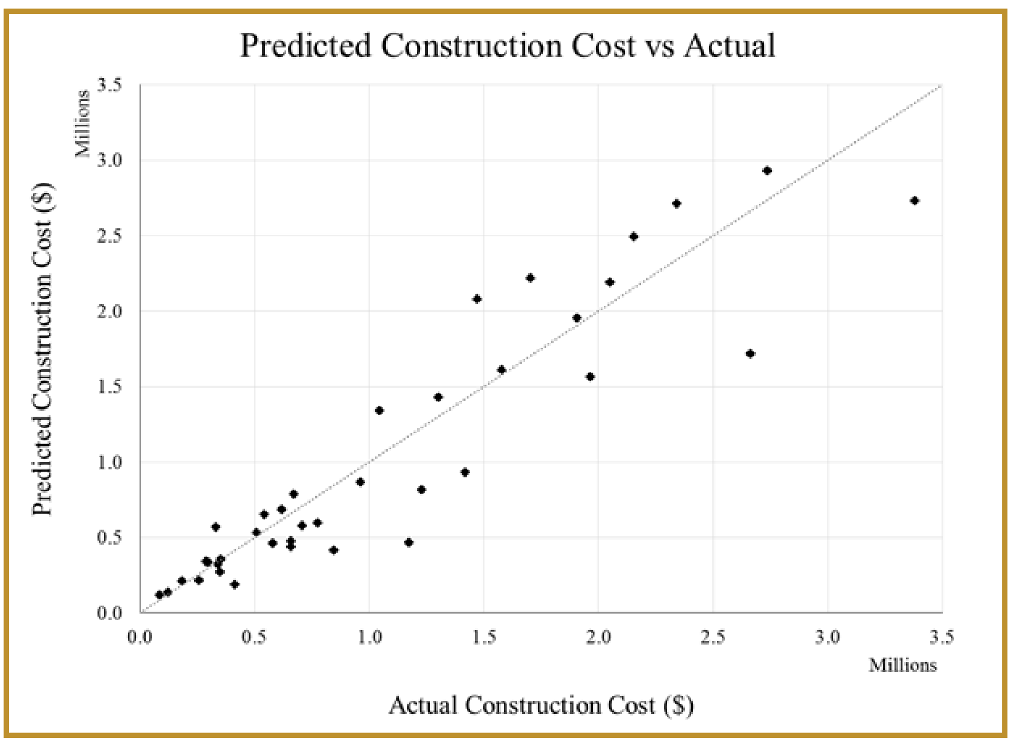

Figure 4: Visual representation of the ANN prediction modeling tool

For More Details . . .

The research is documented in Report FHWA/MT-17-007/8227-001, http://www.mdt.mt.gov/research/projects/const/cost_est_neural_network.shtml

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MDT Implementation Status: July 2017

MDT will use information from this research in the process of updating and improving cost estimating practices, guidance and tools.

ALTERNATIVE FORMAT STATEMENT

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