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TITLE: A FEASIBILITY STUDY FOR MODEL BASED ESTIMATING FOR CONCRETE BRIDGES

ABSTRACT

Designing and estimating civil concrete structures is a complex process which to many practitioners is tied to manual or semi-manual processes of 2D design and cannot be further improved by automated, interacting design-estimating processes. This paper presents a feasibility study for the development an automated estimator for concrete bridge design. The study offers a value proposition: an efficient automated model-based estimator can add value to the whole bridge design-estimating process, i.e., reducing estimation errors, shortening the duration of success estimates, and increasing the benefit of doing cost estimation when compared with the current practice. This is then followed by a description of what is in an efficient automated model-based estimator and how it should be used. Finally the process of model-based estimating is compared with the current practice to highlight the values embedded in the automated processes.

Keywords:
Model-based design and estimating

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THE PAPER

1.0 INTRODUCTION

Designing and estimating civil concrete structures is a complex process which to many practitioners is tied to manual or semi-manual processes and cannot be further improved by automated computer based processes. This paper presents a feasibility study for the development an automated estimator for concrete bridge design, and demonstrates that such estimators can add significant value to interacting design and estimating and offer themselves a future.

An earlier CRC-CI project on automated estimating has shown the key benefit of *model-based design methodologies* in building design and construction to be the provision of timely quantitative cost evaluations (Drogemuller 2003). A building model was input into the estimator which automatically produces the estimated prices of the concrete trade for the building's construction. The speediness of cost estimation has produced an important impact on the building design – the easier cost estimation is obtained, the better it can be used to guide the design of buildings. From a theoretical perspective, Yum (2005) proved that using model-based approach during building design can improve design options, with shorter design turn-around times, better design quality and/or lower costs. The question is: Does the benefit of efficient estimation warrant further development of automated estimators outside the realm of buildings?

Automated estimating for civil engineering structures do not exist; and research partners in the CRC-CI expressed interest in evaluating whether it is feasible to extend automated estimating for buildings to the realm of design of civil concrete structures. This paper presents the work done on these investigations to the construction community, with the view that they can add values to the further research and development of automated estimators for civil concrete structures in the future.

The scope of the study is to investigate whether it is feasible to develop an automated estimator for civil concrete structures – questions asked are: Do such estimators add value to the design and construction of concrete structures? And if the answer to the first question is yes, where does the benefit lie? And what is the functional form of the estimator?

The following are out of the scope of the study:

- A fully developed business case for an automated estimator for civil concrete works.
- Designing processes for the model model-based design approach.
- Designing schemas for the planning/design/estimating of bridges.
- Implementing the above designs in supporting software applications.

The contribution of this paper is twofold: (a) to identify points where values can be added to the processes of design, assessment and construction of concrete bridges, and (b) to embed such values into the process of automated estimating and the functional requirements of the automated estimator.

2.0 METHODOLOGY

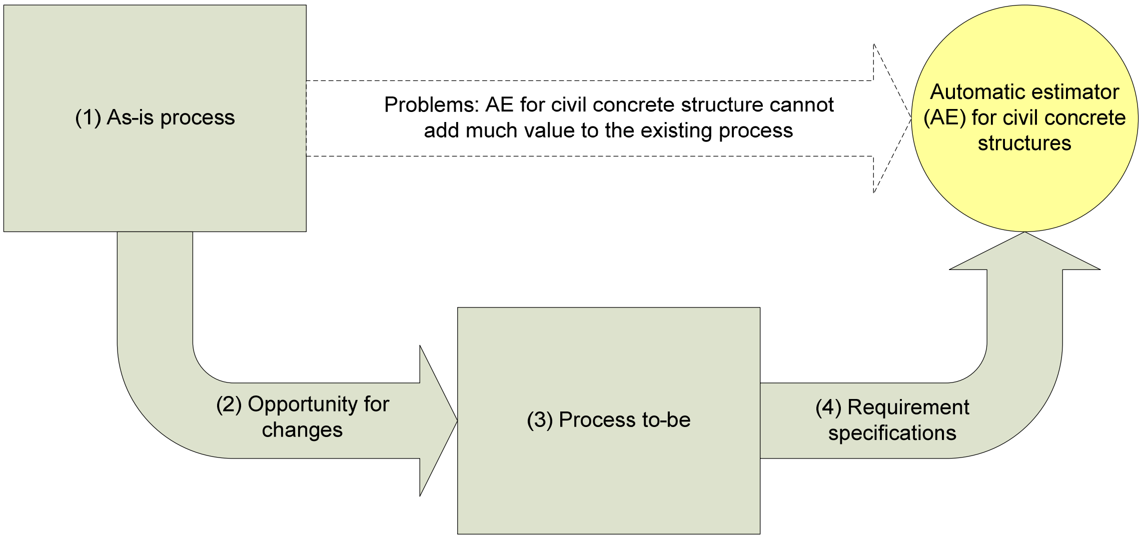
Figure 1 shows the context and methodology used to investigate the feasibility pf developing an automated estimator for civil concrete works.

The study first established the fact that there are two types of estimating in the current practice of bridge estimation. Of these two types only the type of estimation for design has potential to add significant value the whole design-estimating processes.

The second part of the study identified the opportunities of improvement - viz. model-based technology adds efficiency and functionality to software that supports the interaction of design and estimating. A value proposition is established: an efficient automated estimator can add value to the design-estimating process, i.e., reducing estimation errors, shortening the duration of success estimates, and increasing the benefit of doing cost estimation when compared with the current practice. The value proposition rests on the availability of an efficient automated estimator for design-estimating interaction – if such an estimator is available, the use of it will add significant value to bridge design and thus enable the tool to grow in the commercial market.

The last two parts of the study was in synergy with each other: (a) designing typical use scenarios for using the model-based estimator efficiently, and (b) identifying the functional requirements for an efficient automated estimator of bridges.

Figure 1: Context and methodology for the research



3.0 CURRENT PRACTICE OF ESTIMATION

From this section onward planning/design and estimating are considered together as they are always intertwined to give the planner/designer some assurance of the quality and economy of the work to be carried out. As the Queensland Government of Main Roads (QDMR) has developed a full set of estimating standards (e.g., QDMR 1999, 2002, 2004, 2005), including standard Work Breakdown Structures (WBS), we believed that investigating the current practice of estimation in the state of Queensland would perhaps give us a good starting point.

Estimating is executed in the context of project management in order to be an integral part of a system of interdependent core inputs of scope, time, cost and quality. Table 1 shows planning, design, estimating and construction activities in the context of project management lifecycle stages.

A project budget results from the approval of a business case concept estimate at the end of the concept phase. This estimate is based on a sound definition of scope of the preferred option derived from scope analysis. Once the project is justified, it is placed in the

Roads Implementation Program (RIP) for further development. The total development time in RIP is about 5 years (indicative only). It is expected that project scope and details are progressively refined. As more information is added to the design over time, the estimation percentage errors relative to the final total cost of the project are expected to decrease.

Table 1: Estimating in the context of project life cycle stages (QDMR 2005)

Project Life-cycle Stage	Pre-project	Project						
	Strategic	Concept phase			Development phase		Implementation phase	Finalisation phase
	Network planning	Proposal	Options analysis	Business case	Preliminary design	Detailed design		
Timing	Pre-RIP (pre-Road Implementation Program)	Before RIP Year 5		For inclusion in RIP Year 5	For inclusion in RIP Year 2	Firm RIP Years 2-0		
Estimate	NIL	Concept phase budget	Comparative cost of options	Concept costing	Preliminary design costing	Detail design costing	Contract price	Final cost
Activities	Road asset use strategy; Road investment strategy; Corridor management plan; Link development plan; Integrated regional transport planning; Community/ shareholder engagements	Project identification	Solution options	Planning	Preliminary design	Detailed design	Construction	Project close down
Outcomes	Road network needs addressed	Project requirements: needs, problem, outcomes	Approved solution options	Scope of work	Project planning report	Scheme prototype, tendering documents, contract	Road network needs satisfied	Confirm achievement of required outcomes

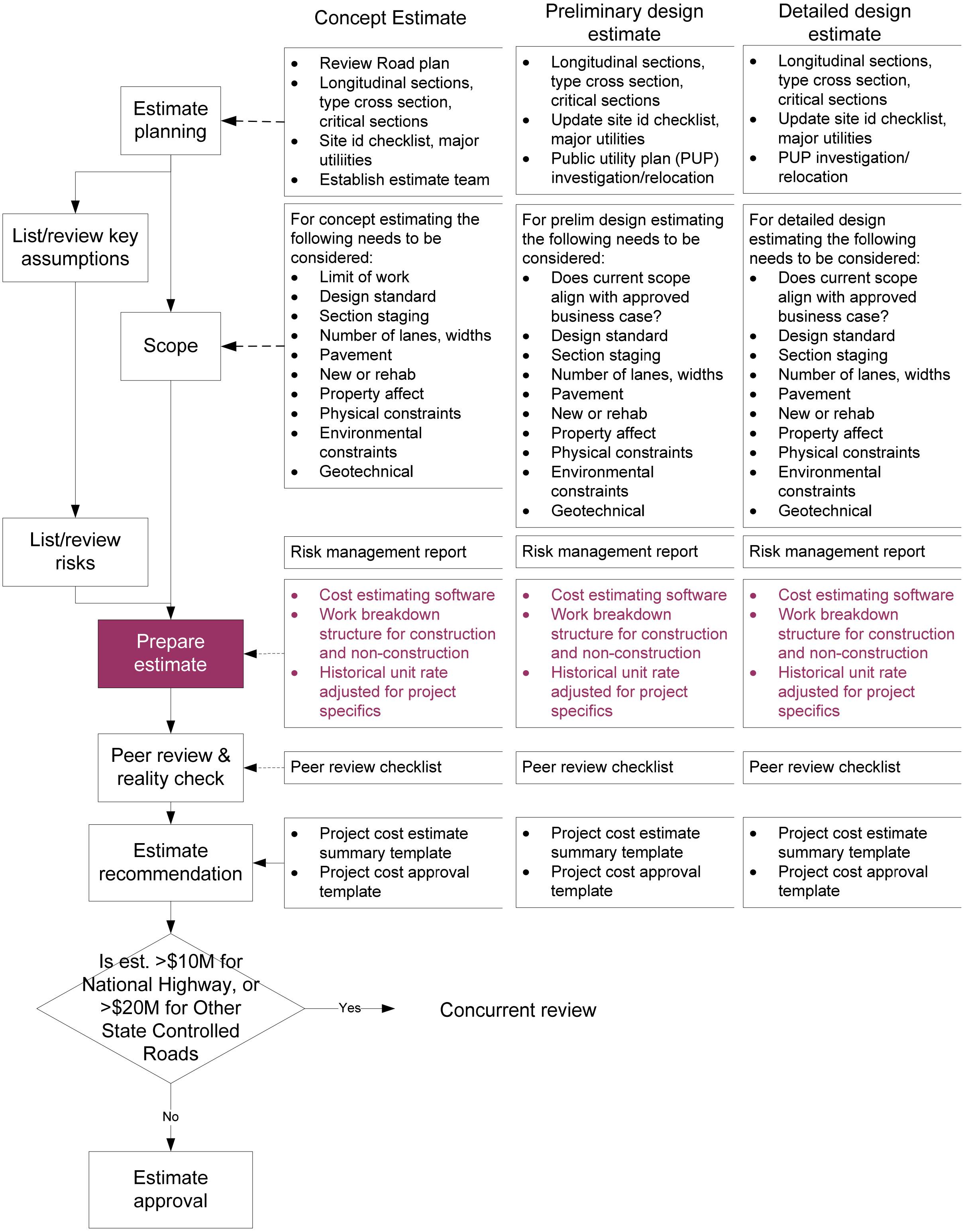
The preliminary design estimate is used to confirm the budget before the project moves into the last two years of firm RIP. At the end of the detailed design period, the design is completed; and tender documents are prepared for contractors to bid on.

Figure 2 shows the current procedures of preparing and approving an estimate at the concept, preliminary design and detailed design stages a la QDMR. In the figure, the preparation process for estimating is highlighted because it is highly relevant to the subject matter of this report – the automation of the estimating process.

3.1 MACRO LEVEL ESTIMATING

Planning and design of roads and bridges is a very complex process. To overcome the complexity, the whole planning and design process is compartmentalised into life-cycle stages, viz: concept stage, preliminary design stage and detail design stage. The estimating process at the end of each lifecycle stage is needed for project budgeting and approval. Each project life cycle stage has its own timeframe (5 years to months) and scope of work. It needs a lot of work to get the project to move from the concept stage to the next; and it needs even more work if a preliminary design plan is scrapped and goes back to the conceptual design stage. Due to the long duration of the project lifecycle stage (months or years), the estimate for each stage cannot be used to guide the fine tuning of design options – too many design hours have gone into the plan and it would be inefficient to redo it all again.

Figure 2: Procedure for preparation, concurrent review and approval of an estimate of costs at various project lifecycle stages (QDMR 2004).



Concept Estimate	Preliminary design estimate	Detailed design estimate
• Review Road plan • Longitudinal sections, type cross section, critical sections • Site id checklist, major utiliities • Establish estimate team	• Longitudinal sections, type cross section, critical sections • Update site id checklist, major utilities • Public utility plan (PUP) investigation/relocation	• Longitudinal sections, type cross section, critical sections • Update site id checklist, major utilities • PUP investigation/ relocation
For concept estimating the following needs to be considered: • Limit of work • Design standard • Section staging • Number of lanes, widths • Pavement • New or rehab • Property affect • Physical constraints • Environmental constraints • Geotechnical	For prelim design estimating the following needs to be considered: • Does current scope align with approved business case? • Design standard • Section staging • Number of lanes, widths • Pavement • New or rehab • Property affect • Physical constraints • Environmental constraints • Geotechnical	For detailed design estimating the following needs to be considered: • Does current scope align with approved business case? • Design standard • Section staging • Number of lanes, widths • Pavement • New or rehab • Property affect • Physical constraints • Environmental constraints • Geotechnical
Risk management report	Risk management report	Risk management report
• Cost estimating software • Work breakdown structure for construction and non-construction • Historical unit rate adjusted for project specifics	• Cost estimating software • Work breakdown structure for construction and non-construction • Historical unit rate adjusted for project specifics	• Cost estimating software • Work breakdown structure for construction and non-construction • Historical unit rate adjusted for project specifics
Peer review checklist	Peer review checklist	Peer review checklist
• Project cost estimate summary template • Project cost approval template	• Project cost estimate summary template • Project cost approval template	• Project cost estimate summary template • Project cost approval template

Estimating at the end of a project lifecycle stage is referred to as *macro level estimating*. It is used for managing the total cost and/or budget estimating, but it is a brunt tool for planning and/or design.

3.2 MICRO LEVEL ESTIMATING

While the previous estimating process is related to project management, this subsection discusses the estimating process during the design process. The main difference is that the former process is performed to get approvals from one management lifecycle stage to another (total cost estimating); whereas the latter process is performed within the project team so that, at any moment of design, the cost factors are taken into design consideration (partial and total cost estimation).

QDMR (2002) is a road/bridge planning and design manual that collects a comprehensive set of design parameters, which include traffic parameters, human factors, speed parameters, safety barriers, sight distance, alignment design, intersections, transport systems, bridges, etc. These parameters (formally termed as *design domains*) and their values are selected for the justification of a design, which is either based on empirical safety research, or theoretical physical models, or both.

Any design with respect to a design domain is a compromise between competing requirements, expectations and contextual information (i.e. in terms of location and geometry problems, cost, safety, driver expectations, economic, environmental and social impacts.) Figure 3 shows a qualitative cost and benefit analysis of the selection of the width of a motorway shoulder (a paved strip beside the motorway). Selection of a value within a design domain depends on a trade-off between the issue context and various benefits and costs.

Figure 4 shows the interactions between planning/design and estimating with respect to any bridge elements at any level of details. The estimated cost is a part of the multi-criteria assessment (MCA) that helps select a solution from various design options. In any key design parameters such as traffic parameters, speed parameters, cross sections, safety barriers, lightings, bridge deck, piles, etc., a design domain (design parameter) is evaluated according to multiple values (such as mobility, maintenance cost, capital costs, environmental impact, accident rate, etc.) This loop defines the *micro level estimating* which assess the cost of *any part of the design at any planning/design time*.

3.3 CAN WE ESTIMATE QUANTITATIVELY AT MICRO LEVEL ESTIMATING?

If micro level estimating can help design optimisation at any planning/design time, the improvement can be significant because it is improved any concept/component and any time in the project planning and design process. However, the current practice seems to rely heavily on a human expert to judge qualitatively at the design time. The optimisation of using computer-based tools is only possible in the new planning/design paradigm – model-based design and planning, which will be considered in the next section.

4.0 VALUE PROPOSITION

This section develops the overall value proposition for an automated estimating system over the current processes that were summarised in the preceding section. It describes the areas where an automated estimating system could add value to civil works projects, discusses some of the issues impacting the cost/benefit considerations, and suggests ways in which the characteristics of such an estimating system impact the estimating strategy.

4.1 TECHNOLOGICAL CONTEXT – MODEL BASED DESIGN

A model-based automated estimating system requires a semantically-rich project data model as input (e.g., a Building Information Model, IFC model or similar). The project data model is an integrated model that can be used across a number of disciplines, such as geometry design of the road/bridge, structural loads, traffic requirements, stormwater systems, electricity equipment, etc., not just limited to estimating.

Figure 3: Design domain trade-off, shoulder width (TAC, 1999)

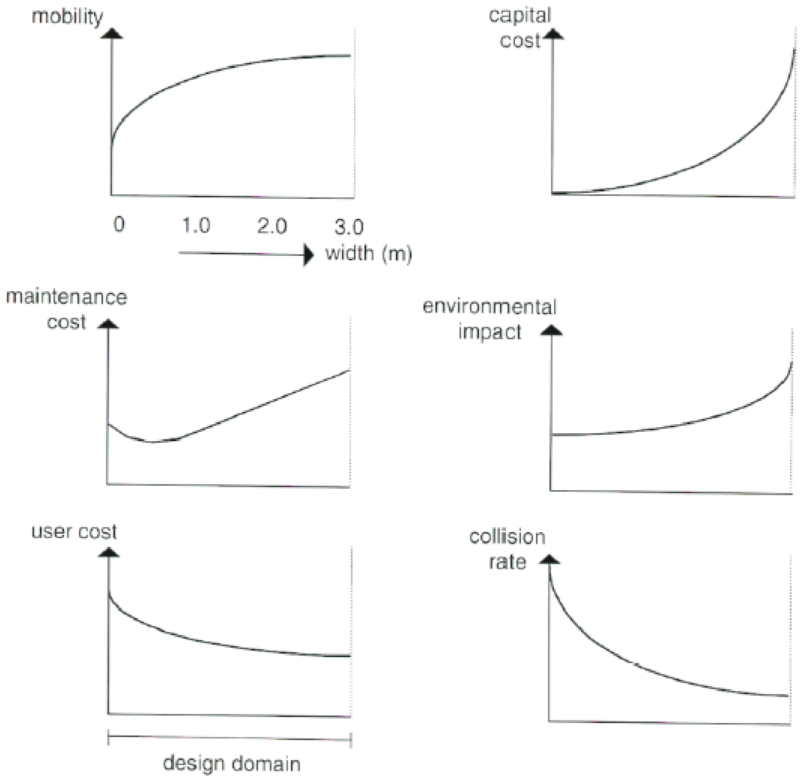
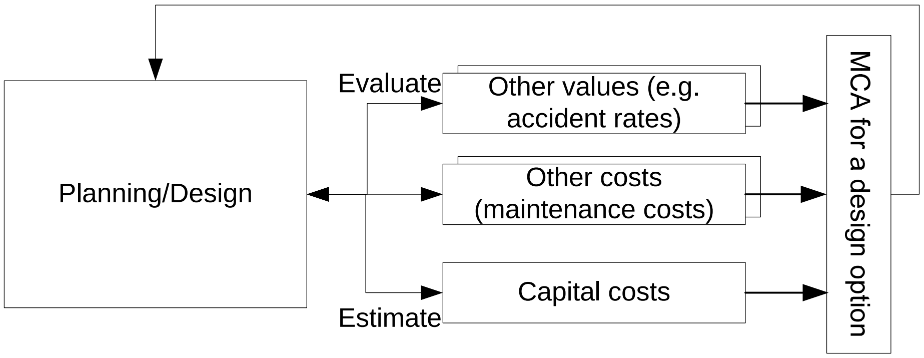


Figure 4: Micro level estimating and multi-criteria assessment (MCA)



It only makes sense to develop an automated estimator based on model-based design so that estimators re-use the data from the design model to assess costs. It makes little or no sense to require the user to manually re-enter design data into the automated estimator in order to evaluate costs.

Model-based technologies add value in two broad categories: (1) they add efficiency and functionality to individual software tools by allowing automatic generation of 3D views and design versions for project management; and (2) they improve data sharing, integration, and interoperability between design and estimating (i.e. the geometry design data of bridges can be re-used for the purpose of structural engineering design and cost estimation).

As a comparison, the general building construction industry appears to be in the early stages of adopting model-based technologies, and those companies that have made the transitions are experiencing positive overall outcomes. There is no reason to expect that the civil works industry would not similarly benefit from model-based technologies, although the required software systems, standards, etc. may be less-developed at present.

4.2 ORGANISATIONAL CONTEXT – ALLIANCING CONTRACT

In the traditional form of civil works project organisation, the owner engages design consultants who complete the project design before a contractor is brought onto the project through competitive tendering. Increasingly, variations in projects' organisational forms introduce a range of new relationships, tasks, and sequencing among the project participants. These organisational forms include design-build contracts, alliancing agreements, public-private partnerships, etc. Some of the outcomes of these organisational evolutions lead to a blurring of the boundary between the design stage and the construction stage, increasing collaboration between design and construction parties, and increasing participation of the contractor earlier in the project.

The organisational context impacts the system value proposition because the greater the interaction between design and construction throughout the early project phases, the greater the opportunity for an automated estimating systems to be used to produce frequent, reliable costs estimates throughout the design and tendering phases with minimal time, effort, and cost. This increased value arises because the designers are able to provide the early design information and to take advantage of improved cost estimates to guide design decisions; the contractors are able to provide construction methods decisions and costing information to improve the estimates' reliability; and the estimating system is able to convert these information inputs to cost estimates with a high degree of automation (and thus reduces time and cost).

4.3 DESIGNER'S VALUE ADDING PROPOSITION – ESTIMATING UTILITY THEORY

The most salient characteristic of model-based automated estimating is that, by automating quantity takeoff and other estimating tasks, it significantly reduces the amount of time and effort required to produce an estimate. This increased speed and efficiency provides several advantages that make up the most direct value propositions: (a) it provides substantial savings in the cost of producing estimates; (b) it provides quicker turn-around times for estimates, making estimating more convenient and timely; (c) it relieves pressure on estimating resources. For example, it would increase the capacity of a single estimator and reduce the likelihood of their acting as a bottleneck in the design process; (d) it also ensures that estimates are higher quality than might otherwise have been the case because measurements are prepared in a consistent and rigorous manner.

The less direct, but potentially greater value, proposition lies in the premise that, because it is much quicker, cheaper, and easier, estimates will be produced much more frequently throughout the design process and will thereby lead to better design outcomes. In its simplest form, this value proposition suggests that the outcome of any civil works project will be improved if an accurate cost estimate could be produced at any point throughout design and construction "at the touch of a button". This value arises because improved cost forecasts would facilitate better planning, design, and construction decisions. This proposition is clearly hypothetical—complete and accurate cost estimates can never be provided with no time and cost. Yet, acceptance in principle of this hypothetical value proposition motivates an examination of how near to this ideal we can approach with practical estimating solutions, and how much value these practical automated estimating solutions could provide.

A final value proposition lies in the fact that cost-related risks could be reduced if better cost information where available throughout the planning and design phases.

Conceptually, the *value* of producing an estimate is taken to be the monetary benefit of producing the estimate divided by the cost of producing it.[1] If the value (i.e. benefit/cost) is greater than 1.0, it should be worthwhile to produce an estimate, and given a range of possible estimating strategies, the alternative that yields the highest value should be chosen. To assess this value, we must evaluate both the benefit and the cost of producing an estimate.

Planning and design practices involve a lengthy sequence of decisions intended to produce a final outcome that meets cost and other project objectives. Given perfect information and prediction capabilities, the outcome would be very nearly optimal. However, information and prediction capabilities are not perfect, so results follow a bounded rationality—they are the best choices available given the limited information available.

With respect to costs objectives, explicit cost estimating provides the best available prediction of project costs. Yet, this explicit cost estimating is carried out only infrequently during the design process, and it is only at these infrequent times that the designers have the best possible cost information upon which to base their design decisions. In between these estimate points, design decisions are not arbitrary with respect to costs, but are based on cost-related judgements that designers are able to predict *without* the benefit of full cost estimates.

The *benefit* of cost estimating arises from the difference in cost between the design that would be produced without the estimate information, and the cost of a more optimal design that could be produced with the estimate information (the estimate information may also allow more optimal design decisions with respect to other project objectives such as lower risks, better decisions about additional features that could be included within budget targets, etc.) A number of factors impact the extent or magnitude of this benefit, including the accuracy of the estimate, the time intervals between successive estimates.

The benefit of the cost estimate will be proportional to the accuracy of the estimate. Very accurate estimates would provide near perfect cost information and will clearly be better than the assumptions that designers could make without any cost estimate. Very inaccurate estimates may be little better than the designer's judgement, thus providing negligible benefit. There are, of course, significant inherent uncertainties involved in predicting future construction costs, so there are very real practical limits to the accuracy attainable with cost estimates. Yet up to these accuracy limits, the following relationship exists: greater estimate accuracy can be achieved with greater estimating effort (i.e., the more accurate the estimate, the more costly it is to produce the estimate).

The combined effect of benefit/cost, as shown in Figure 5, relates the value of the estimate to the accuracy achieved. This relationship suggests an estimating strategy: that for a given situation, there will be an optimal level of accuracy to try to achieve (more accuracy will lower value by disproportionally increasing costs, less accuracy will lower value by disproportionally decreasing benefit). With a similar argument, the relationship between value of estimating and time interval between estimates is shown in Figure 6.

The next two figures (Figures 7 and 8) show the effect of automated estimating. The greater estimating efficiency will increase the relative value of the estimates and will shift the points of maximum value to the left in both figures. This will lead to a change in estimating strategy that constitutes the value proposition for designers to use automated estimating: the total cost of producing estimates will be less, estimates of greater accuracy will be produced

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[1] In this section, the term "cost" is referring to the *cost* of producing estimation. It is different from the terms like "project cost" and "cost estimating", which refers to the cost of the project.

more frequently, the overall value of the estimates will be higher, and the design outcome will be more cost-optimal.

Figure 5: Value of producing an estimate versus the accuracy achieved, where value is defined as the benefit/cost

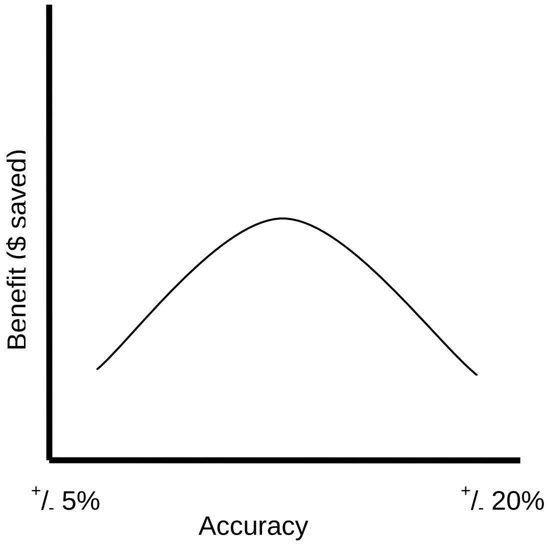
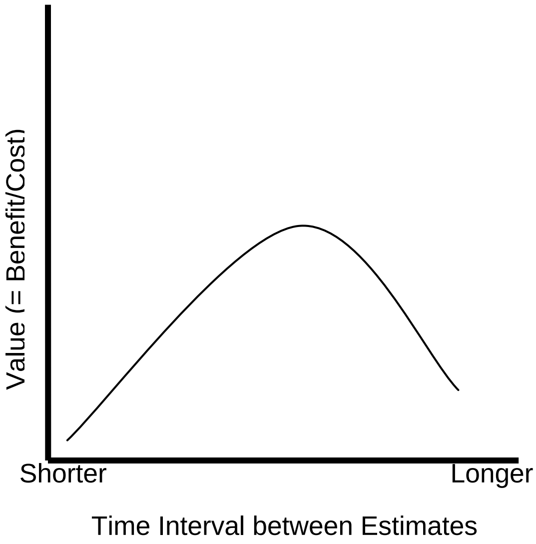


Figure 6: Value of estimates versus the time interval between successive estimates.



The exact degree of these changes is difficult to predict until model-based estimating systems are more fully developed. At the extreme, the estimating process will be highly front-end loaded, with the bulk of the work required to produce estimates coming near the beginning of the design process. In this scenario, each successive incremental estimate could be derived from the design model at essentially no cost, thus providing essential continuous and "real-time" cost estimates during design.

Figure 7: Value of producing an estimate versus the accuracy achieved with current practice and with automated estimating.

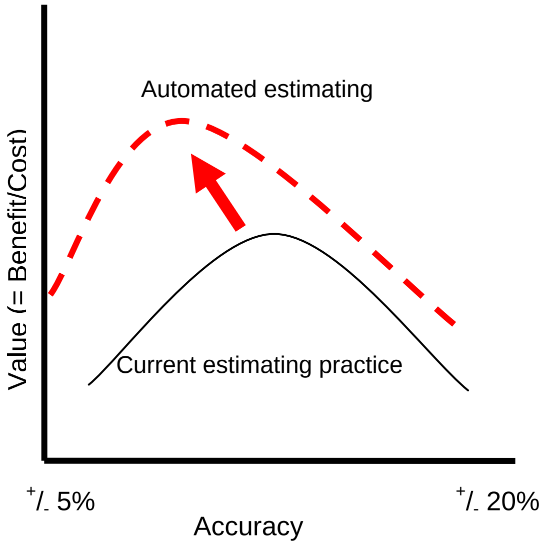
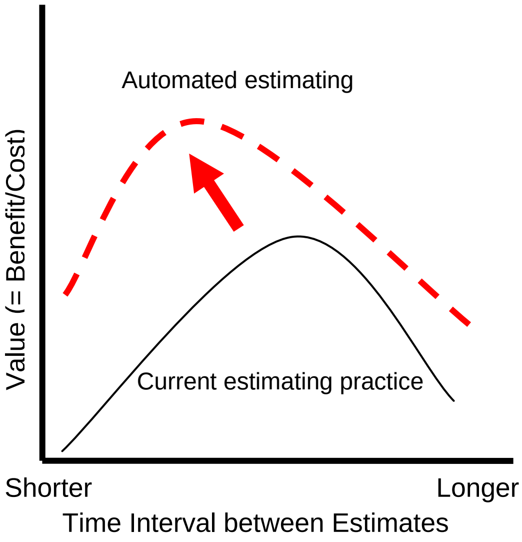


Figure 8: Value of estimates versus the time interval between successive estimates with current practice and with automated estimating.



4.4 CONTRACTOR'S VALUE ADDING PROPOSITION – CONTRACTOR'S EARLY INPUT TO DESIGN

If contractors use a model-based automated estimating system solely to produce total project estimates *at the time of bidding*, then the value proposition lies in the fact that they will be able to produce these estimates more quickly and at less cost. This value proposition is very narrow in focus, because it produces little or no impacts on design quality.

A more far-reaching value proposition arises in situations where contractors have an opportunity to provide input throughout the design process, as in alliancing agreements, design-building contracts, etc. In such cases, the one of the primary roles of the early construction input is to provide cost-related advice on the whole and/or parts of the bridge during design in order to improve the design constructability and overall value. This would require cost estimating activities at multiple times throughout the design process. Here, the value proposition parallels that of the designers value proposition shown previously, except that the contractors have the potential to produce even more accurate and therefore significant cost information throughout the design, and that doing so is closely associated with an increase in their scope of work over their traditional role, and can result in substantial value improvements to the overall project outcome.

5.0 PROPOSED PROCESSES

The following is series of use scenarios that describes typical processes of using the model based estimator at a very high level of summary:

5.1 GENERATE WBS FROM PROJECT MODEL

The system takes a semantic project information model of a bridge as input (e.g., output from a model-based CAD tool, IFC file, or similar). By evaluating the contents of the bridge model, the system must be able to derive a work breakdown structure (WBS) for the proposed project. This WBS is a "Quantity Takeoff" type of WBS (called 'Assemblies" in some estimating systems): it lists the units of work to be completed at a level of detail that corresponds to the quantity measurements derived from the design information. In addition to the input project model, the system will input from some standard or master WBS (a list of all possible work items), and a component that maps, or reasons about, the linkages from the project model to the WBS. The user may be required to enter information about the project that is not contained in the project model (any such information should be retained for use in subsequent estimates).

5.2 GENERATE QUANTITY TAKEOFF

Given the project model and the derived WBS, the system must apply geometric and semantic reasoning to calculate the quantities associated with each WBS item. Most input will come directly from the project model but, again, some additional user input may be required and should be retained for successive estimates.

5.3 DERIVE DETAILED WBS

From the "Quantity Takeoff" or assemblies WBS and the calculated quantities, the system will apply mapping rules to develop the WBS at the level of individual estimate line-items. This step is identical to the "assemblies-to-estimate items" that is performed by traditional estimating systems.

5.4 DETERMINE UNIT PRICES

The system determines the appropriate unit prices to apply against each estimate item. The process of selecting unit prices from a database containing prices for each type of estimate item is quite straight-forward. However, the system should also be able to apply adjustments to these unit prices to reflect the specific context of a project that will lead to price variations from historical averages (e.g., remote and difficult locations, novel technologies, work force shortages, etc.). These adjustments may be either automated or entered manually. Some such adjustments may be reasonably simple to apply, but other adjustments will require increasingly complex levels of reasoning if they are to be automated.

5.5 COMPLETE ESTIMATING CALCULATIONS AND PRESENT RESULTS

Given the WBS, quantities, and unit costs have been developed, the final estimate costs and mark-ups can be computed. The resulting estimate can then be presented in a suitable output format. This includes mapping the detailed estimate WBS to any standard WBS's required by tendering or reporting requirements. Optionally, the resulting cost information may be transferred into a combined project data model to be available for appropriate uses by others.

6.0 FUNCTIONAL SPECIFICATIONS

The following is a summary of functional requirements of the model=based automated estimator for concrete bridges.

6.1 SUPPORT DIRECT AND INDIRECT COST

The estimate must be able to include both direct and indirect costs associated with a project (including all temporary works, all construction equipment and project overhead costs, etc.). Since there will typically be no direct element in the project model that corresponds to indirect costs (e.g., the costs associated with providing general cranage on site), the system must be capable of reasoning from the direct product components to the required indirect costs. Where possible, indirect costs should appear as explicit line-items in the detailed estimate, but some indirect costs may appear as mark-up values to the total direct project costs.

6.2 SUPPORT PROJECT LIFE CYCLE CONCEPTUALISATION

The value propositions require that the estimating system be able to provide cost advice throughout the design process. Thus, it must be able to produce cost estimates based on preliminary, conceptual and incomplete design information. As a result, changes in the middle of project life cycle stages can re-use what has been established up to that point of change.

There are at least three principle approaches for achieving this requirement:

- Conceptual estimating through separate estimating modules: One possibility for providing estimates throughout the design process is that the system has multiple modules for a variety of different stages of the design. For example, the system may have distinctly different modules for estimating at conceptual stage, preliminary design stage, detailed design stage, etc. Each module may have distinct work breakdown structures, mapping and quantity takeoff rules, unit prices, etc. This approach may offer the best potential for taking early design information, as it currently exists, and yielding reasonable cost estimates. However, it has several significant drawbacks, such as the very onerous task of developing and maintaining several different versions of the system, the fact that estimates can still only be produced at certain “milestone” points during the design, etc.
- Conceptual estimating through template project models: An alternative approach for allowing estimates throughout the entire design process is to use template project models. With this approach, template (typical) project models would be developed for each different type of project. There would be some degree of modification of the standard template models to adjust them for the current project (e.g., adjustments for inflation, size scaling, and numerous other parameters). The template model, then,

would be a complete and detailed model from which a detailed cost estimate could be produced. The resulting estimate would provide a crude estimate of the actual project costs, since the template model will only loosely approximate the actual project. Then, as the design of the actual project progresses, the actual design information will begin to replace the template model information, until at the end of the design, the entire model reflects the actual project design with no remaining traces of the template model. In this way, a complete model (and therefore a complete estimate) is available throughout the design process, but the degree of accuracy of the model information and the cost estimates increases throughout the design process. This approach provides an elegant solution to the model-based estimating requirements, but it requires the use of template models in a way that does not exist in current practice, and further development is required to determine the practicality of the approach.

- Conceptual estimating through parametric approaches: Another option for achieving estimates throughout the entire design process is to rely on parametric approaches such that, by selecting a number or parameters that define a proposed bridge structure, the system can automatically generate appropriate design solutions (as design models, from which the estimates can be produced). This approach is not limited to an estimating technique; rather it introduces a full design paradigm. This is a potentially extremely powerful technique, and certain elements of road and bridge design appear to have been parameterised in current practice. Never-the-less, it represents a significant systems development effort to adopt this approach.

6.3 SUPPORT INCREMENTAL ESTIMATING

In addition to supporting estimates throughout the design process, the system should be able to support a process whereby estimates are developed incrementally. For example, estimators or designers should be able to use the system to compare the relative costs of two design alternatives based on relatively minimal information about the two options. The system should be able to support multiple versions of an estimate developed throughout the project life cycle, including roll-back capabilities, etc.

6.4 ACCOMMODATE NON-MODEL BASED INFORMATION

While the central characteristics of the estimating system are that it can automate estimating from a project model, it should restrict itself only to pricing the contents of the model. Even in a fully model-based design process, there will be many items that contribute to the overall project cost that simply do not appear in a project data model. In other cases, the project will follow only partial model-based processes. The estimating system should be able to accommodate non-model-based estimating in much the same way as traditional estimating systems. This should extend all the way to serving effectively as a traditional estimating system if no model-based information is available.

6.5 INTERFACE WITH LEGACY SYSTEMS

The estimating system must be able to interface with all relevant legacy systems, such as interfacing with an existing legacy unit price database system

6.6 SUPPORT FOR ESTIMATORS AND DESIGNERS

The system should support use by both estimating specialists and by designers that may have relatively little estimating expertise (possibly two different modes or even versions of the system).

6.7 SUPPORT FOR VISUALISATION

Like model based design processes, the automated estimating system will be equipped with visualisation capability. Both line items and their corresponding 3D view of bridge elements are automatically generated from the model.

7.0 COMPARISON BETWEEN THE CURRENT PRACTICE AND THE NEXT GENERATION ESTIMATING

Currently, design engineers analyse designs using computer-based simulators of theoretical models such as Spacegass, Aces, Coldes and many in-house designed spreadsheets and DOS-based programs. Input and output data from all these tools are likely to have minimal compatibility with each other. As design experience accumulates over time, design parameters are collected in project databases. This simplifies design processes. With the help of these design databases, they can zero in on a mature estimation of the design prior to computer-based modelling and analysis.

Once the design has been verified to meet alignment, geometric, aesthetic and any hydraulic requirements (e.g. flood forces, speed environments, flood immunity ...etc), it is handed over for drafting finalisation. Designers can then draw on their database of previous drawings to efficiently produce drawings to suit the new project. This often saves significant time during the drafting process. AutoCAD customisations (developed in-house) are used to draw at least part of each drawing and, in the case of deck units, all of the drawing.

Co-operation and interaction between drafters and engineers occurs during the preliminary fixing (i.e. fixing span lengths, skew, coordinates, type of deck and etc.) and design stages and is more pronounced during a complex or one-off design. This may include some 3D drafting to provide models for Spacegass analysis. All drawings are produced in a 2D environment (plan/elevation/section) unless there is a case-specific need to do otherwise.

The above can be compared with the processes of model-based estimating as follows:

- Unlike the current uncoordinated practice of design and estimating, model-based estimating is derived from a project data model of a bridge (e.g., the equivalent to a building information model or IFC model). Such a model must either be produced as a result of a preceding model-based design process, or must be produced as the first step in the estimating system.
- Estimated items in automated estimating are generated from a bridge project data model, whereas the current practice requires full manual intervention to list them.
- The estimate items in automated estimating will include temporary works (e.g., falsework), costs associated with specific construction methods (e.g., cranage), etc., whereas the current practice requires full manual intervention to list them.
- The automated estimating system can produce a quantity take-off by evaluating the geometric and non-geometric parameters of the project data model to derive the quantities required for the estimate items, whereas the current practice requires full manual intervention to list them.
- The automated system will be able to apply appropriate unit prices to the estimate items, which combine with the quantities to produce the overall cost estimate. This is similar to what is done in the current practice through a semi-auto system using price databases linking to WBS tables.
- The automated estimating system will likely work with multiple sets of estimate items at varying levels of detail, e.g., a higher-level of assemblies or standard estimate items, which map to a lower level of detailed estimate items.
- The automated system may use “template estimates” to provide default values for information that is missing during early design phases. This is similar to what is done in the current practice through a manual process.
- The automated estimating system supports various stages of project life cycle conceptualisation. It allows users to jump into various points of change while allowing them to re-use what has been established up to those points of change. This is by far

the most efficient way of re-using established data – in contrast, the current manual way has to re-draw the design on a 2D diagram from scratch.

- The automated estimating system generates automatically 3D view (drawing) from the (modified) model, whereas the current practice must redraw the 2D drawing every time when changes are made.
- All of the steps described above will be largely automated, but are likely to require certain manual inputs and decisions (e.g., selection of certain construction methods).
- The automated system enable the user to make changes at any point in any life cycle stages without the need to repeat what have been correctly established. On the other hand, for every changes made, the current practice must re-draw the 2D plan.

8.0 CONCLUSIONS

This paper has represented a feasibility study of model-based automated estimating for the civil works/bridge industry. The research has defined and assessed relevant contextual issues, such as the state of model-based design and estimating in the building construction industry. It has examined current practices and systems used in the design and estimating of roads and bridges. It has then developed value propositions for moving to model-based automated estimating and has developed a series of use cases to outline the functional requirement of such an approach. Finally it compared the new model-based automated estimating processes with the current practice to highlight the similarity, differences and points where efficiency is derived for the design of automated estimator.

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