CRC Construction Innovation
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Final Report
Model Based Estimating System for Civil Concrete Structures

Research Project No: 2005-0008-C-01

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Research Program: C
Delivery and Management of Built Assets

Project: 2005-008-C
Automated Estimating for Civil Concrete Structures

Date: June 2007

Leaders in Construction and Property Research

Distribution List

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EXECUTIVE SUMMARY

An earlier CRC-CI project on ‘automatic estimating’ (AE) has shown the key benefit of model-based design methodologies in building design and construction to be the provision of timely quantitative cost evaluations. Furthermore, using AE during design improves design options, and results in improved design turn-around times, better design quality and/or lower costs. However, AEs for civil engineering structures do not exist; and research partners in the CRC-CI expressed interest in exploring the development of such a process. This document reports on these investigations. The central objective of the study was to evaluate the benefits and costs of developing an AE for concrete civil engineering works.

By studying existing documents and through interviews with design engineers, contractors and estimators, we have established that current civil engineering practices (mainly roads/bridges) do not use model-based planning/design. Drawings are executed in 2D and only completed at the end of lengthy planning/design project management lifecycle stages.

We have also determined that estimating plays two important, but different roles. The first is part of project management (which we have called *macro level estimating*). Estimating in this domain sets project budgets, controls quality delivery and contains costs. The second role is estimating during planning/design (*micro level estimating*). The difference between the two roles is that the former is performed at the end of various lifecycle stages, whereas the latter is performed at any suitable time during planning/design.

Micro level estimating adds *significant* value to the quality and costing of planning/design. The overall value of AE in the context of model-based planning/design is that the cost of a design can be generated as soon as a design is assigned. This noticeably reduces the costs of preparing estimates; it provides shorter turn around times for estimates, making estimating more timely; and it reduces pressure on estimating resources. As a result of these savings, the selection of design options as optimal solutions can be completed quickly and objectively; thus increasing the quality of each planning/design iteration.

Although an AE can be used for **macro** level estimating, it will currently *not* add significant advantage compared to current processes (non-model based planning/design). As the durations between consecutive life cycle stages are far apart (months or years), any fine tuning opportunities for improvements after balancing quality and costs will be lost. However, macro level estimating is still needed for budgeting and approval purposes in model-based planning/design.

We have shown that from an information theory perspective, model-based planning/design improves the cost benefit ratio, and at the same time, increases the accuracy of estimates. Our study also shows that model-based planning/design improves the combined effect of influencing outcomes and providing timely information, as it reduces the time interval between estimates. Both of these improvements are relative to running non-model-based planning/design.

The planning and design practice involves a lengthy sequence of decisions intended to produce a final outcome. All the abovementioned improvements are made at every single decision-making point which is a significant improvement over non-model-based planning/design practices. From a contractor’s perspective, if an AE is used only for the purpose of producing bids, the benefit is limited. However, if contractors are involved in planning/design processes, as in alliancing agreements, design-build contracts, etc., many estimating activities are required throughout the planning/design process. The benefits to contractors are considered significant compared to non-model-based practices (e.g. improves constructability at the planning/design stage).

The major functional requirements of a model-based AE are provided as a series of use cases, which describe typical usage scenarios from the perspective of system users (planner/designer, estimator, and contractors). This study also defines the functional components of AEs.

In current civil engineering practice, planning and design are primarily based on paper based 2D drawings. This is far removed from best-practice model-based approaches. Model-based AE has the potential to be applied to civil projects and offers significant advantages over current estimating practices. No inherent barriers to model-based automated estimating have been identified. There is, however, a significant pre-condition for model-based design practices to be in place before most of the value of model-based estimating is realised.

In comparison with buildings, concrete civil works have greater variety and lower volumes. Their adoption of model-based practices will be understandably slower than for buildings. With the advance of object-oriented technologies, integrated information models will be widely used across the whole life cycle of structures, including production materials, machinery, planning, design and construction. As general manufacturing and building construction are evolving in this direction, civil structures will also follow. So the issue is not "if" it will occur, but more of "when and how".

In view of this vision for the future, we offer two sets of recommendations for processes to change from non-model-based to model-based practices. The first relates to the **broad scope of model-based planning and design processes.**

- There needs to be an awareness campaign run for industry partners. The purpose of this campaign will be to raise awareness in the industry of the strategic advantages and trends of AE and related technologies, how these have assisted other industries, and how they could help their own.
- Strategies for the adoption of model-based planning and design technologies need to be developed. These should include a review of current tools and practices, with a clear commitment to moving on from current technologies to a new generation of model-based approaches.
- Building from the abovementioned strategies, industry partners can then take steps (such as feasibility studies, business case developments, and conceptual design initiatives) to adopt model-based AE technologies.

The second set of recommendations relates to the **narrow scope of model-based, automated estimating**

- Industry partners should create medium to long term strategies to develop model-based automated estimating tools in conjunction with the model-based design processes, so that estimates are available as soon as designs are completed.
- The concept of developing a fully functional AE should be considered.
- Interested industry partners should consider developing an AE for the civil engineering works to harness the significant benefits these systems provide.

1. INTRODUCTION

In a CRC-CI project (Drogemuller 2003), an automatic estimator for buildings (prototype) has been created to demonstrate how the quantities for the concrete, formwork and reinforced concrete trades of a *building* are automatically taken off and their costs are estimated. It demonstrated significant benefits to the coordination of structural design of the building and its construction: The automatic estimator enables speedy interactions between the designer and the cost estimator and thus facilitates the selection of optimum designs and that reduces costs at the early design stage.

The purpose of this project is to assess whether it is feasible to extend the benefits of automatic estimating from buildings to civil concrete structures (mainly concrete bridges).

Currently there is no automatic estimator for bridges. Design drawings are carried out in 2D (plan and cross sections). The industry typically uses traditional processes in which design and contracting are separated. During tendering, cost estimating is on a critical path between design and contracting.

An automatic estimator for bridges requires a 3D model for each bridge design. However, designers appear to be resistant to changing current 2D practices to produce 3D models, unless there is considerable motivation from the design and construction value chain.

In comparison with buildings, concrete civil works have greater variety and lower volumes. Their adoption of model-based practices will be slower than for buildings. With the advance of object-oriented technologies, integrated information models will be widely used across the whole life cycle of structures, including production materials, machinery, planning, design and construction. As general manufacturing and building construction are evolving in this direction, civil structures will also follow. So the issue is not “if” it will occur, but more of “when and how”.

In the light of this future vision, the scope of the project is to examine the existing practice within current design and construction practice, assess the capability of existing software systems which are used in design and estimating, and develop recommendations on how bridge designers/contractors/ estimators could move from their current practice to 3D integrated modelling and estimating.

The following is an overview of the sections of this report that follow. Section 2 introduces the context of the problem and scope of the report. Section 3 explains the methodology of the feasibility study: (1) it starts from investigating the current practice of the design and construction of civil concrete structures; (2) then it identifies interoperability as an opportunity for improving the existing process; (3) finally it designs the “to be” process that will require the use of the automatic estimator to achieve the improvement. Section 4 describes the current practice. Section 5 presents a value framework from both the designer’s and contractor’s perspectives. Section 6 describes the proposed process: design and construction collaborative virtual prototyping. Finally Section 7 provides some concluding recommendations.

2. CONTEXT AND SCOPE

This study is related to five different contexts. Each of them is presented in the following sub-sections to provide a comprehensive background picture of the study.

Subsection 2.1 covers the origin of the concept – the automatic estimator for buildings. Subsection 2.2 discusses the broader context – the model based design process which uses the automatic estimator. Subsection 2.3 covers the current *design and estimating* practice for civil concrete works. Subsection 2.4 presents the current *project management practice* civil concrete works. Subsection 2.5 is about the new paradigm of model-based design for civil concrete works. Subsection 2.6 states what is out of the scope of the study.

2.1. Automatic Estimator for Buildings

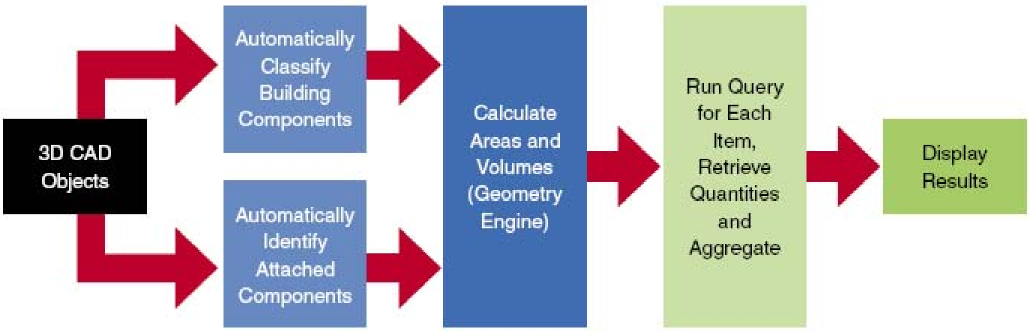
As the subject matter of this study follows directly from the CRC-CI automatic estimator for buildings (Drogemuller 2003), it is deemed appropriate to present an overview of this estimating system.

The automatic estimator is a software package that reads in a building information model (BIM) represented in the form of the building data standard Industry Foundation Class (IFC), and then automatically generates a bill of quantities (BoQ) and a cost estimate. In addition, the automatic estimator incorporates a viewer that displays the correlation between building components and items in the BoQ and also from the BoQ back to the building components. A rule editor allows users to define estimating rules or modify existing rules to suit the user's preferred processes. The rule format is flexible, allowing information to be extracted at various design stages.

The first version of the software covers the following trades: reinforced concrete, post tensioning, formwork, masonry and steel work at detailed documentation stage.

Figure 1 shows the automatic estimating process in the software application.

Figure 1: The inner working of the automatic estimator



The benefits of using the automatic estimators are:

- It automatically creates quantity takeoffs and cost estimations.
- It reduces the time required to take-off quantities from weeks to minutes.
- It reduces human errors inherent in the estimating process.
- It minimises disputes resulting from estimating errors.
- It allows cost consultants to spend more time on value–adding activities.
- It assists in identifying errors and/or ambiguities in CAD data.
- It reduces overheads since the risk component allocated to the price to cover errors is reduced. (CRC-CI 2005)

On the other hand, possible weaknesses of using automatic estimators are:

- A complete data model is required to use the system correctly.
- A mapping module needs to be developed to reason about the classification of items and quantity calculations.
- Errors can be introduced by the inability of the embedded algorithms to fully interpret the design (for example, by applying a classification and quantity rules that are not appropriate for a certain object). The system includes methods that allow users to catch any such errors, but certain errors could be difficult to identify.

2.2. Model Based Process for Buildings

While the narrow-scope context of this study is automatic estimating, the wider context is the model-based design. Model-based design has the following characteristics:

(1) The design is based on a building model, which contains components such as spaces, walls, floors, doors windows.
(2) Each of the building components in the model has properties which are designed by experts from various disciplines, e.g. thermal performance indicators (from the thermal analyst), identity and strength of the materials (from the structural engineer), dimension and orientation (from the architect), and perhaps the cost (from the human estimator).[1]
(3) The properties of the building components readily support simulations, visualisations and all other modelling activities including cost modelling needed for design evaluation. As a result, all building elements in the building model are inherently represented in 3D.[2]
(4) Like other results of modelling or simulations, all 3D views of the building (3D diagrams) are generated automatically from the building model. As a result, when data of the building model changes, the 3D view changes, automatically. Designers only need to design/change the model; they never need to draw 3D diagrams.
(5) All project related experts using the model can conveniently communicate with each other through data exchange as the design of one property attribute (e.g. the length of a beam) may affect that of the other (e.g. the cost of construction, transport and placement.)

Although model-based design and documentation originates from the 1980's (mainly from mechanical engineering and manufacturing processes) it has taken some thirty years for a significant shift in building and construction to take place. For instance, in the USA, the Architect's Handbook of Professional Practice provides a new standard and guideline to produce building information and documentation, to design building solutions, and to analyse construction processes. The American Institute of Architects identified that model-based design for buildings is primarily being used for design development (91 percent), schematic design (86 percent), and construction documentation (81 percent) phases (AIA 2007).

Other countries that have demonstrated clear industry benefits on the use of model-based building information include Norway with a range of applications being implemented by both the public and private sectors. Singapore has also shown leadership with a Government-developed model-based reader used for building approvals. The system is named CoreNet and has been developed and implemented by its Building and Construction Authorities. It is expected that a global trend towards model-based technologies will emerge in both building and civil engineering industries. This shift follows an earlier uptake of model-based design in manufacturing, including automotive, aeronautical and industrial engineering fields. Today,

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[1] Costs are usually stored in databases rather than attached to building elements as they are subjected to changes over times.
[2] 3D is a necessary condition for model-based design, but it is not a sufficient condition. That is, a 3D model alone (typically constructed in CAD software from geometric operations) is insufficient to support model based design. Rather, the BIM model (typically built up from objects such as beams, columns, walls, etc. with BIM-based CAD software

model-based techniques and protocols are more responsive to the building and construction sector. It has been a long wait, attributed to the 'project' nature of the industry – as opposed to mass production manufacturing where business and economic incentives have been clear from day one. This has not been the case with building and civil engineering.

Model-based design fundamentally changes how buildings are designed and documented. The current shift towards model-based design within the building industry is evident. For instance, the American Institute of Architects (AIA) recently produced a report called Collaborative Practice (Broshar *et al.* 2007) which highlights current changes and future directions within the building and architectural profession. More recently, the Royal Australian Institute of Architects at its National Conference in Melbourne dedicated half of its venue to model based design. Although this push is evident in building, it is not the same in civil public works. The adoption of model-based design and documentation will certainly be an important move in building and civil engineering.

Amongst the added value for creating model-based building documentation include the ease of linking drawings and technical information to project specifications. Thus, a system (such as an automated estimator) would be able to easily generate quantity take-offs and estimates. This is possible as all drawings are interpreted by the system not as pictorial information (such as lines and circles) but as object information with tags attached. This means that specified materials may typically include attribute data such as costs, resources, durations, sequencing, installation tasks, material strength and so forth. When a model is assembled within a model-based approach, it can be queried at the touch of a button.

All information extracted from model-based design documentation can easily be linked to building information databases. Thus, a model based design could also be database driven (as opposed to graphic or drawing documentation). In the case of a design-build relationship, a model could also be modified not on drawings but by altering information in its database.

It is expected that there major benefits will accrue from the adoption of model-based design for civil concrete structures. The benefits include the possibility of having the automated estimator available. This project examines both scopes:

- Model-based design – as a shift in industry practice.
- Automated estimator – as a tool to automate the quantity take-off

Figure 2 illustrates the design process in a model-based approach. The system is a functioning prototype system for quantity takeoff and cost estimator for buildings, developed by the CRC-CI and CSIRO (Drogemuller 2003). The value of the application has been assessed by Rider Hunt with clear benefits for the client and associated project stakeholders including:

- The automatic generation of quantities from a model based building model;
- The automatic generation of cost estimate from the model;

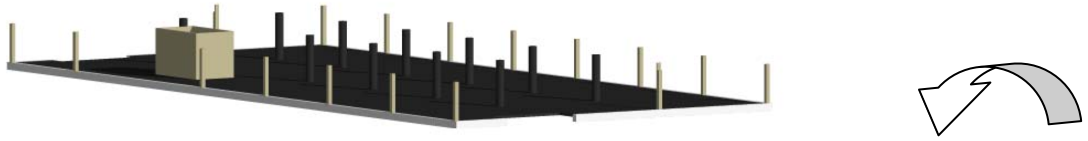
The application is able to link the bill of quantities with a viewer for inspection of results and anomalies.

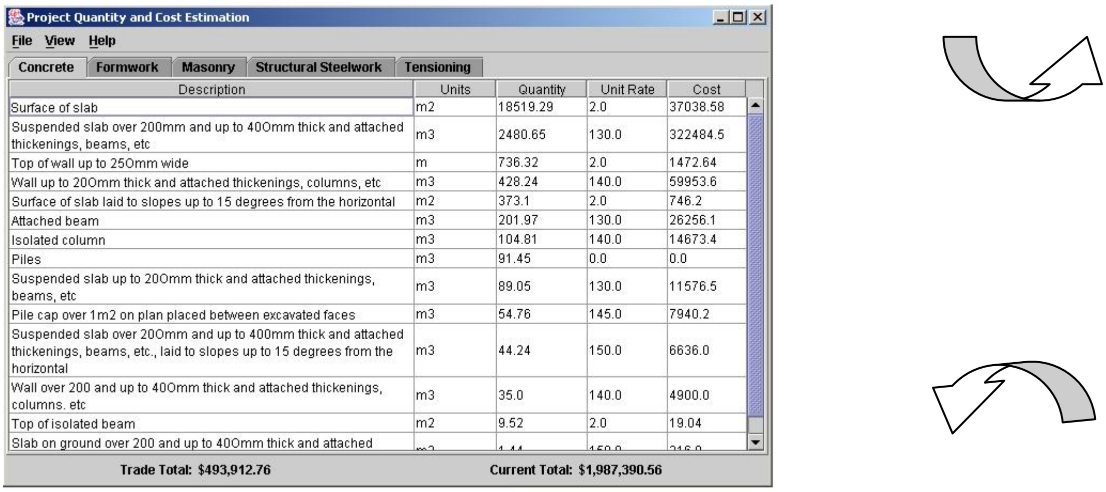
It is proposed in this report that similar benefits could be applied to civil concrete structures.

The more direct benefits of the model-based approach are:

- Time savings in the decision-making process
- Ability to quickly check what-if scenarios
- Accuracy (dependent upon model)
- Getting the strategic benefit of being an early adopter

Figure 2: Using the automatic estimator in design (Courtesy John Oliver of Rider Hunt)





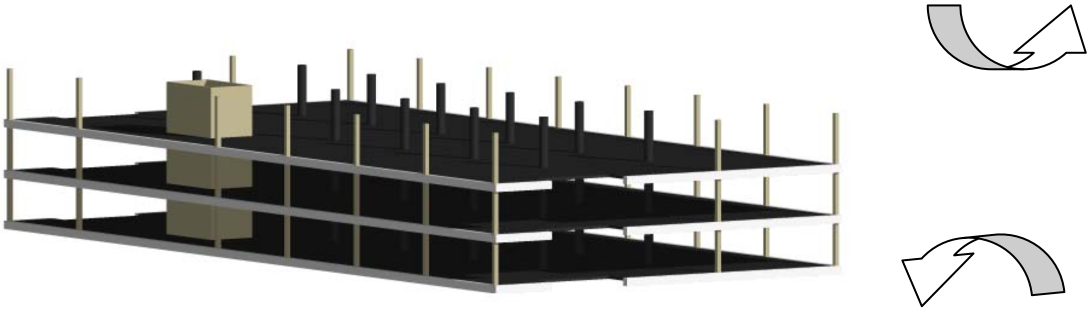
Project Quantity and Cost Estimation

File View Help

Concrete | Formwork | Masonry | Structural Steelwork | Tensioning

Description	Units	Quantity	Unit Rate	Cost
Surface of slab	m2	18519.29	2.0	37038.58
Suspended slab over 200mm and up to 400mm thick and attached thickenings, beams, etc	m3	2480.65	130.0	322484.5
Top of wall up to 250mm wide	m	736.32	2.0	1472.64
Wall up to 200mm thick and attached thickenings, columns, etc	m3	428.24	140.0	59953.6
Surface of slab laid to slopes up to 15 degrees from the horizontal	m2	373.1	2.0	746.2
Attached beam	m3	201.97	130.0	26256.1
Isolated column	m3	104.81	140.0	14673.4
Piles	m3	91.45	0.0	0.0
Suspended slab up to 200mm thick and attached thickenings, beams, etc	m3	89.05	130.0	11576.5
Pile cap over 1m2 on plan placed between excavated faces	m3	54.76	145.0	7940.2
Suspended slab over 200mm and up to 400mm thick and attached thickenings, beams, etc., laid to slopes up to 15 degrees from the horizontal	m3	44.24	150.0	6636.0
Wall over 200 and up to 400mm thick and attached thickenings, columns, etc	m3	35.0	140.0	4900.0
Top of isolated beam	m2	9.52	2.0	19.04
Slab on ground over 200 and up to 400mm thick and attached	[illegible]	[illegible]	[illegible]	[illegible]

Trade Total: $493,912.76 Current Total: $1,987,390.56



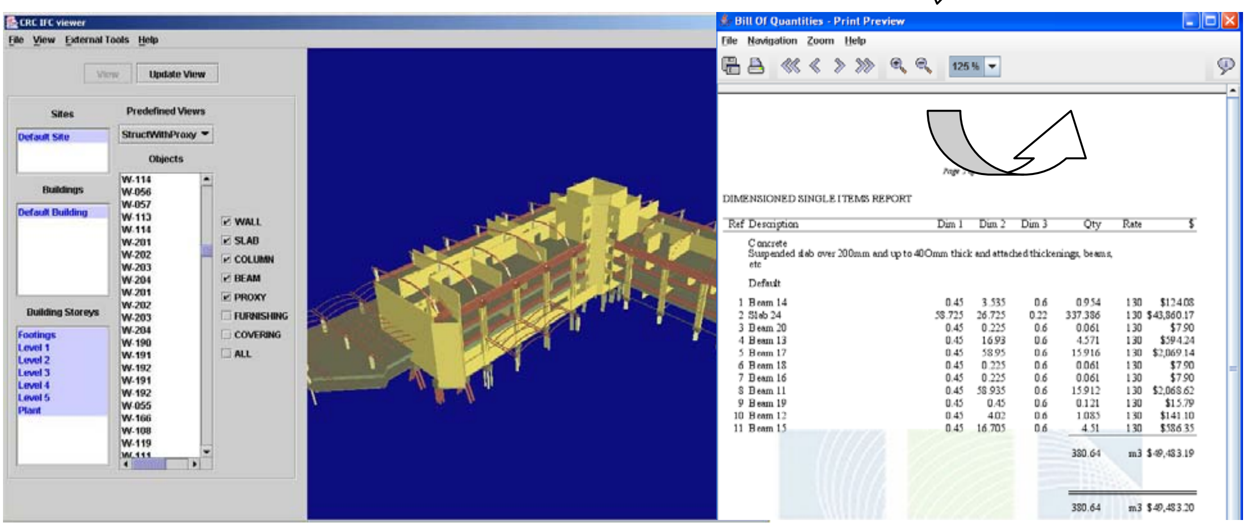


Figure 3 illustrates the ability to generate estimates at the push of a button and assess the best option in relation to value for money.

Figure 3: Using the automatic estimator to compare design options (Courtesy John Oliver of Rider Hunt)

	A	B	C	D	E	F
1	**FENDER KATSALIDIS** Architects					
2	IFC File: **ARP_2007.03.27_1840 Level 2_1 2x3**					
3	Scheme: **Flat Plate with Drop Panels**					
4						
5	**QUANTITIES PRODUCED BY ESTIMATOR**					
6						
7		**CONCRETE TRADE**	**Unit**	**Qty**	**Rate**	**Value $**
8						
9		Suspended slab over 200mm and up to 400mm thick and attached thickenings, beams, etc	m3	360.27	255.00	91,868.85
10		Wall up to 200mm thick and attached thickenings, columns, etc	m3	12.62	295.00	3,722.90
11		Isolated column	m3	12.45	330.00	4,108.50
12		Surface of slab	m2	1,533.57	3.00	4,600.71
13						
14		**FORMWORK TRADE**				
15						
16		Soffit of slab over 200mm thick including strutting over 3 and up to 4m high	m2	1,533.57	120.00	184,028.40
17		Sides and soffit of attached beam	m2	217.93	125.00	27,241.25
18		Face of wall	m2	126.16	165.00	20,816.40
19		Face of isolated square column	m2	9.12	130.00	1,185.60
20		Face of 600mm dia isolated circular column	m2	78.76	130.00	10,238.80
21		Edge of drop panels in soffit of slab up to 250mm wide	m	176.00	45.00	7,920.00
22		Edge of suspended slab up to 250mm wide	m	39.67	45.00	1,785.15
23						
24		**REINFORCEMENT TRADE**				
25						
26		Bar reinforcement in suspended slab and attached thickenings, beams, etc (40 kg/m3)	t	14.41	2,150.00	30,983.22
27		Bar reinforcement in wall and attached thickenings, columns, etc (125 kg/m3)	t	1.58	2,250.00	3,549.38
28		Bar reinforcement in isolated column (200 kg/m3)	t	2.49	2,250.00	5,602.50
29						
30		**POST TENSIONING TRADE**				
31						
32		Post tensioning in suspended slab and attached thickenings, beams, etc including cables, sheath, anchors, tensioning and grout (4.5 kg/m2)	t	6.90	8,200.00	56,588.73
33						
34					**Estimate Total**	**454,240.39**
35						

	A	B	C	D	E	F
1	**FENDER KATSALIDIS** Architects					
2	IFC File: **ARP_2007.03.27_1845 Level 2_1 2x3**					
3	Scheme: **Slab with Band Beams**					
4						
5	**QUANTITIES PRODUCED BY ESTIMATOR**					
6						
7		**CONCRETE TRADE**	**Unit**	**Qty**	**Rate**	**Value $**
8						
9		Suspended slab over 200mm thick and attached thickenings, beams, etc	m3	339.03	255.00	86,452.65
10		Wall up to 200mm thick and attached thickenings, columns, etc	m3	12.62	295.00	3,721.72
11		Isolated column	m3	5.81	330.00	1,917.30
12		Surface of slab	m2	1,533.57	3.00	4,600.72
13						
14		**FORMWORK TRADE**				
15						
16		Soffit of slab over 200mm thick including strutting over 3 and up to 4m high	m2	1,257.14	120.00	150,856.80
17		Sides and soffit of attached beam	m2	573.82	125.00	71,727.50
18		Face of wall	m2	126.16	165.00	20,816.40
19		Face of isolated square column	m2	77.52	130.00	10,077.60
20		Edge of suspended slab up to 250mm wide	m	39.67	45.00	1,785.15
21						
22		**REINFORCEMENT TRADE**				
23						
24		Bar reinforcement in suspended slab and attached thickenings, beams, etc (40 kg/m3)	t	13.56	2,150.00	29,156.58
25		Bar reinforcement in wall and attached thickenings, columns, etc (125 kg/m3)	t	1.58	2,250.00	3,548.25
26		Bar reinforcement in isolated column (200 kg/m3)	t	1.16	2,250.00	2,614.50
27						
28		**POST TENSIONING TRADE**				
29						
30		Post tensioning in suspended slab and attached thickenings, beams, etc including cables, sheath, anchors, tensioning and grout (4.5 kg/m2)	t	5.66	8,200.00	46,388.47
31						
32					**Estimate Total**	**433,663.63**

Currently, there are only a handful of model-based examples of bridges modelled in an object environment. Figure 4 shows a concrete structure that successfully made use of what model-based design has to offer.

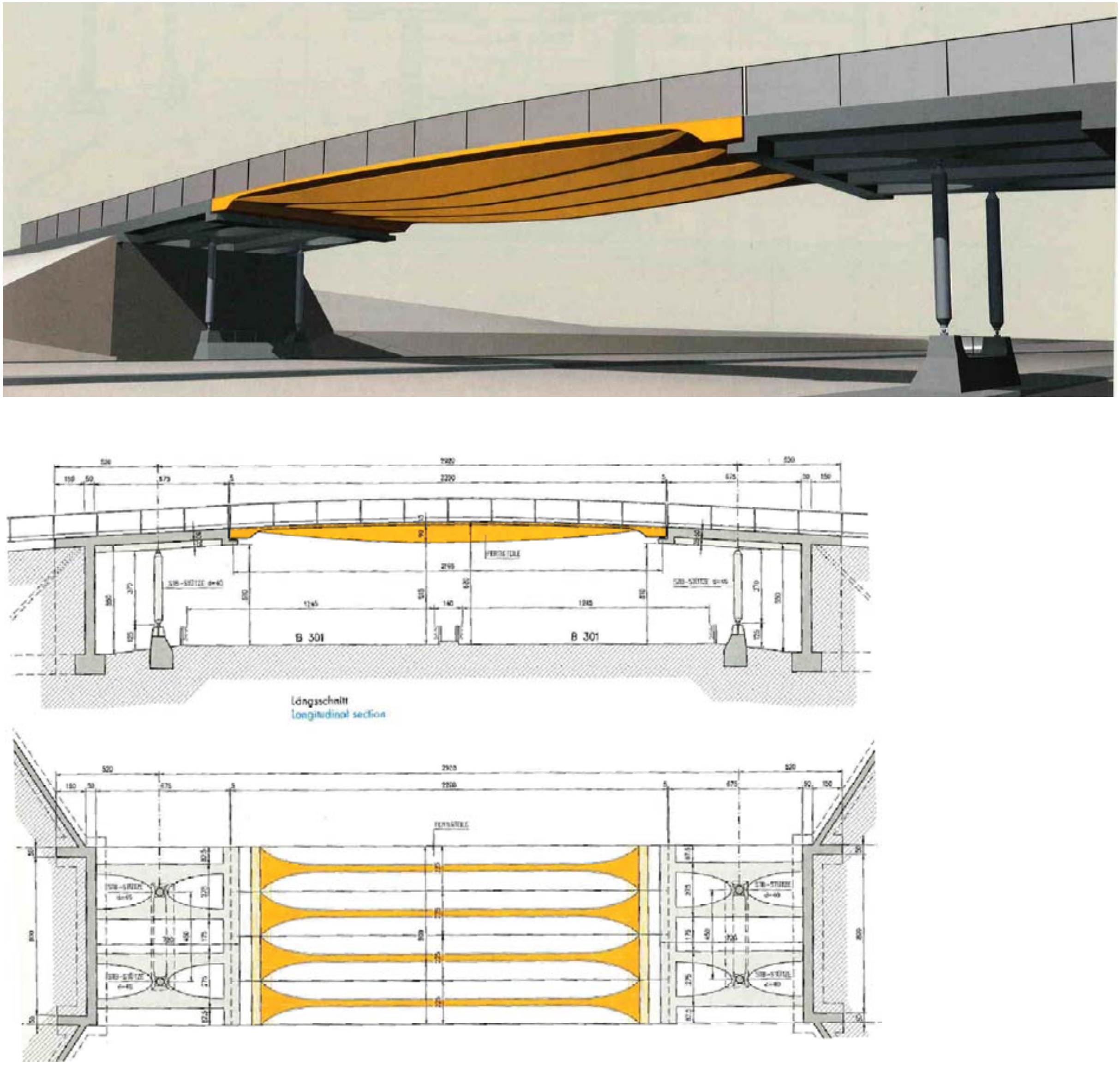
In Figure 4, model-based (or object-based) information was not used for estimation but for solving design and constructability issues. Nearly ten years ago the Austrian motorway authority requested their in-house design team to build a high-quality and economical by-pass system in the South of Vienna. The design solution was arrived at through collaboration in a model-based environment. The solution included a system for the pre-fabrication and the installation of concrete elements. Construction solutions were also proposed using the model-based system. For the client (the Austrian motorway authority) the project paid off in its first attempt with clear benefits on the end product, including a better product for the approved budget (i.e. a better design that was easy to visualise before construction took place). This also resulted in a new solution responding to the sensitivities of the environment, increased constructability, and was completed within budget. (Ziesel, 1998)

2.3. Current Design and Estimating Practice for Civil Concrete Structures

The third context is the current planning and design of civil concrete structures. As the original automatic estimator for buildings gives estimates for concrete trades, the question is: can the automatic estimating process be extended to civil concrete structures?

In this study, the scope of civil concrete structures is limited to concrete bridges only. However, bridges and roads are considered and normally designed together. In this context it is more appropriate to consider the design and estimating of *bridges and roads together*.

Figure 4: Designing a bridge in 3D



In order to capture the benefit of model-based design (which supports the use of an automatic estimator), a pre-requisite is that the design model must be represented in 3D in the first instance. Is this a realistic expectation for the current practice of road and bridge design?

After consulting with some design engineers, an overview of bridge design and estimating work practices emerges as follows.

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. This makes the design process more complex than it need be.

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.

Drafters (designers) then calculate quantities for each estimate item using a number of tools. Primarily, they use spreadsheets to calculate some of the more repetitive and predictable quantities. Otherwise they use AutoCAD measurements and project-specific spreadsheet calculations.

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. Appendix E shows some typical examples of design drawing.

Generally, bridge designers are resistant to 3D design. Without adequate supporting software, they tend to equate 3D design to drawing 3D diagrams using low-level 3D drafting operations on the computer. This is understandable as drawings are the last part of their design. For example, if a road alignment is changed late in the design process, they would redo the design and redraw the design output. Few drawings exist during intermediate planning and design stages that could be used for interim quantity take-off and estimating. Until the design tools are available for full model-based design, there is little advantage to design in 3D.

However, we cannot say that the industry does not use model-based design. The use of the Spacegass system is itself a model-based design tool. The AutoCAD cut and fill application (3D) has been used to estimate earthworks. However, these applications address only limited portions of the overall design process and they can not effectively share the design models with other applications and tasks.

The scope of this study covers the interactions between planning/design and estimating; in particular, the focus is on the selection of design options in the face of multiple evaluation criteria (including cost).

2.4. The Current Estimating and Project Management Practice for the development of Civil Concrete Structures

Apart from its relationships with planning and design discussed in the previous subsection, estimating is also closely related to project management. Project management is a process for the budgeting, quality control and cost control of the project. The scope of this study covers the estimating practice in the context of project management for civil concrete structures. This covers the following:

- The overall framework of planning and design as seen by a typical government (Queensland government)
- The planning and design process within the framework.
- The estimating principles and stages of cost estimates.
- The estimating process in the context of project management lifecycle stages.
- The estimating methods.
- Work breakdown structure and cost structure.

2.5. Model-Based Design for the Planning, Design and Estimating of Civil Concrete Structures

The current approach to the planning/design, project management and estimating of concrete bridges is predominately 2D-based (Subsection 2.3). However, as discussed at the beginning of Subsection 2.2, a model-based design is the enabler of the use of an automatic estimator—any investment in automated estimating for bridges should take place in conjunction with an overall evolution to model-based approaches for planning and design. In this context, it is important to raise the following questions under the scope of the study:

- What does a model-based design approach look like for civil concrete structures?
- How does it affect the processes of design, project management and estimating?
- What does an automatic estimator (software) look like when it is designed to support model-based design?
- How do we move from a 2D, paper-based design approach to a 3D, model-based approach?
- What can we do now to enhance the abovementioned transition?

2.6. Out of Scope

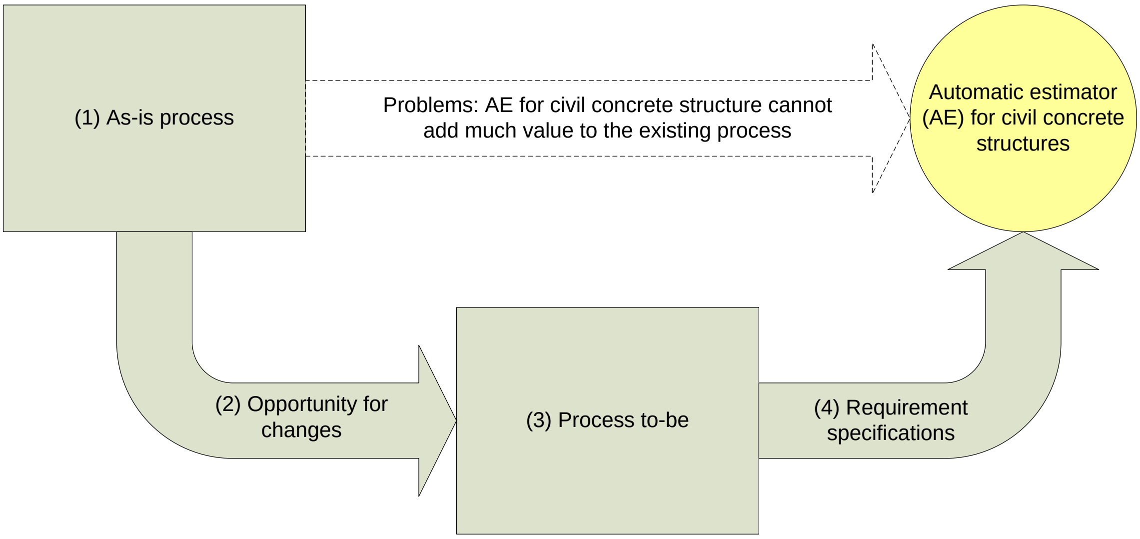
The following aspects are considered to be out of scope:

- A fully developed business case for an automatic 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.

3. METHODOLOGY

Figure 5 shows the context of the problem and the methodology to circumvent the issues in order to deliver the project. As Section 2 has discussed the context and scope of the project, this section presents the methodology used to investigate the feasibility pf developing an automatic estimator for civil concrete works.

Figure 5: Context and methodology for the research



(1) The first part of the research methodology is *to investigate the as-is process*, which involves the following:

- Interviewing bridge designers to find out how they design bridges and estimate their costs. References is made to existing planning and design manuals (e.g. QDMR 2002, QDMR 2005) to find out the overall picture of information flow between planners, designers and contractors.

- Interviewing contractors to find out how they estimate the construction cost after they have received the designer's plan. References is made to existing cost estimating manuals (e.g. QDMR 2004) to ascertain the flow of information between planners, designers and contractors.

- Interviewing estimators to find out if the construction industry has adopted any standard items and measurements for quantity takeoff and estimating, and to what extent such standard items/measurements have been used.

- Devising questionnaires to help extracting information from research collaborators (Appendix A).

(2) The second part of the methodology identifies opportunities for improvement. The key questions are:

- What benefits can be brought to the industry if model based design and evaluation is adopted? – model-based design/evaluation has two advantages: (1) better tools (2) better communications between tools.

- What framework of collaboration/coordination between designers, contractors and estimators should be adopted to achieve the benefit? – model-based processes.

(3) The third part of the methodology is to identify the proposed (or “to-be”) process when the model-based approach is adopted for the overall coordination of design and build of civil concrete structures.

(4) The final part of the methodology is to identify the functional requirements for an automatic estimator for bridges.

4. THE AS-IS PROCESS DESCRIBED

The planning, design and construction of roads and bridges is highly complex. In this section, the planning, design and estimating of both roads and bridges are considered together, since it is often difficult to separate the two. The contents of the following subsections (4.1-4.7) have been derived from either interviews or manuals from QDMR. Section 4.8 covers the variations from other states. Section 4.9 presents a summary of the as-is process.

4.1. Planning and Design Framework

Before a road project receives its "project" status, it goes through a pre-project planning process that articulates the road network needs and priorities. This processes lays down the four requirements for roads/bridges (QDMR 2005):

- Safer roads to support safer communications
- Fair access and amenity to support liveable communities
- Environmental management to support environmental conservation
- Efficient and effective transport to support growth and industry competitiveness

The pre-project planning process ensures that the road network under consideration can cope with the traffic at least 20 years after the opening of the facilities.

The outcome of the network planning process is to place the road projects into the Roads Implementation Program (RIP). The RIP is a rolling 5-year project management process of detailed project planning, design, implementation and finalisation.

From the government's point of view, managing a road project requires a methodology that consists of the following elements:

- Project management lifecycle: 4 inter-related phases including concept, development, implementation and finalisation.
- Templates: specific project document templates that can facilitate road/bridge projects.
- Roles and responsibilities: clearly defined roles for key players in the project.
- Approval processes: A number of holding points are mandated in the project process. A project cannot proceed until the necessary approvals have been obtained.
- Processes, tools and techniques that support project staff to apply government's policy and principles to individual projects.

4.2. Planning and Design for Roads and Bridges

QDMR (2002) specifies a whole-of-government approach to the planning and design of roads and bridges that spans the breadth of government concerns. A long- term vision provides the basis for an objective assessment of an affordable standard that is appropriate for various types of roads. A context-sensitive design approach offers the flexibility to tailor road solutions for local practices and environments.

A bridge is a structure designed to carry a road over a depression or obstacle. Bridges are relatively expensive compared to earthworks and paving, and they have a longer economic and design life than roads. Hence the design should provide for a longer period of growth, and they should allow for future widening.

Appendix B displays the basic types of bridges, each of which has its own typical span. Based on the contexts and requirements, the bridge designer selects a bridge type and begins to develop a corresponding design.

In the planning of bridges, the road alignment is usually selected first and the bridge location and alignment is designed to fit the road. The detailed planning, design and costing of the bridge is then carried out.

Different bridge types may have different cost implications, depending on location and contextual issues. Significant cost savings may be available if a different bridge type is used. As a result, road alignment can be adjusted if necessary to accommodate a more cost-effective bridge solution.

Projects and costs are intimately related from two perspectives: one is from the project management point of view; the other is from the design point of view. The existing practice of estimating focuses predominantly on the project management perspective; so it will be discussed first (Subsections 4.3-4.6). Section 4.7 will cover the relationship between design and costing.

4.3. Estimating Principles and Stages of Cost Estimates

To ensure that consistent outcomes are delivered according to government priorities and objectives, QDMR develops investment strategies to identify, fund and deliver the highest priority road project to meet the needs. All these processes rely on sound estimating principles for project cost planning and control. QDMR (2004) states the following estimating principles:

- Adoption of a single project management methodology will bring better and more consistent project outcomes (including cost).
- Estimates prepared on an "unlikely to be exceeded but not excessively conservative" basis at various stages of project life cycle will provide confidence in the process of project justification, prioritisation and budgeting.
- Estimates will be subject to a review and approval process based on consistent clear lines of responsibility and accountability to ensure that costing standards and control are applied to any public budget information.

In order to be an integral part of a system of interdependent core inputs of scope, time, cost and quality, estimating must be executed in the context of project management. 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 RIP (Roads Implementation Program) for further development. The total development time 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 (Figure 6).

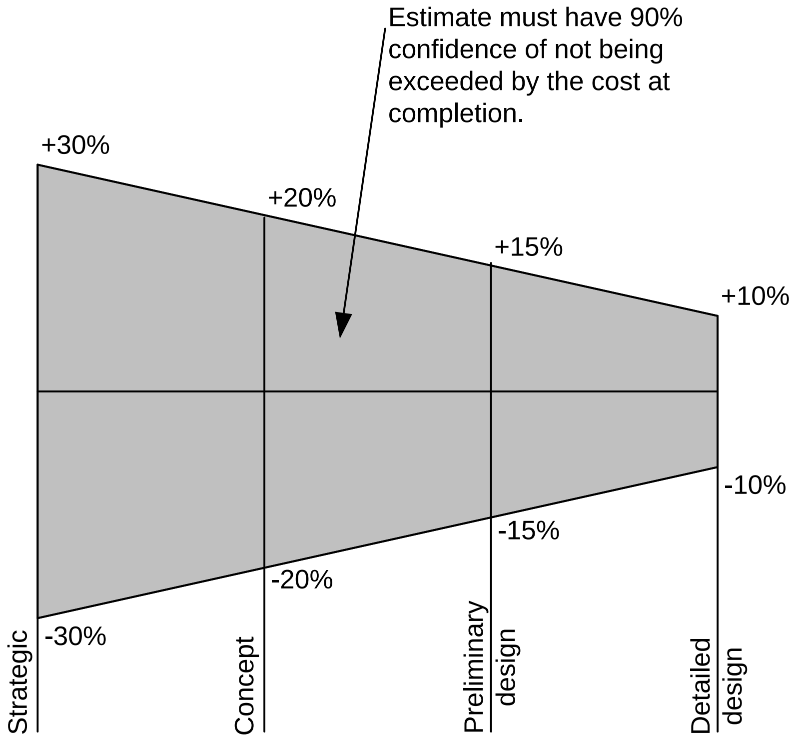
The preliminary design estimate is used to confirm the budget before the project moves into the last two years of firm RIP.

At the end of the detailed design period, the design is completed; and tender documents are prepared for contractors to bid on.

Table 4.3.1: Estimating in the context of project life cycle stages (QDMR 2005)

Project Lifecycle 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

Figure 6: Estimates are expected to fall within a specified error range (QDMR 2004).



4.4. Estimating Processes

Estimating is an integral part of project cost management. Project cost planning is concerned with the planning and control of project costs from concept to finalisation. It consists of four key processes: resource planning, cost estimate, cost budgeting and cost control (Table 2).

The cost estimating process comprises four key activities:

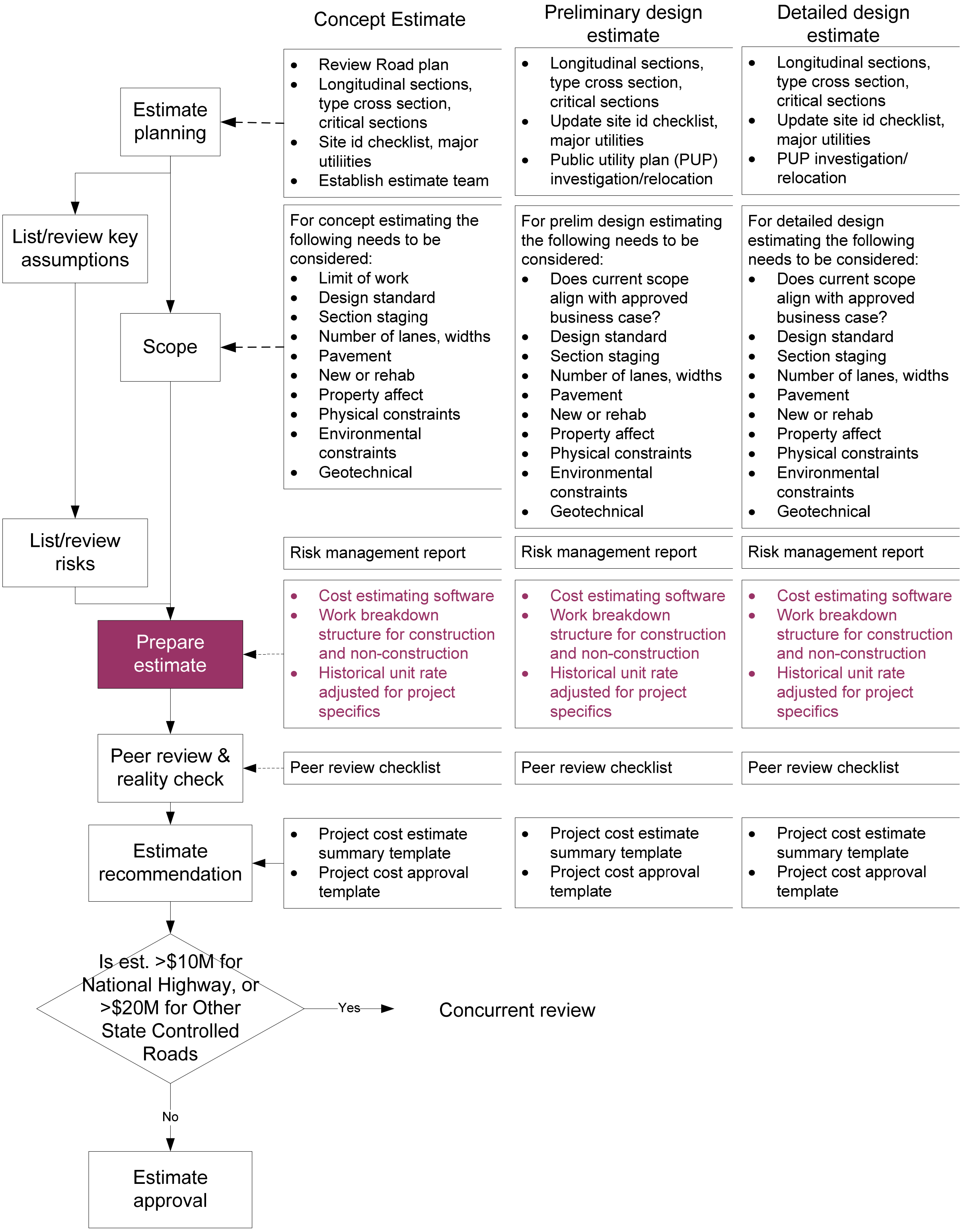
- Scope definition
- Risk identification
- Estimate planning
- Cost estimating

Figure 7 shows the procedures of preparing and approving an estimate at the concept, preliminary design and detailed design stages. 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.

Table 2: Project cost management processes (QDMR 2005)

Processes	Inputs	Tools	Outputs
Resource planning	• Project scope • Design plan and specifications • Work breakdown structure (WBS) • Quantities • Work methods • Program of work • Resource productivities • Resource availability	• Option analysis – alternative work methods • Procurement contracts	• Resource requirements in terms of types and quantity
Cost estimating	• Project scope • Design plan and specifications • Work breakdown structure (WBS) • Resource rate • Program of work • Risk schedule • Historical information	• Unit rate method • First principles method • Computer software for estimating and risk quantification	• Project cost estimate • Cost management plan
Cost budgeting	• Project cost estimate • Project schedule	• Cost index • Roads implementation program	• Cost baseline
Cost control	• Cost baseline • Cost management plan • Performance measurement • Change requests	• Performance reporting • Cost change control system • Project tracking software	• Variation orders • Corrective actions • Cost updates • Forecast cost at completion • Lessons learnt

Figure 7: Procedure for preparation, concurrent review and approval of an estimate of costs at various project management lifecycle stages (QDMR 2004).



4.5. Estimating Methods

The basic estimating method is to divide the project into smaller elements so that a single unit rate can be applied to each of these elements. After the costs of all elements are computed, they are summed and then factored with mark-up adjustments such as indirect costs to produce a complete estimate.

Essentially there are two different methods of estimating for QDMR: (a) Unit rate estimating and (b) first principles estimating. [3]

Unit rate estimating calculates the cost of each element of the project by multiplying the quantity of work by historical unit rates. The unit rate is normally determined from a number of recently completed projects of similar or the same type. Allowances are typically made for adjustment of the following considerations:

- Inflation
- Site conditions (mountainous or flat terrain)
- Contractor's pricing[4]
- Front-end loading
- On-site and off-site overheads and profit
- Selection policy of lowest or medium price
- Scale of work
- Site location (urban or remote)
- Design complexity (unique or routine)
- Risk profile
- Ground type
- Construction methods (specialised or conventional)
- Specialisation of materials and finishes

First principles estimating is the calculation of project specific costs based on a detailed study of the resources required to finish each work item in the project.

4.6. Work Breakdown Structure and Cost Structure

QDMR (2004) establishes a standard work breakdown structure (WBS) that offers a high level of consistency of project cost management over the years. Each standard item in the WBS corresponds to a construction activity that is associated with a unique 4-digit number (Table 3). The whole set of WBS is governed by QDMR's published standard (QDMR 1999).

Table 3: Work breakdown structure and standard items (QDMR 2005)

Work breakdown Structure (WBS)		
Standard item number group		Description
From	To	
1000	1999	Site establishment (MRS11.02), provision for traffic (MRS11.03), environmental management (MRS11.51)
2000	2999	Drainage, protective treatment, retaining structure
3000	3999	Earthworks, landscape works
4000	4999	Unbound pavements, stabilised pavements
5000	5999	Sprayed bituminous surfacing (MRS11.11), asphalt pavements
6000	6999	Road furniture (MRS11.14), Pavement marking, electrical conduit and pits, traffic signal and road lighting footings, traffic signals, road lighting
7000	8999	Bridge

Each standard item in the WBS is subdivided into finer activities according to the processes needed to complete the work. For example: concrete in a bridge deck is typically subdivided into formwork, reinforced steel, concrete supply and placement, finishing and cutting.

[3] There are other classifications of estimating methods. For example, one way is to divide them into the following categories: (1) Unit rate estimating, (2) operational rate estimating, and (3) spot rate estimating.

[4] Contractor's pricing may be included into the adjustments. It is evident that QDMR's approach to estimating straddles both internal estimating and external tendering.

Resources such as plant, labour and materials are then allocated to the schedule quantity of work.

The work breakdown structure reflects a phased approach to project management (e.g. from concept stage to preliminary design and detailed design). The WBS offers a cascading menu of activities commencing with the broadest approach at level 1 (e.g. bridge 8000), then developing increasing precision in Level 2 (e.g. bridge deck 8300), Level 3 (e.g. Concrete class Mpa/20 in cross girder 8301) and Level 4 (e.g. Concrete class 50 [compressive strength] Mpa/20 in cross girder 8301.01). This makes the WBS flexible to accommodate project management at various levels. Activities may be added or deleted within the series to reflect the scope of a specific project.

If non-standard work items are used, the work specified in project documentation will take precedence over the corresponding standard work item (if any).

The cost structure of any standard work item can be broken down into: (a) direct job/operation cost (plant, labour, materials, sub contracting, etc.), (b) indirect on-site cost (project management, site facility, plant and equipment, consumables, insurance, travel, etc.), (c) indirect off-site costs (including corporate cost, contingency, inflation, profit, etc.)

Each standard work item comes with a standard unit of measurement that measures the associated construction work (e.g. in terms of cubic metres, tonne, each unit, or lump sum). The method of measurement seems to be highly compatible with AS 1181 (1982) – although we have not been able to ascertain its degree of compatibility due to time restriction. The work operations that are associated with any specific work standard item include specific operations defined by the standard (QDMR 1999), plus all the following basic operations for the purpose of finishing the construction work (MRS 11.01):

- Establishment and disestablishment
- Provision of all facilities
- Provision of all labour, plant and equipment
- Supply, delivery, handling and storage of materials
- Provision of all supervisory and support staff
- All costs associated with OHS obligations
- All costs associated with governmental legislations
- All costs associated with respect to security, interests, charges
- All costs associated with workshop drawings, schedules and material lists
- Any design for work required to be designed by the contractor
- All overheads and profits
- All other expenses associated with the work but not yet specified above.

Appendix C presents an example of a cost estimating standard format in a contract document. It is a schedule containing the following elements: an item number. Description of work, unit of measurement, estimated quantity, unit rate and amount (quantity by unit rate).

During the actual estimating process, multiple breakdown structures may be used. For example, the tender documents may provide a specific work breakdown structure to be used for reporting estimated costs in the bid. Within a contractor's estimating system, however, a finer-grained (more detailed) work breakdown structure may be used to tabulate all project costs. This finer grain of estimating WBS can be rolled-up into the reporting WBS. Still earlier, the estimating software may have a higher-level breakdown of estimating assemblies or packages to support a quantity take-off process (e.g., entering dimensions for one "slab-on-grade" item in the assemblies WBS may allow the system to add numerous items into the detailed estimate WBS such as concrete, sand, gravel, membranes, reinforcing steel, forming curbs, etc.)

4.7. Interactions between Design and Costing

While the estimating process in the above sections 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; 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.

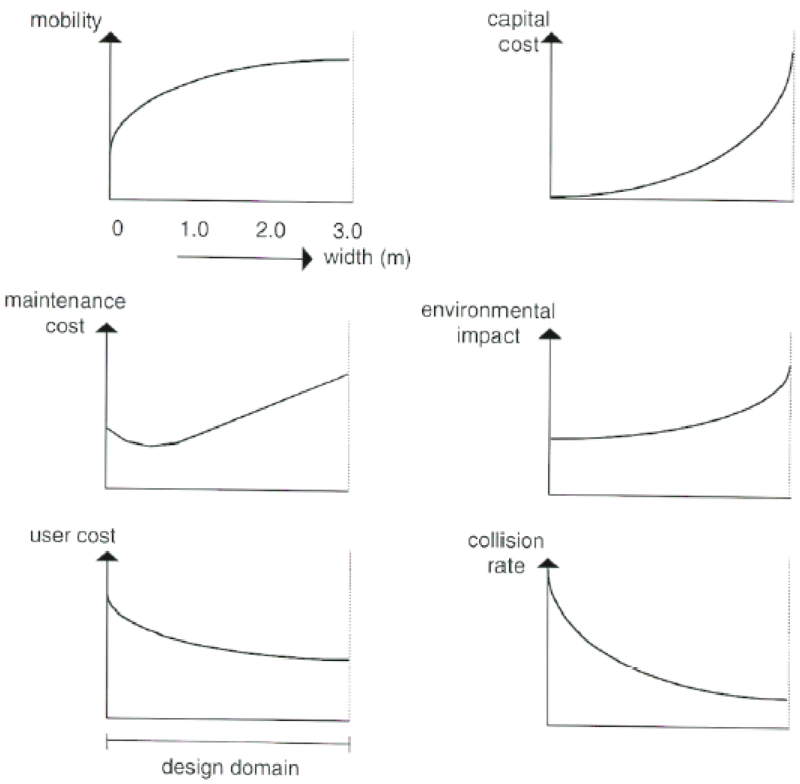
QDMR (2002) is a road/bridge planning and design manual that collects a comprehensive set of design parameters, which include traffic parameters, human factors, speed parameters, safety barriers, sight distance, alignment design, intersections, transport systems, bridges, etc. These parameters (formally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

The QDMR road planning and design manual offers the following guidelines to help designers:

- Guidance to numerical values in the form of tables and graphs showing the upper and lower bounds of design domain.
- Commentary on design criteria.
- Issue discussions.
- Providing quantitative evaluations of performance where possible.

Any design with respect to a design domain is a compromise between competing expectations and requirements (i.e. in terms of cost, safety, driver expectation, economic impact, environment considerations and social issues.) Figure 8 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 various benefits and costs.

Figure 8: Design domain trade-off, shoulder width (TAC, 1999)



Throughout the design manual (QDMR 2002), there are many qualitative considerations of cost of various design domains, and these cost relationships are typically used as the basis for selecting design solutions. However, the qualitative cost information that is generally available to designers will have very high uncertainty and variability, leading to an inevitable outcome that designers will frequently make sub-optimal design choices. The possibility and opportunity exists to turn qualitative costs into quantitative costs. If quantitative cost estimates are available at design time, the engineer will have more design options to choose from and thus will be better equipped to select a design solution that is both high in quality and low in cost. Section 5 will develop a value proposition for just that.

4.8. Software Used

Some of the software used by our industrial partners is shown in Appendix D. Drafting packages such as AutoCAD and ArchiCAD are the standard for design, whereas for modelling and structural simulation, packages such as Spacegass, Aces and Coldes are used.

The approach for quantity take off typically involves using a spreadsheet such as Microsoft Excel as a template to calculate estimates from known costs and volumes. Measurements are taken off the screen using the AutoCAD dimensioning tool or from a printed copy (2D) of the plans.

The dimensions of the new components are entered into the spreadsheet and an estimate is generated. This is done for standard bridge components such as piers, columns and the horizontal struts and members.

More difficult and one-off components are sometimes modelled by engineers using 3D CAD to help better understand the design and quantity. However this approach is rarely taken, as most costing work involves using a standard pallet of components, with variations in size.

Some organisations use additional software written for a specific purpose. For example, for the estimation of steel components in bridges, one organisation still uses a program which was written approximately 20 years ago by a member of the design team. The application was written in the Fortran programming language.

Quantity take off in 3D is considered fairly new in the estimation of civil structures such as bridges. There is a general recognition of the approach and possible advantages 3D take off could present to the industry. However most are happy with their current estimating practice and believe that moving to 3D estimation would be difficult and require a significant financial investment. Also, because of the unique way in which each team operates, any application would need to be custom designed to their specific needs.

4.9. Issues Arising

Planning and design is a very complex process. To overcome the complexity, the whole planning and design process is divided into life-cycle stages. The estimating process at the end of each lifecycle stage (Subsections 4.3-4.6) is needed for project budgeting and approval. Due to the long duration of each lifecycle stage (months or years), the estimate 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. Even in model-based planning/design practice, the impact of improvements is limited to the estimating efficiency, not to other aspects of the overall process.

On the other hand, estimating at design time (Subsection 4.7) offers the best chance for far-reaching improvement because each individual design type (e.g. horizontal alignment, road width, shoulder width, lighting, etc.) is determined over a much shorter time frame (hours, days). If it is possible to further improve estimating in quantitative terms, the balance between qualities and costs can be articulated and thus improve the quality delivery of the whole design. The following chapter considers improvements in this direction.

4.10. Variation over States

The above-mentioned planning and design processes are mainly summarised from Queensland Government's practice and their manuals. Other states will be different in details, but generally very compatible with each in principle.

There is a major difference though. QDMR has its own WBS specified as a common standard used in roads project costing. NSW government may have its own standard too (we did not have time to assess this); while other states do not appear to have similar WBS standards.

In other states, contract work items are grouped at the very high level, such as lightings, earthworks, etc. On the other hand, these contracts will have very specific details to limit the ways in which construction work is carried out.

To reduce the estimating workload, the contractor sometimes pays the road/bridge designer to produce their quantity takeoff list based on their own work breakdown structure. Once they receive the detail work breakdown, the contractor can do the costing readily (using database, guided by human experience.)

Nowadays, design and build is the most common contracting method in roads projects. Designers and contractors work together on design at very early stage. This improves the optimisation of the balance of cost vs. constructability. Also, this practice lays the fundamentals for the future development of model-based design (Subsection 5.5).

4.11. Summary

The study above concludes that estimating plays two important, but different roles. The first role is estimating as part of project management: to determine project budget, control quality delivery and contain costs. This role is well documented in various pre-construction and project estimation manuals. The estimation process is formally defined with clear and consistent line of responsibilities and is carried out at the end of project management lifecycle phases (Proposal stage, option stage, business base stage, preliminary design stage and detail design stage).

Figure 9 shows the complete stages of the as-is design and estimating process from the project management perspective.

In this figure, each of the match-stick-like objects represents a planning/design activity (e.g. design life of ancillary elements, specific effects, waterway requirements, environmental requirements, geometry requirements, etc.) There is a long list of such tasks, all of which must be completed at each lifecycle stage. The total time for the five stages (from Proposal stage to detail design stages) is about 5 years. There are at least 5 points at which the project costs are officially estimated for the purpose of controlling quality and costs – each of these estimating times are at the end of the five stages. As the result of such an arrangement, feedbacks related to project costs only happen at the end of the project stages. When the design is completed, it is passed to contractors for tendering. If the design is deemed expensive to build by the contractors, the design may go back to the drawing board. Estimating only at the end of a project lifecycle stage is referred to as *macro level estimating*.

The second role of estimating is the estimating activity at the planning/design time. 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.) The role of estimating is documented in the “Design Philosophy” chapter of a roads planning and design manual. Although not mentioned elsewhere, the design engineers seem to accept the design philosophy and put it into design practice. However, in current practice, there is little or no attempt to quantify the MCA process, including the cost of the design domain. This role defines the micro level of estimating because it is estimating at any *planning/design time*.

Figure 10 shows the interactions between estimating and the evaluation with respect to the design of a parameter.

Figure 9: As-is planning/design and estimating stages in bridge/road design –macro level estimating

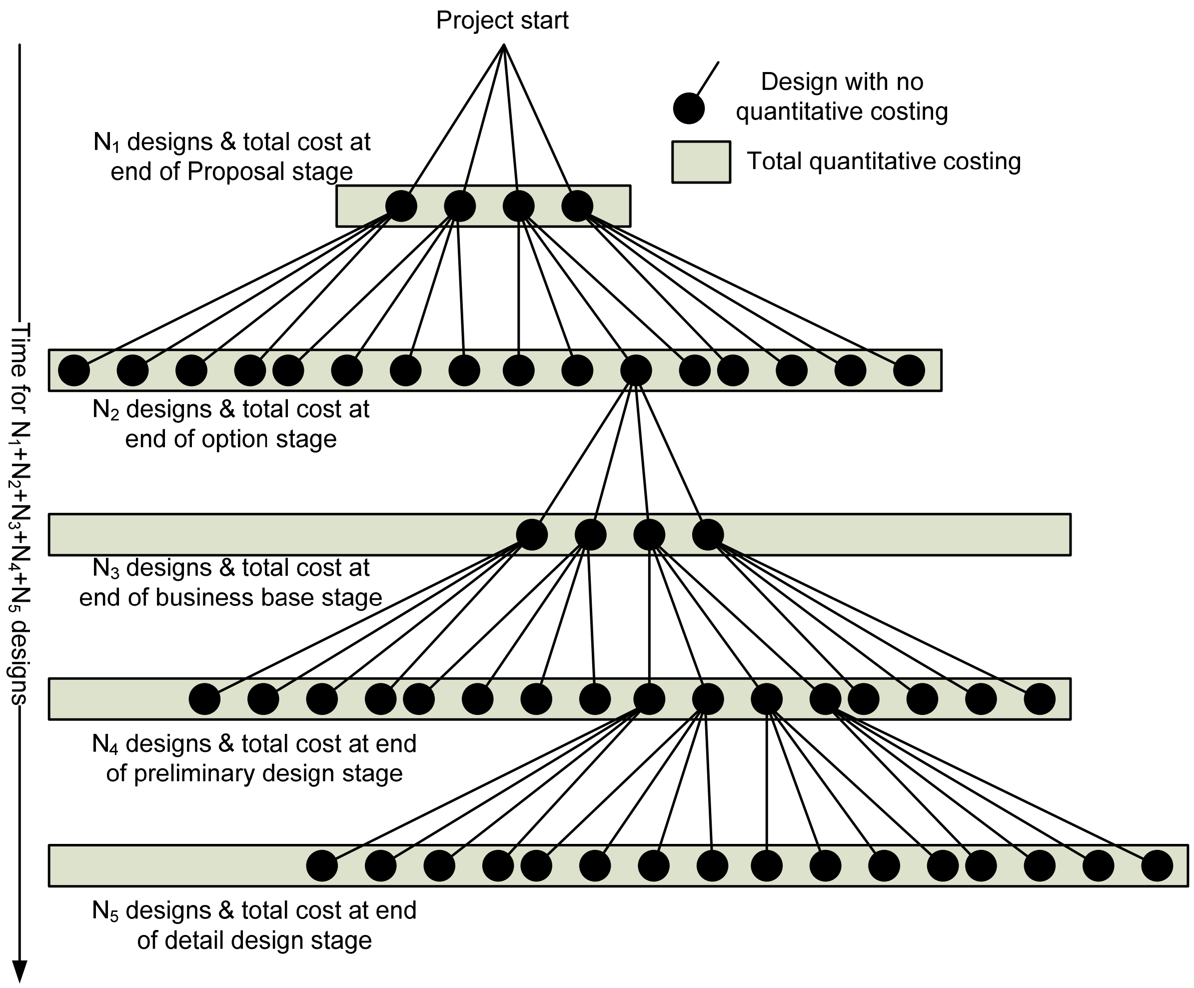
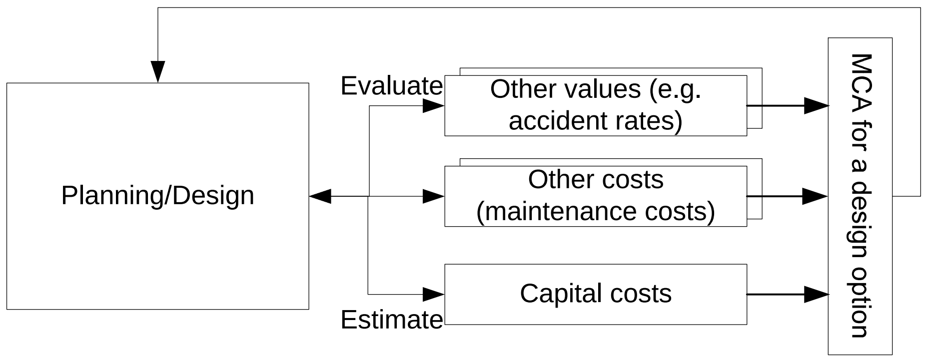


Figure 10: Micro level estimating and multi-criteria assessment (MCA)



While macro level estimating is performed at the end of each lifecycle stage (Figure 9), micro level estimating is performed at any estimating time during the planning/design. The interval between any consecutive estimating times at macro level (months, years) is much longer than that at micro level (hours, days). In fact, for each design activity (represented by a "match stick"), there should be at least one MCA related evaluation (Figure 10).

If micro level estimating is optimised at any planning/design time, the improvement of the design can be very significant because it is improved anywhere and any time in the project planning and design process. However, the current practice seems to rely heavily on a human expert to optimise 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.

5. VALUE FRAMEWORK FOR CIVIL WORKS

5.1. Overview of the 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.

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:

- It provides substantial savings in the cost of producing estimates.
- It provides quicker turn-around times for estimates, making estimating more convenient and timely.
- 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.
- 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 automated estimating system has no characteristics that allow it to provide inherently better or more accurate estimates than the current practice. However, it may improve the overall estimating quality by allowing a degree of estimators' expertise to be made available to designer and others.

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. For example, the risk of missing budget targets may be reduced if better cost predictions were available at the time when the financing and budget targets were initially set.

The following sections develop these value propositions in greater detail. They first discuss the technical context of model-based processes, and then the organisational context of increasing alliancing approaches. The value proposition is then considered from the perspective of the project designers and, finally, from the perspective of project contractors.

5.2. Technological Context: Model-Based Processes

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).

It is possible that the estimating process could start with traditional design information (e.g., paper-based 2D CAD drawings) and could develop a 3D project model as the first step in producing an estimate. This approach is sometimes used at present in the building industry, but it is considered to be a stop-gap method until building information models are more commonly available from the design process. Although it is possible that this approach could offer cost/benefit value compared to current practices, it does not represent a significant value proposition for automated estimating. This is because it would add substantial effort and cost to the estimating process, and because the resulting project data model would offer many additional benefits beyond estimating, thus it is unlikely that the model would be limited to the estimating process alone.

The primary value proposition, then, involves an overall transition to model-based technologies throughout the design process, resulting in a project data model that is available for estimating. There are a great many benefits and costs associated with an overall shift to model-based technologies, and an extensive evaluation of these issues is beyond the scope of this report. However, a brief discussion of an overall shift to model-based technologies follows.

Model-based technologies for civil works projects would involve the use of 3-D, object-based systems to support many of the project planning, design, and management processes. Most typically, this includes the migration of all 2D CAD tools to 3D CAD for the core project design tasks. However, it is likely to extend beyond the design CAD system into systems such as various engineering analysis systems (structural analysis, earthworks, etc.), visualisation/rendering systems, estimating systems, construction planning and scheduling systems, etc. Model-based technologies add value in two broad categories: they add efficiency and functionality to individual software tools by allowing greater "intelligence" (the systems know what kind of real world object/component each data element represents), and they improve data sharing, integration, and interoperability (by providing a standard language for exchanging information between the different classes of systems used throughout the project). The costs and barriers to adopting model-based technologies range from the costs associated with "re-tooling" to new software systems and problems with the lack of availability and relative immaturity of suitable model-based software and interoperability solutions. The on-going effort to use model-based technologies is not expected to be greater than current technologies.

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.

5.3. Organisational Context: Alliancing Approaches

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.

These trends are occurring and will continue without requiring any specific change in estimating systems, and the proposed automated estimating approach would be possible with or without these changes. However, 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).

5.4. Designer's Value Adding Proposition: Estimating Utility Theory

As stated earlier, the value proposition for automated model-based estimating from the design perspective is not simply that current estimating practice can be completed more efficiently. Rather, the value arises because estimating would become considerably quicker and cheaper that it would be done much more frequently, resulting in better cost information throughout the design process. This in turn will deliver more optimal design outcomes. In order to explore this value proposition, the theoretical basis for estimating utility (value) is first considered.

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. 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, then, 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.). There is no way of directly measuring this benefit value (because once a design has been selected, the cost of any alternative designs will never be known), but for the purposes of developing an estimating strategy, a subjective value might be assumed (for example, what percentage reduction in the overall project cost might be obtained if perfect cost estimates were available at every point throughout the design compared to the case where no cost estimates were available: 0.2%?, 2%?, 20%?, …).

A number of factors impact the extent or magnitude of this benefit, including the accuracy of the estimate, the amount of information available, and the ability to influence design outcomes:

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 expensive it is to produce the estimate). Figure 11 illustrates a relationship between the benefit of producing an estimate versus the level of accuracy attained by the estimate. Since the overall value (V) of the estimate is related to the benefit (B) and the inverse of the cost (c) of producing the estimate (V=B/C), and the level of detail is also related to this cost, a corresponding relationship, shown in Figure 12, 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).

Figure 11: Benefit of producing an estimate versus the accuracy achieved

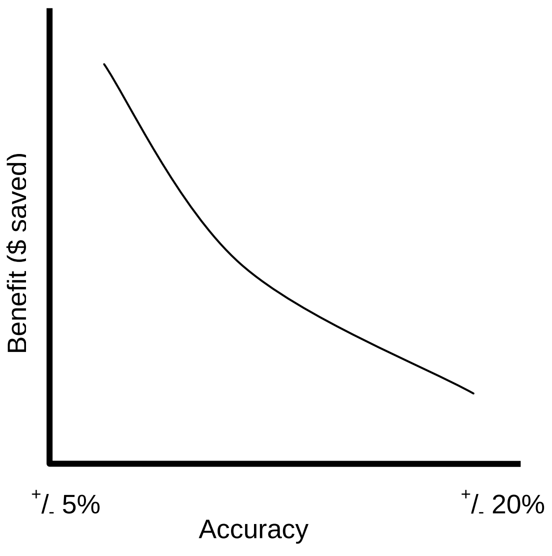
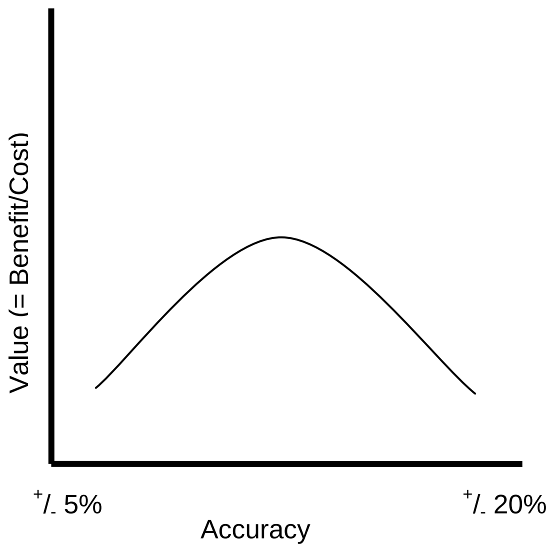


Figure 12: Value of producing an estimate versus the accuracy achieved, where value is defined as the benefit/cost.



The benefit of the estimate is also proportional to the ability to influence the design outcome—accurate cost information will add little benefit if design outcomes are not altered as a result. The implication is that estimates must be made at the time that design decisions are considered in order to provide the maximum benefit. The longer the time interval between the design considerations and the estimate, the less likely it is that sub-optimal designs will be "rolled-back" to better solutions (or, if the design is changed, much of the design effort in the interim will have been wasted). Over the whole length of the design process, this relationship suggests that the benefit (ability to influence the outcome) reduces from a maximum at the beginning of the design phase to a minimum at the end of the design phase. Alternatively, this relationship can be expressed in terms of benefit versus the time interval between estimates, as illustrated in Figure 13.

However, a counteracting aspect of the benefit-to-time-interval relationship is that the benefit of the cost estimate is proportional to the amount of design information available upon which to base the estimate. In particular, the benefit relates to the amount of new information available since the previous estimate was prepared. An extremely detailed cost estimate adds no value to a project if it is completed immediately following an earlier similar estimate. Thus, the benefit of the estimate increases as the time interval between estimates increases (Figure 14).

Figure 13: Benefit of producing estimates versus the time interval between successive estimates based on the ability to influence outcomes.

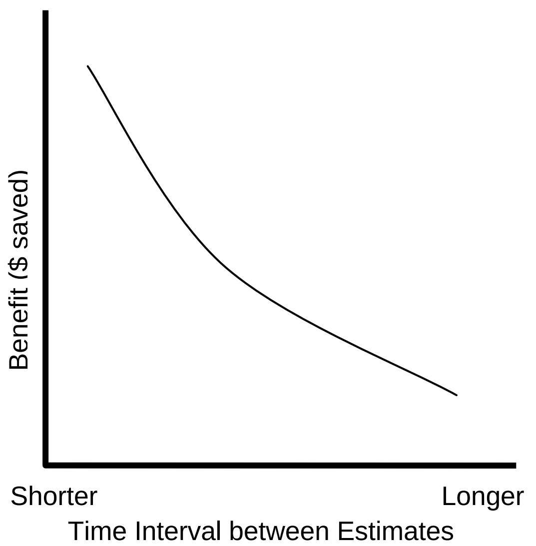
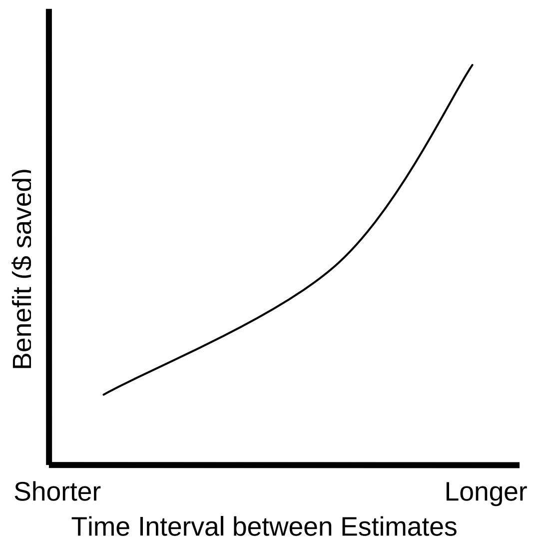


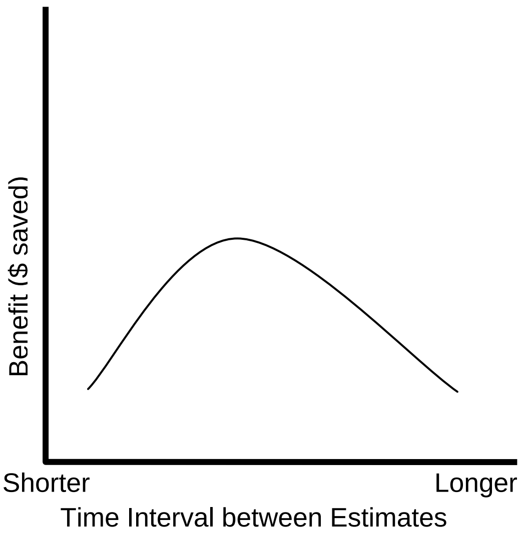
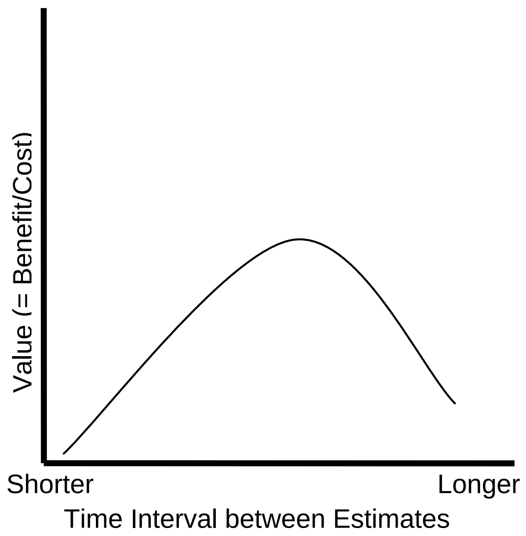
Figure 14: Benefit of producing estimates versus the time interval between successive estimates based on the availability of new design information.



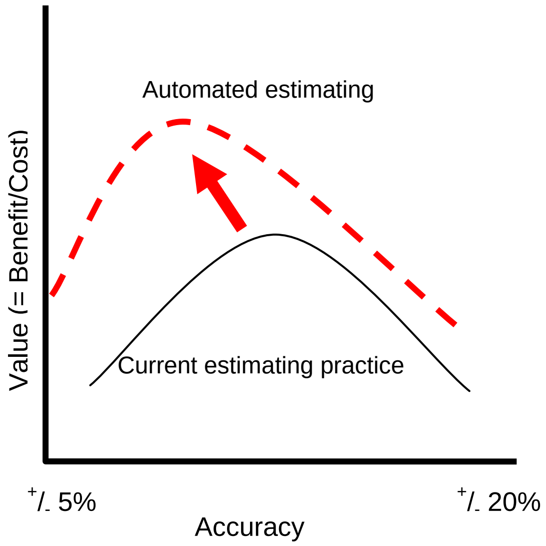
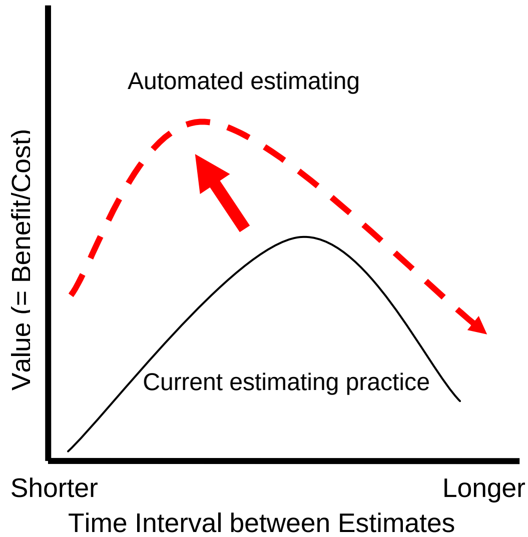
The effects of the ability to influence the design and the availability of incremental design information would combine to produce some benefit-to-time-interval relationships as shown in Figure 15. Since estimate value is directly proportional to the benefit but inversely proportional to the estimating cost, and the cost of producing estimates for the project will increase as the time-interval between successive estimates decreases, there is some relationship between estimating value and estimating time-interval as shown in Figure 16. Again, this suggests estimating strategy, in that for a given situation, there is some optimal frequency with which to produce successive estimates during the design process.

The above analysis developed relationships between the value of estimates, the cost of producing an estimate, and the time interval between successive estimates. These relationships show that there will be some optimal estimating strategy. For actual projects, an actual quantitative analysis of this sort would be very difficult, but the relationships would be implicitly reflected in decisions made about the estimating strategy.

Having made these relationships explicit, the impact of model-based automated estimating can be seen. With automated estimating, the quantity takeoff process can be very highly automated, and can be completed almost instantly. Other parts of the estimating process will involve a mixture of manual and automated tasks, although successive estimates produced after an initial set-up may be very highly automated. In addition to these drastic reductions in time and cost of producing estimates, there are some opportunities for improving estimate accuracy.

Figure 15: Benefit of producing estimates versus the time interval between successive estimates based on the combined availability of information and ability to influence outcomes.	Figure 16: Value of estimates versus the time interval between successive estimates.
	

The next effect of the automated estimating is shown by the red lines in Figures 17 and 18. 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, where the total cost of producing estimates will be less, estimates of greater accuracy will be produced more frequently, the overall value of the estimates will be higher, and the design outcome will be more cost-optimal.

Figure 17: Value of producing an estimate versus the accuracy achieved with current practice and with automated estimating.	Figure 18: Value of estimates versus the time interval between successive estimates with current practice and with automated estimating.
	

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.

5.5. Contractor's Value Adding Proposition: Contractor's Early Input to Design

If contractors use a model-based automated estimating system solely to produce 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, although it could certainly be quite significant in terms of the money saved.

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 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.

6. PROPOSED PROCESS AND FUNCTIONAL COMPONENTS OF AN AUTOMATIC ESTIMATOR

6.1 Use Cases

Here, the major functional requirements of a model-based automated estimating system are defined by describing a series of use cases. Use cases describe typical usage scenarios that illustrate activities that the system must be able to accomplish from the perspective of users. They are very intuitive from the users' point of view, and effective in expressing system requirements. The use cases are presented here at a very high level; future system development will expand these use cases into greater detail.

6.1.1 Basic Estimating Process Use Cases

The following sub-use-cases develop the basic sequential steps associated with the automated estimating process:

6.1.1.1 Generate WBS from Project Model

The system takes a semantic project information model as input (e.g., output from a model-based CAD tool, IFC file, or similar). By evaluating the contents of the project 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).

6.1.1.2 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.

6.1.1.3 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.

6.1.1.4 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.

6.1.1.5 Complete Estimate Calculations and Present Results in Appropriate Formats

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.

6.1.2 Include Direct and Indirect Costs

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.

6.1.3 Support Estimating Throughout the Entire Design Life-cycle (Ability to Handle Conceptual and Incomplete Information)

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. There are at least three principles approaches for achieving this requirement:

6.1.3.1 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.

6.1.3.2 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.

6.1.3.3 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.

6.1.4 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.)

6.1.5 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.

6.1.6 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.

6.1.7 Support for both 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).

6.2 Functional Components of an Automatic Estimator

Although the actual design of an automated estimating system is beyond the scope of this report, the previous use cases suggest the basic elements of such as system. These elements are shown in Figure 19 in terms of major system processes and components/information sets, and are listed as follows:

- The estimate is derived from a project data model (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.

- The estimating system can evaluate the project model to identify the list of estimate items to be included in the estimate.

- The estimate items will include temporary works (e.g., falsework), costs associated with specific construction methods (e.g., cranage), etc.

- The 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.

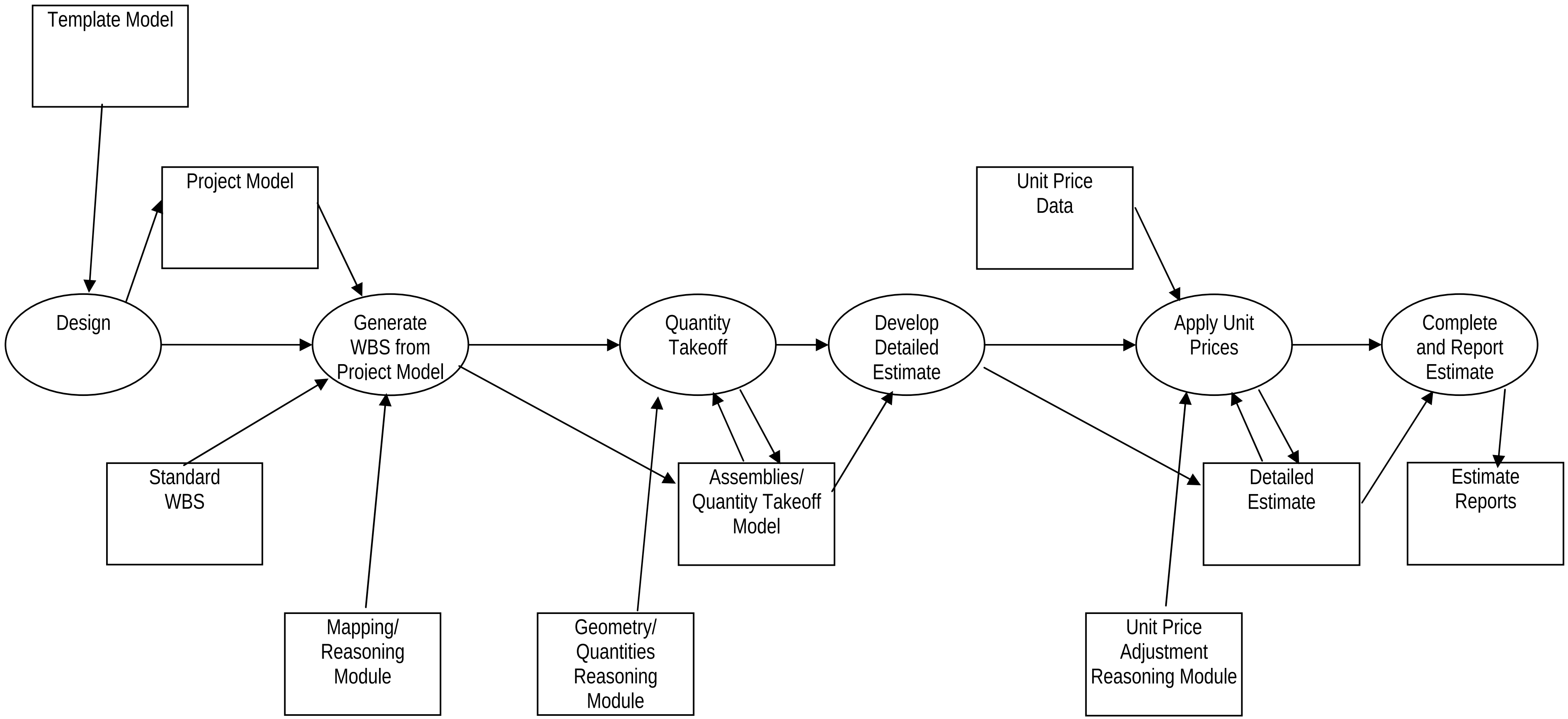
- The system will be able to apply appropriate unit prices to the estimate items, which combine with the quantities to produce the overall cost estimate (this portion of the system will be essentially the same as current estimating practices)

- The 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.

- 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 system may use “template estimates” to provide default values for information that is missing during early design phases.

Figure 19: Overview of functional components of an automated estimating system. Ovals represent major system processes; boxes represent major system data sets or modules.



7. Conclusions and Recommendations

The objective of this report is to assess the feasibility 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. From these results, the following conclusions and recommendations are drawn:

- Model-based automated estimating has the potential to be applied to civil works projects and to offer significant advantages over the current estimating practice. No inherent barriers to model-based automated estimating have been identified. There is, however, a significant pre-condition that model-based design practices must be in place before most of the value of model-based estimating are to be realised. This leads to two primary areas of further recommendations: those relating to the broad scope of model-based planning and design, and those relating to the narrow scope of automated estimating systems:

- Conclusions and recommendations relating to the broad scope of model-based planning and design practices are as follows:

    1. The landscape for model-based practices (technologies, advantages, barriers, etc.) in civil works projects is very similar to the building construction industry, where model-based technologies are in the early stages of mainstream adoption. However, civil works are several years behind the building industry in terms of available technologies and their impact on work practices.

    2. Some 3D and model-based technologies are well established within design practices for roads and bridges, but the overall process remains predominately 2D CAD-based.

    3. There is limited understanding of model-based technologies and practices within the civil works industry. It is recommended that industry partners undertake an active awareness and education program within their industry to help understand the technology, how it has helped other industries, and how it could help their own.

        - A typical awareness and education program for model-based design should point out that the planning and design processes as documented in the design manual (QDMR 2002) already contain elements that are compatible with parametric model-based design (Subsection 4.7). In the new model-based planning/design paradigm, the geometric elements of the design will be automatically generated by collaborative computer programs. The planner/designer will control the design parameters as in today's practice (conceptually). This should allay any fears among professionals that, in the new paradigm, they would have to discard any existing concepts or experience; or that they would have to spend time on unproductive drawing activities. Such awareness and education programs will reduce resistance to 3D and model-based design.

    4. In terms of technological feasibility, technological benefits, and technology trends, there appears to be a clear strategic advantage in moving towards model-based planning and design techniques for civil works projects.

    5. The full business case for model-based planning and design (i.e., how, when, who, who much, etc.) is outside of the scope of this report.

6. It is recommended that industry partners proceed with subsequent steps towards the adoption of model-based planning and design technologies for civil works, such as feasibility studies, business case development, conceptual design initiatives, etc.

    - This strategy should include a detailed review of the current tools and practices for road/bridge design and construction, and consider the potential for model-based evolution of these tools. A successful adoption of model-based planning and design requires a rationalisation of tools that can be used together with an inventory of road/bridge design aspects. In the transition from one design aspect to another, tools will be changed from one to another. This requires the compatibility of scales and data standards among the automatic tools.

    - This strategy must address not only the software and systems technologies, but work practices, organisation and legal issues, etc.

    - This strategy should clearly emphasise how to transition from current design tools and techniques to a new generation of model-based approaches. Where possible, new technologies should build upon the existing parametric and model-based elements within current practice.

    - This strategy should consider how industry practitioners can exert leadership on the software industry to provide the tools and technologies that would allow them to migrate to model-based approaches.

    - Parties should appoint internal champions to groups to develop and promote the strategy.

    - The new CRC-CI initiative "Integrated Digital Solutions" can be also a relevant reference point that is related to the goal of developing and sustaining model-based planning/design practice in the industry.

- Conclusions and recommendations relating to the narrow scope of model-based, automated estimating:

    1. If model-based planning and design practice are used, then model-based automated estimating is feasible and is likely to provide significant advantages over current practices.

    2. A strategy should be created to develop model-based automated estimating in conjunction with model-based design, such that estimating is available as soon as the design tools are available (rather than waiting for the availability of model-based design tools before beginning to develop estimating capabilities).

    3. It is anticipated that this strategy should involve a conceptual development (as in the sense of software development) initiative to follow this feasibility study.

    4. The strategy should consider not only the software and systems for estimating, but the overall socio-technical system, including work practices, organisational roles and relationships, etc.

    5. The strategy should involve collaboration between owners, planners, designers, contractors, cost consultants, software developers, and researchers.

    6. Model-based automated estimating is a medium to long-term strategy that is not likely to reach a production level for at least several years and is expected to require a moderate level of systems development resources to achieve it.

However, the approach should offer value within a very short time after it becomes operational, and parties that are involved in developing the approach will have several years advance over parties that wait for fully developed solutions to emerge through traditional commercial software channels.

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9. GLOSSARY

Automatic Estimating (AE)

The process of estimating a specific piece of work. Sometimes the acronym AE is also used to refer to the automatic estimator. See also Estimator below.

Bill of quantities (BoQ)

A list of quantities used as a form of cost planning and mapping to monitor and control the construction cost during the execution or post-contract period of construction. The list can be drawn up by a human professional – quantity surveyor, or prepared by a computer program for automatic quantity takeoff.

Building information model (BIM)

A semantic model of a building to be designed. See also "model based planning/design" below.

Civil concrete structure

A civil structure that is made of concrete, e.g., concrete bridge, culvert, retaining wall, tunnel and etc. In a narrow context of this study, the term is restricted to any concrete bridge only. In a wider context, it includes the discussion of roads because roads and bridges are normally planned and designed together.

Concept estimate

An estimate prepared towards the end of the concept phase of a project after the options analysis, for the purpose of evaluating the project in the business case. The estimate, which is based on the scope of the preferred option, forms the basis of the project budget. Concept estimate is expressed in out-turn dollars.

Concept phase

The initial phase of a project during which the project scope is defined. It commences with the development of a project proposal and concludes with the approval of the business case. Community consultation commences during this phase.

Design

A process of selecting elements that, combined, will make up the end product.

Detailed design estimate

The total estimate of all components of a project prepared prior to calling of tenders for construction and based on final designs, specifications and bill of quantities. It is normally expressed in out-turn dollars.

Development phase

The phase that follows the concept phase and the approval of business case, during which the preferred option is developed into a detailed design and tenders are called.

Estimate

A calculated prediction of the amount of money required to undertake a specific piece of work, expressed in dollar values of the year in which it was prepared or alternatively in out-turn dollars. Estimate can be calculated as a total cost estimate of the project, or as any part of the project. The latter is particularly relevant to (*partial*) estimates that are carried out at any decision making point during any planning/design life cycle stages.

Estimator

A person or a computer program that provides an estimate of a specific piece of work. When the term is used, the context of the discourse should make it clear whether a person or a computer program is referred to.

Industrial Foundation Class (IFC)

A neutral data format used to specify, exchange and share information typically used within the building and facility management industry sector. The IFC specification is developed and maintained by the International Alliance for Interoperability (IAI) as part of its BuildingSmart mission. The IAI also facilitates the implementation and adaptation of IFC.

Model based planning/design

A planning/design process that requires interacting between the planner/designer and a computer based semantic model of the product to be developed (e.g. a building or a concrete bridge). The model contains components of the planning/design (such as spaces, walls, doors, bridge deck, piers, etc.). Each of the components in the model has properties that are assigned by experts of various disciplines (e.g. thermal performance indicators, name and strength of the materials). The properties of the model readily support simulations, visualisation and all other modelling activities including cost modelling that support design evaluation. Like other modelling or simulation results, the 3D views of the (building or bridge) model are generated automatically from the model – As a result, the planner/designer needs only to plan/design through the model, they do not need to draw the 3D views. All experts using the model can conveniently communicate with each other through data exchange.

Multi-criteria Assessment (MCA)

An assessment measured against a set of commonly agreed, defined (and objective) criteria. Usually each of the criteria are weighted to give due emphases of the common agreement.

Out-turn dollars

Cost expressed in dollars of the period in which the work was or will be performed. Estimates prepared at a particular date can be converted to out-turn dollars by applying an appropriate inflationary rate to the time series cost of the project.

Planning

A process that translates policy directions and broad strategic choices and priorities into plans of action for a specific purpose. It involves the setting of visionary targets and implementation strategies for a specific period (say 10-30 years) based on a total system view incorporating broader contextual objectives (such as whole of government land use and traffic objectives).

Project

A series of inter-related activities with defined start and end dates designed to achieve a unique and common objective.

Project life cycle

The total duration in which the project is delineated into sequential phases (i.e. concept, development, implementation and finalisation)

Project management

The discipline of planning, organising, monitoring and controlling all aspects of a project into a continuous process to achieve its objectives.

Quantity takeoff

A process of counting the number of items of work and list them in a schedule that is convenient for cost estimating.

Work breakdown structure (WBS)

A hierarchy of construction activities or tasks that subdivide project deliverables into smaller, more manageable components of work.

Appendix A - Interview Questions

Context

This document relates to item 2 of the Research Methodology, Objectives, Strategies section of the Project Agreement

> *Meet with contracting industry partners to discuss how design information is currently input to the tendering / cost estimation process.*

"Design Information" is interpreted to encompass:

- drawings
- specifications
- bills of quantities

Interview Questions

Section 1 – Drawings

Approximately what percentage of the tender drawings you work with is prepared using CAD systems?

Less than 10%	☐
10% to 25%	☐
25% to 50%	☐
More than 50%	☐

Is it easy to interpret / work with CAD drawings compared to those that are prepared manually? (Or should this be rephrased to address 2D and 3D?)

Are you ever provided with electronic version of tender drawings? If so, in what format? If so, how have you used these drawings? (in e-paper or paper)

Section 2 – Specifications

In general, do you find that the tender specifications you are provided with are clear and unambiguous (i.e. do not conflict with other tender documentation)?

In general, do you experience problems locating specifications for particular items of work?

Section 3 – Bills of Quantities

Please categorise the tender workload of your organisation

Building work	
Civil engineering work	
Other	
TOTAL	100%

What percentage of work in a **building** tender do you let to sub-contractors?

What percentage of work in a **civil engineering** tender do you let to sub-contractors?

When tendering for **building** work, what percentage of tender documents provided to you by the client include bills of quantities?

Less than 10% ☐

10% to 25% ☐

25% to 50% ☐

More than 50% ☐

When tendering for **civil engineering** work, what percentage of tender documents provided to you by the client include bills of quantities?

Less than 10% ☐

10% to 25% ☐

25% to 50% ☐

More than 50% ☐

For the **building** tenders you prepare that are based on your own bills of quantities, does your organisation generally:

employ your own staff to prepare bills of quantities ☐

sub-contract the preparation of bills of quantities to other parties ☐

do something else (please explain what) ☐

For the **civil engineering** tenders you prepare that are based on your own bills of quantities, does your organisation generally:

employ your own staff to prepare bills of quantities ☐

sub-contract the preparation of bills of quantities to other parties ☐

do something else (please explain what) ☐

For the **building** tenders you prepare based on your own bills of quantities, does your organisation use any computer programs to assist in taking off measurements?

Yes ☐

No ☐

If you answered “yes”, please identify the computer software and hardware you use

For the **civil engineering** tenders you prepare based on your own bills of quantities, does your organisation use any computer programs to assist in taking off measurements?

Yes ☐

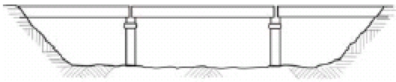
No ☐

If you answered “yes”, please identify the computer software and hardware you use

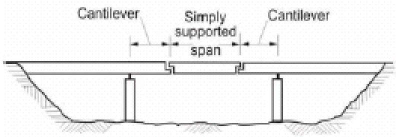
Appendix B - Bridge Types (QDMR 2005)

Beam bridges form a very high proportion of the total number of bridges in Queensland because they are the most effective bridge structure. The bridge types include:

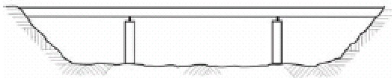
- Simply supported girder bridges
- Cantilever girder bridges and
- Continuous girder bridges.



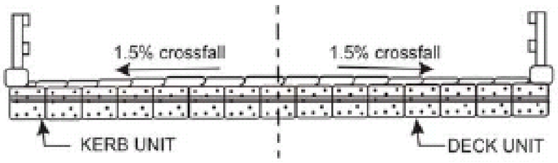
SIMPLY SUPPORTED BEAM BRIDGE



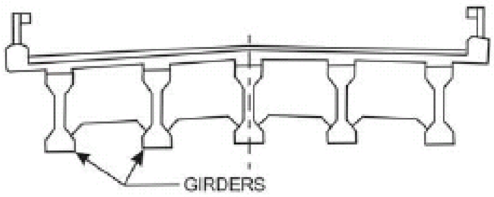
CANTILEVER BEAM BRIDGE



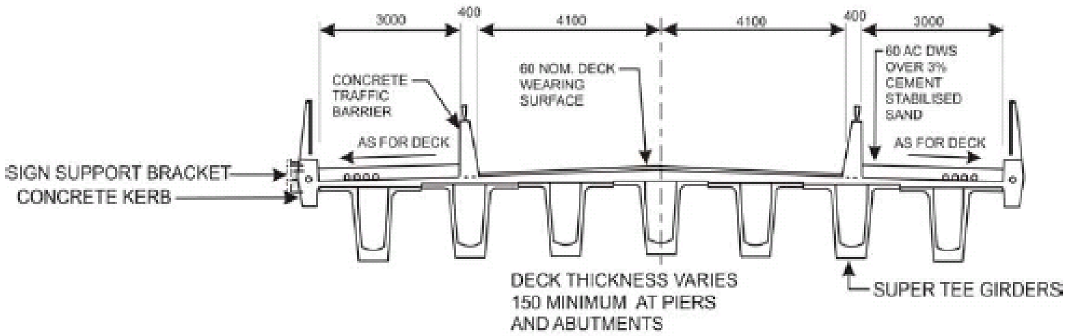
CONTINUOUS BEAM BRIDGE



PRESTRESSED DECK UNITS



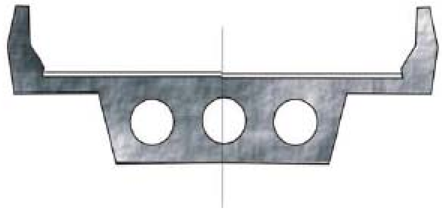
PRESTRESSED GIRDERS & IN-SITU DECK



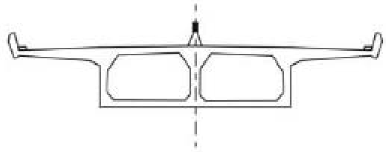
SUPER TEE GIRDERS & IN-SITU DECK

Beams (cross section) can be I-shaped or T-shaped. A bridge with pre-stressed girders and in-situ deck has max economic span of about 26 m.

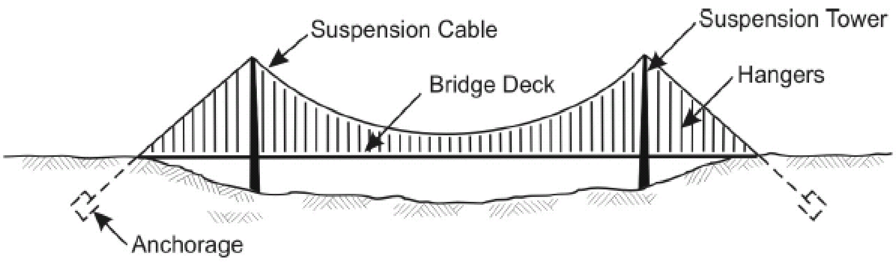
Beams (cross section) can contain circular or rectangular voids for the purpose of reducing weight. A prestressed concrete box girder can has max economic span of over 200 m.



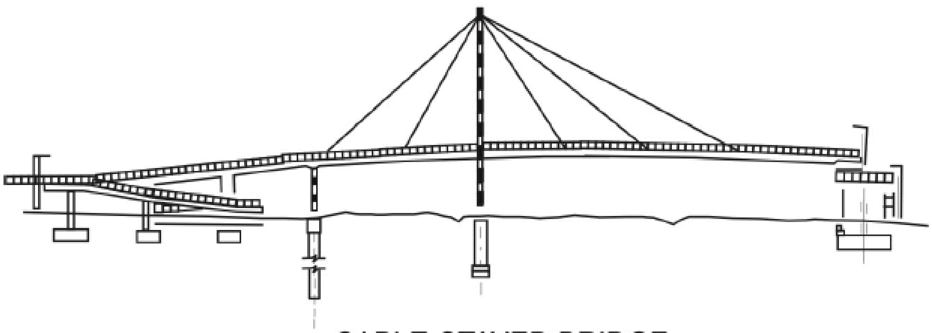
VOIDED SLAB



BOX GIRDERS



SUSPENSION BRIDGE



CABLE-STAYED BRIDGE

Suspension bridges and able-stayed bridges are only economical for very large spans. The span of suspension bridges can be as long as 2km. The span of cable staged bridges is 250m or more.

Appendix C - Costing Estimating in a Tender Contract

Tender Schedule M1

Schedule Summary

Queensland Government
Department of Main Roads

Schedule J; Robinsons Creek Bridge **Contract Number: SCHD 1587**

The Tenderer's attention is directed to the Conditions of Tendering and the General Conditions of Contract for requirements for the Schedule of Rates and Payment Provisions.

Item No	Description	Unit	Quantity	Unit Rate $ c	Amount
	PROTECTIVE TREATMENTS MRS11.03				
2631.06	Hand-placed concrete paving, 100mm thick	m2	350		
2642.02	Grouted rock pitching	m2	300		
2643.01	Rock protection (incl Geotextile fabric wrap)	m3	165		
3503.01P	Backfill with free draining granular material behind abutments (Provisional Quantity)	m3	500		
2502.02	Subsoil drains, Type D	m			
	REINFORCED SOIL STRUCTURES MRS11.06				
2781.01	Design of Reinforced Soil Structure, [structure number]	lump sum			
2782.01	Reinforced Soil Structure materials, [structure number]	lump sum			
2783.01	Construction of Reinforced Soil Structure, [structure number]	lump sum			
2784.01	Designer's inspection and certification, [structure number]	lump sum			
3303.02	Special embankment, Crushed rock, from all sources	m3	540		
2701.01	Concrete slabs and barrier kerb over retaining walls, concrete 40 MPa/40	m3	93		
2703.01	Concrete slab and barrier kerb over retaining walls, steel reinforcing	tonne	9		
	BRIDGE SUBSTRUCTURE MRS11.62				
7304.01	Concrete Class 50 MPa/20 in pier headstock	m3	93		
7305.01	Concrete Class 50 MPa/10 in pier pedestal	each	26		
7314.01	Concrete Class 50 MPa/20 in abutment headstock excluding parapet terminal, with deadman anchors	m3	217		
7315.01	Concrete Class 50 MPa/10 in abutment pedestal	each	26		
7321.01	Steel reinforcing bar in piers and abutments including parapet terminals, with deadman anchors	tonne	37		
	CAST-IN-PLACE PILES MRS11.63				
7404.01	Steel pipe liners, supply on Site 1000mm dia	m	154		
7404.02	Steel pipe liners, supply on Site 1200mm dia	m	50		
7405.01	Supply and fixing of stiffening bands	each	18		
7406.01	Handling and pitching of steel liners	each	18		
7407.01P	Driving steel liners 1000mm dia (Provisional Quantity)	m	154		
7407.02P	Driving steel liners 1200mm dia (Provisional Quantity)	m	50		
7408.01P	Extension of steel liners (Provisional Quantity)	each	6		
7411.01	Excavation of liners	m3	176		
7412.01	Excavation below toes of liners	m3	32		
7421.01P	Concrete Class 50 MPa/20 in abutment lined pile (Provisional Quantity)	m3	144		
7422.01P	Concrete Class 50 MPa/20 in pier lined pile (Provisional Quantity)	m3	79		
7425.01P	Steel reinforcing bar in lined and bored piles (Provisional Quantity)	tonne	25		
				Carried Forward	

Tenderer

Name of Tenderer

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C6810.M1.B
January 04

Tender Schedule M1

Schedule Summary

Queensland Government
Department of Main Roads

Schedule J; Robinsons Creek Bridge **Contract Number: SCHD 1587**

The Tenderer's attention is directed to the Conditions of Tendering and the General Conditions of Contract for requirements for the Schedule of Rates and Payment Provisions.

Item No	Description of Work	Unit	Quantity	Unit Rate $ c	Amount
	Amount carried forward from previous sheet				
	PRESTRESSED CONCRETE T GIRDERS MRS11.75				
8212.01	Transport of prestressed concrete T girders to the Site, T-roff, 1500 mm deep, 30 metres long, ex works [location]	each	26		
8213.01	Erection of prestressed concrete T girders,[T-roff 1500 mm deep, 30 metres long	each	26		
	BEARINGS MRS11.75				
8221.01	Laminated elastomeric bearings, 450 x 600 x 157	each	52		
8231.01	Girder restraints	each	52		
	BRIDGE DECK MRS11.77				
8301.01	Concrete Class 50 MPa/20 in cross girder	m3	36		
8302.01	Concrete Class 50 MPa/20 in deck	m3	322		
8303.01	Concrete Class 50 MPa/20 in in situ kerb	m3	65		
8305.01	Concrete Class 50 MPa/20 in median	m3	20		
8306.01	Concrete Class 50 MPa/20 in relieving slab	m3	106		
8306.02	Concrete Class 20 MPa/20, binding concrete under relieving slab	m3	14		
8311.01	Reinforcing steel in decks, cross girders, kerbs and parapets, excluding parapet terminals	tonne	64		
8312.01	Reinforcing steel in medians, in situ kerbs and parapets	tonne	15		
8313.01	Reinforcing steel in relieving slabs	tonne	11		
8321.01	Evaporative retarding curing compound	m2	2070		
	CAST-IN ANCHORS MRS11.77				
8331.01	Anchors for bridge rail	lump sum			
8332.01	Anchors for guardrail terminals	lump sum			
8333.01	Anchors for road lighting brackets	lump sum			
8334.01	Sockets for expansion joint	lump sum			
	MISCELLANEOUS CAST-IN ITEMS MRS11.77				
8341.01	Date plate	each	1		
8342.01	Permanent survey mark	each	1		
	JOINTS AND FILLERS MRS11.77				
8351.01	Bridging strips, compressible fillers and isolation inserts	lump sum			
8352.01	Joint sealants	lump sum			
	FOOTWAY AND MEDIAN MRS11.77				
8371.01	Stabilised sand in footway	m3	32		
8371.02	Stabilised sand in median	m3	28		
	BRIDGE BARRIER, STEEL MRS11.80				
				Carried Forward	

Tenderer

Name of Tenderer ____________________

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Tender Schedule M1

Schedule Summary

Queensland Government
Department of Main Roads

Schedule J; Robinsons Creek Bridge **Contract Number: SCHD 1587**

The Tenderer's attention is directed to the Conditions of Tendering and the General Conditions of Contract for requirements for the Schedule of Rates and Payment Provisions.

Item No	Description of Work	Unit	Quantity	Unit Rate $ c	Amount
	Amount carried forward from previous sheet				
8401.01	Supply and fabrication of bridge traffic rail, steel	m	139		
8402.01	Supply and fabrication of bridge balustrade, steel (bridge , RW1, RW3 and RW4)	m	144		
8402.02	Supply and fabrication of bridge balustrade,with visual screen barrier	m	101		
8403.01	Supply and fabrication of bridge safety rail, steel	m	139		
8404.01	Transport and erection of bridge traffic rail, steel	m	139		
8405.01	Transport and erection of bridge balustrade, steel	m	144		
8405.02	Transport and erection of bridge balustrade, steel with visual screen barrier	m	101		
8406.01	Transport and erection of bridge safety rail, steel	m	139		
	BRIDGE DECK EXPANSION JOINTS MRS11.82				
8452.01	Cast-in aluminium bridge deck expansion joints	lump sum			
	ANTI-GRAFFITI PROTECTION MRS11.83				
8501.01	Anti-graffiti protection coating, non-sacrificial	m2	550		
	DECK WEARING SURFACE MRS11.84				
8602.01	Dense graded asphalt corrector course, DG 20 mm mix	tonne	80		
8603.01	Dense graded asphalt surfacing layer, DG 14 mm mix	tonne	219		
8606.01	Tack Coat, 0.2 litres/m2 residual bitumen	m2	1685		
	ITEMS SUPPLIED IN SUPPLEMENTARY SPECIFICATIONS				
9130.01	Demolition of old Robinsons Creek Bridge	lump sum			
9131.01	Supply and driving of wooden piles, 250kN working load	m	2000		
9132.01	Trafficable median grate, including fixings	m	60		
				Total for Part	

Tenderer

Name of Tenderer ______________________

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Appendix D - Software Packages Used in Civil Structural Engineering

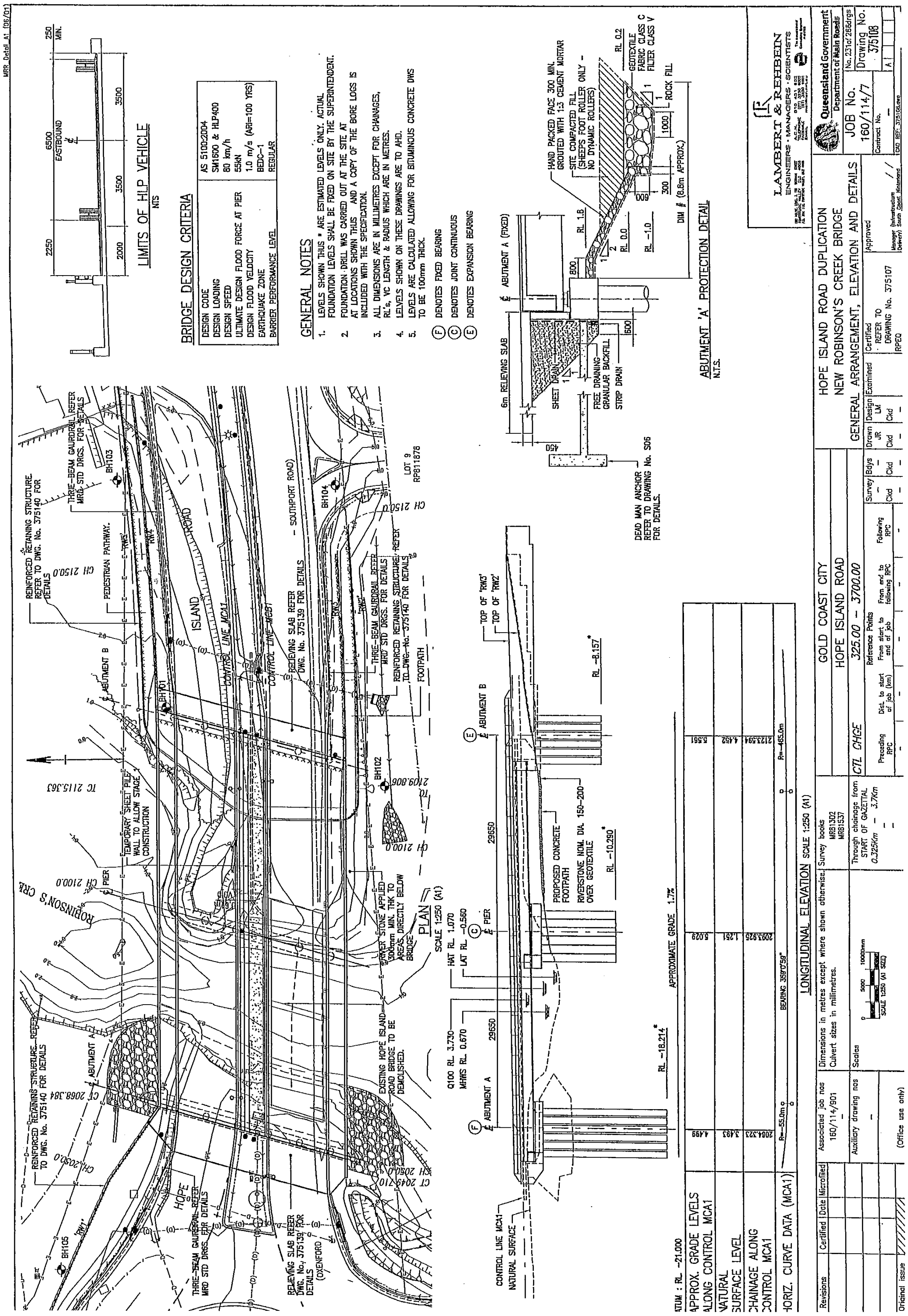
- Courtesy of John Spathonis Queensland MR.

Software Package	Software Type	Functional areas	Company
Archicad	CAD/3D	Architectural, engineering design/ modelling	Graphisoft
AutoCAD	CAD	Architectural, engineering design/ modelling	AutoDesk
Autodesk ABS 2006	CAD/3D	Building Services Modelling	AutoDesk
Autodesk ADT 2007	CAD/3D	Architectural Modelling	AutoDesk
Bentley Structural	CAD/3D	Structural Modelling	Bentley
Catia	3D assembly	Parametric geometry creation + more	Dassault/IBM
Digital Project/ Catia	3D assembly	Parametric geometry creation + more	Gehry Technology
discreet 3d max	3D modelling	3D modelling	
Elcocad	Design	Electrical Design	elcoSystems
Enercalc	Analysis	Structural engineering	ENERCALC
ETABS v6 text file	ASCII Format	Structural and seismic engineering	Computers and Structures
FEMAP	FE Pre-processor	Engineering simulation and modelling	UGS
Frameworks Plus file	Analysis	Analysis package allowing data exchange	Intergraph
Generative Components	Parametric geometry creation	Modelling and simulation	Bentley
GSA	Analysis	???	OASYS
HyperMesh	FE Pre-processor	Design performance analysis	Altair Engineering
I-DEAS	Analysis	Design simulation	UGS
Infograph	Analysis	Visualisation – project management	
LS-DYNA	Analysis	Simulation	
Lusas	Analysis	Simulation and analysis	
Mass Motion	Crowd Sim	?	
Microsoft Access database	Database	Data entry, storage and retrieval	Microsoft
Microsoft Excel workbook	Spreadsheet	Data storage and manipulation	Microsoft

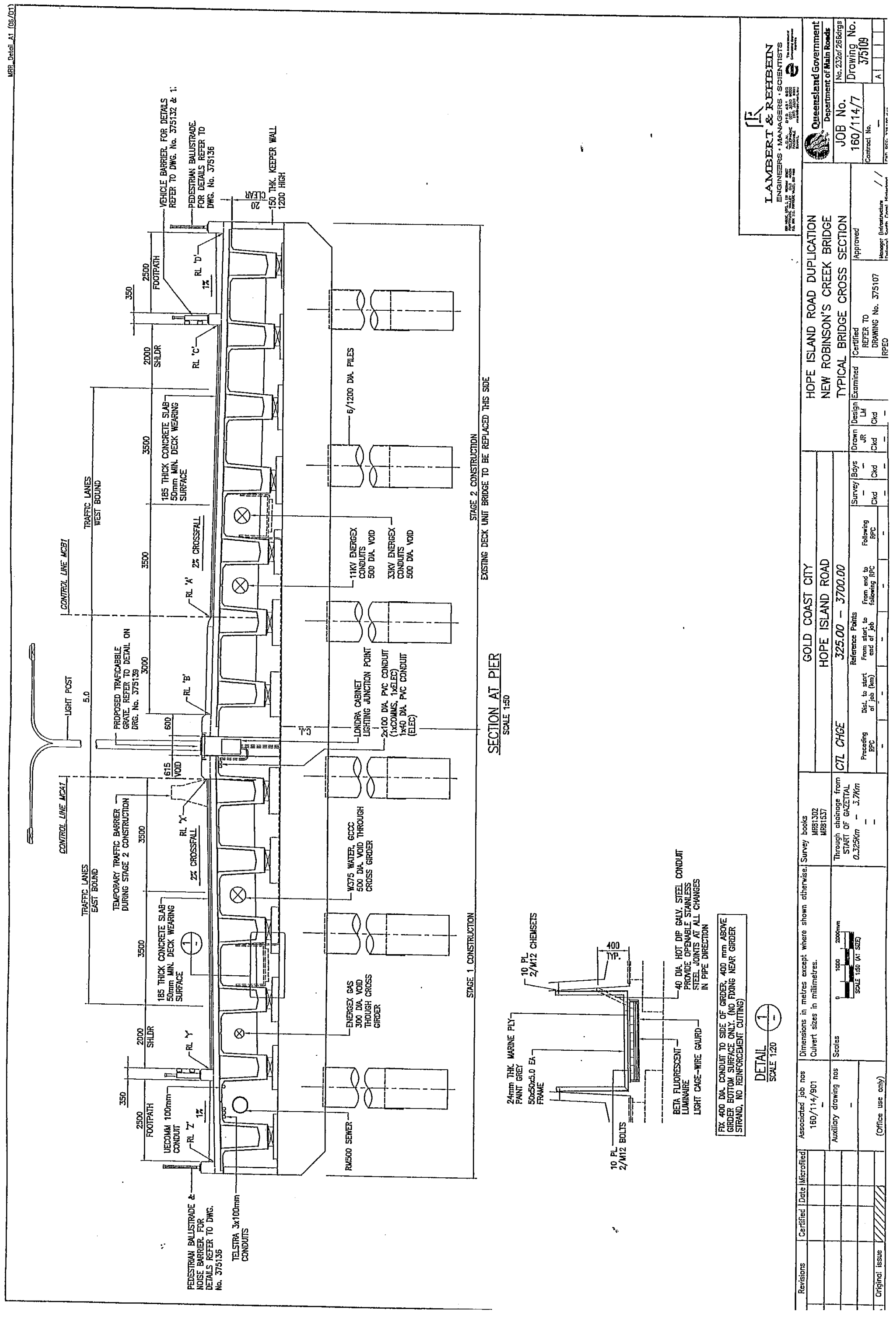
Microstation	CAD	Architectural and engineering design	Bentley
Microstran	Analysis	Structural engineering bridges in particular	
MS Project	Project Management		Microsoft
NASTRAN	Analysis	Finite element analysis	MSC
OpenSees	Analysis	Earthquake engineering analysis	Berkley Labs
PovRay	3d Rendering		www.povray.org
Radiance	Lighting Analysis		Berkley Labs
RamSteel	Analysis		Bentley
Revit Structural 4 / Revit Building 9.1	CAD/3D Structural Modelling		AutoDesk
Rhino	3D modelling		McNeel Associates
Risa	analysis	Structural engineering for analysis and design	RISA Technology
SAFE vt .f2k text file	ASCII Format	?	Computers and Structures
SAP	analysis		Computers and Structures
Sofistik	Analysis	Finite analysis and simulation	Sofistik AG
SpaceGass	Analysis	structural engineering package	SpaceGass
STAAD file	Analysis (ASCII?)		Bentley
Strand7	Analysis		Strand
Tekla (Xsteel)	3D modelling/Fabrication		Tekla

Appendix E - Bridge Design in 2D Drawings (Current Practice)

(1) Plan and elevation views (Courtesy of QDMR)



(2) Cross section view



10. AUTHOR BIOGRAPHIES

Dr Kwok K Yum

Dr. Kwok-Keung Yum is a CSIRO senior research scientist. He is working in computing for building and construction since he joined CSIRO in 1994. From 2001 he has been involved in the modelling work in CRC-CI projects "Managing Information Flows with Models and Virtual Environments", "Contract Planning Workbench", and "Automatic Estimator for Civil Concrete Structures."

Dr Yum is one of the founding members of the IAI Australasia chapter. He is the technical coordinator of the chapter. Through these years, he pursues the goal of promoting industry frameworks for the use of Building Information Models (BIMs) in the construction industry to improve supply chain efficiency. He currently focuses on the development and use of object technology for sustainable urban development in the CSIRO Division of Sustainable Ecosystems.

Dr. Thomas Froese

Dr. Thomas Froese, Ph.D., PEng, is a Professor in the Department of Civil Engineering at the University of British Columbia in Vancouver, Canada. His research and teaching interests are in construction management and computer applications.

Thomas is a leading authority on information technology for the construction industry, particularly systems integration through the use of industry data standards. He has been involved in research and development of computer tools for construction since 1986, has authored over 100 papers and reports on the subject. He has founded two companies, consulted on several national and international projects involving databases, CAD, and web-based systems for the construction industry, and has participated in data standards efforts such as the Industry Foundation Classes (IFCs). Thomas originally studied Civil Engineering at UBC before obtaining his Ph.D. from Stanford University in 1992.

Dr. Guillermo Aranda-Mena

Guillermo is currently a Lecturer in Property, Construction and Project Management at RMIT University, Australia. He holds a PhD in Construction Management and Engineering from The University of Reading and Masters of Science in European Construction Engineering from Loughborough University of Technology, both in the United Kingdom.

Since moving to Australia in 2003 Guillermo has been a principal investigator to the Cooperative Research Centre for Construction Innovation research projects in *'Construction Planning Workbench', 'eBusiness Adoption in Construction', 'Mobilising Construction', 'Business Drivers for BIM' and 'Automated Estimator for Civil Concrete Structures'* in collaboration with the Common Wealth Scientific and Industrial Research Organisation (CSIRO). He is currently supervising various Masters Theses and two PhDs. Guillermo is a Conjoint Academic to the Singapore Institute of Management, Singapore and the University of Newcastle, Australia.

For more information: *www.rmit.edu.au/staff/guillermo*

Mr. Nigel Goodman

Nigel is a CSIRO Physical Chemist which diverse interests including sustainable building and water management. Throughout these years in CSIRO, Nigel has developed excellent analytical ability with expertise in a broad range of scientific disciplines including chemistry, physical science and building technology. He worked with many different clients including the American Water and Wastewater Research Foundation, CRC for Construction Innovation, Portman mining, City West Water, Melbourne Water, the Water Service Association of Australia, British Aerospace Systems Engineering, GE Water and Hunter Water.

Mr. Willy Sher [BSc(Hons), MSc, FAIB, FCIOB]; Senior Lecturer, School of Engineering and the Built Environment.

Willy Sher originally obtained construction industry experience in South Africa before commencing his academic career. Following this he moved to the UK where he was employed as a Senior Lecturer in the Department of Civil and Building Engineering at Loughborough University. There he was involved as a Project Manager of several funded teaching and curriculum development projects to the value of £770,000. Since his move to Newcastle, he has obtained funding for teaching and research projects, including involvement in the Cooperative Research Centre for Construction Innovation [CRC-CI] (http://www.construction-innovation.info/) working on research projects in collaboration with CRC-CI academic and industry partners. He is Assistant Dean for Teaching and Learning for the Faculty of Engineering and the Built Environment at Newcastle.

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Established and supported under the Australian Government's Cooperative Research Centres Program