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## Construction Tender Subcontract Selection using case-based reasoning

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### ABSTRACT

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Obtaining competitive quotations from suitably qualified subcontractors at tender time significantly increase the chance of winning a construction project. Amidst an increasingly growing trend to subcontracting in Australia, selecting appropriate subcontractors for a construction project can be a daunting task requiring the analysis of complex and dynamic criteria such as past performance, suitable experience, track record of competitive pricing, financial stability and so on. Subcontractor selection is plagued with uncertainty and vagueness and these conditions are difficult to represent in generalised sets of rules. Decisions pertaining to the selection of subcontractors at tender time are usually based on the intuition and past experience of construction estimators. Case-based reasoning (CBR) may be an appropriate method of addressing the challenges of selecting subcontractors because CBR is able to harness the experiential knowledge of practitioners. This paper reviews the practicality and suitability of a CBR approach for subcontractor tender selection through the development of a prototype CBR procurement advisory system. In this system, subcontractor selection cases are represented by a set of attributes elicited from experienced construction estimators. The results indicate that CBR can enhance the appropriateness of the selection of subcontractors for construction projects.

Key words: Construction estimating, subcontractor selection, case-based reasoning.

### INTRODUCTION

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Subcontracting is a long-established practice in the construction industry and provides an essential element of flexibility in the overall

construction supply chain. Appropriate use of subcontractors facilitates the execution of works in a cost-effective manner with efficient use of resources. On the other hand, unproductive subcontracting, incorporating such characteristics as multi-layer subcontracting, broker-type subcontracting or "fly-by-night" subcontracting, may have adverse impact on the progress and quality of construction works (Tang, H. 2001).

Generally, building contractors only act as construction management agents in construction projects, subletting a significant proportion (about 90%) of construction works to subcontractors (Shash, 1999). In competitive tendering, construction estimators rely largely on subcontractor's sub-bids to arrive at a final tender sum to be submitted to clients. As the lowest tender is a determinant factor in securing work in traditional competitive tendering environments (Tam, 2003), estimators often need to choose appropriate tender subcontractors who not only offer competitive prices that contribute to main contractors' chances of winning tenders but who also perform well during actual construction of projects. The selection of tender subcontractors therefore needs to be based on a combined assessment of a variety of criteria including past performance, suitable experience, track record of competitive pricing, financial stability, and so on. This assessment is usually based upon intuition and past experience. Set amidst a large and changing number of subcontractors and a short tender period, this activity can be challenging, especially for inexperienced estimators.

It is pertinent to note that commercially available computer-aided estimating systems currently provide limited assistance to estimators in this area. The facilities that are provided include repositories of sub-contractor details and performance indicators, and adjudication tools that assist estimators in selecting quotes for a

particular tender. The provision of facilities such as those described in this paper therefore provides valuable assistance to estimators.

A method of addressing this situation is to draw on solutions to previous similar problems (Kolodner, 1993). Case-based reasoning (CBR) is a computer-assisted approach that draws on repositories of outcomes of such experiences. Aamodt and Plaza (1994) describe CBR as a paradigm that is similar to the way human beings adapt when solving problems.

In this paper, the processes involved in selecting suitable construction tender subcontractors are first scrutinised and a conceptual CBR framework that mimics these processes is then proposed. The design of a prototype Case-based System for Selecting suitable Subcontractors (CASSS) is then described. The

practicality of the prototype is illustrated through an example of a construction tender.

## THE SUBCONTRACTOR SELECTION PROCESS

To confirm the mechanisms of subcontractor selection in Australia, six interviews were conducted with estimators employed by major and medium sized building contractors. These sources established that estimators normally select tender subcontractors based on those used on previous similar successful tender(s). Estimators were found to use a number of factors to establish similarity including: characteristics of proposed construction projects; the market conditions where the project would take place; as well as main contractors' expectations of potential subcontractors. Table 1 outlines these factors.

| Similarity Parameters                                   | Possible Values  |
|---|--|
| <i>Project related</i>                                  |  |
| Project Category  | Administrative and civic; commercial; educational; hospital; industrial; recreational; residential; civil engineering; others            |
| Construction type                                       | New construction; refurbishment; combination of both   |
| Size  | < \$0.3M; \$0.3M-\$0.5M; \$0.5M-\$3M; \$3M-\$20M; > \$20M  |
| Location  | Sydney; Wollongong and Illawara region; Newcastle and Hunter valley region; Mid North Coast; North Coast; North West NSW; South West NSW |
| Complexity  | High, medium, low  |
| Procurement type  | Construct only; Design & construct; Construction Management; Management Contracting  |
| <i>Subcontractor's related</i>                          |  |
| Suitable experience relevant to current type of project | High, medium, low  |
| Track record of competitive pricing                     | Always competitive; average; not competitive   |
| Track record of performance during construction         | Outstanding; average; poor   |
| Financial stability                                     | High, medium, low  |
| Availability of suitable subcontractors                 | High, medium, low  |
| Current dispute with main contractor                    | Yes; No  |

Table 1: Project similarity parameters

In addition to consulting databases of subcontractors used on previous similar tenders, estimators were influenced by how competitive their tenders were. Estimators reviewed selected sub-sets of subcontractors to determine their suitability for the current tender by comparing them to the nominal 'best' subcontractor of the same trade category (e.g. mechanical, electrical, hydraulic, structural steel, etc.). A subcontractor was considered the best

for a particular project if it could be established that they could potentially submit a highly competitive sub-bid. If the tender is won, the subcontractor needs to be able to complete the subcontract in a technically sound and proficient, financially secure and occupationally healthy and safe manner. The process in which the estimators selected subcontractors for their tenders is described in Figure 1.

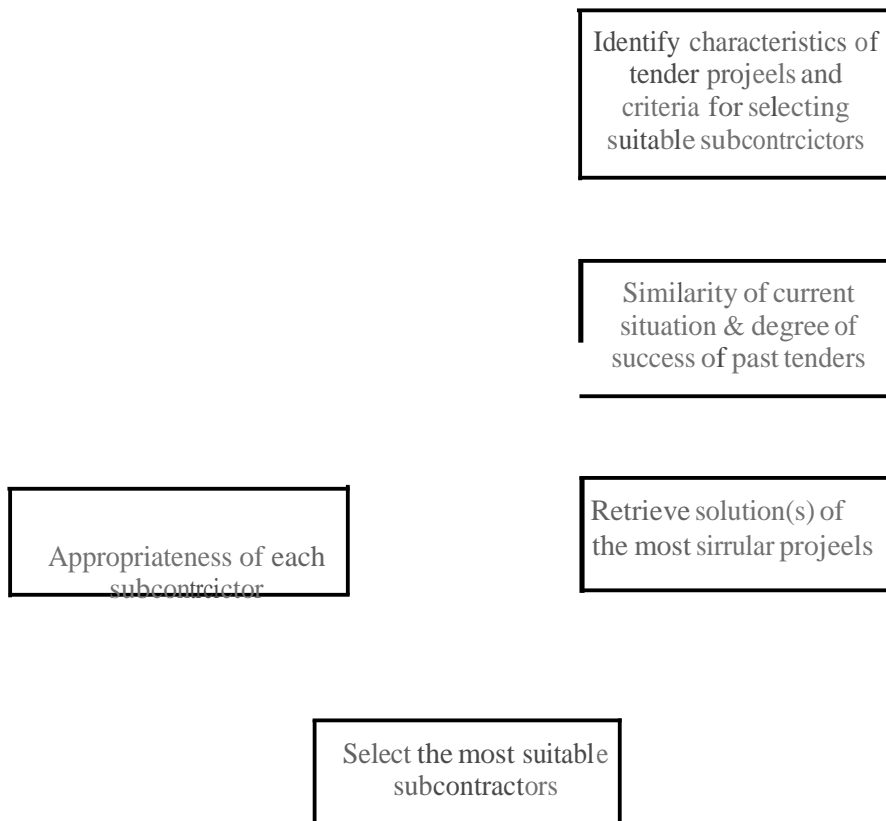


Figure 1: Process of Selecting Subcontractors for Tendering

### **FRAMEWORK FOR THE CBR SUB-CONTRACTOR SELECTION MODEL**

CBR can be beneficially used to support the tender subcontract selection process described above. A conceptual framework that drives the development of a case-based subcontractor selection advisory system is shown in Figure 2. The framework consists of three key modules, i.e. input, selection, and output.

The *Input* module provides construction estimators with a means of submitting data. Estimators need to enter similarity parameters

for construction tenders and rate their importance. Depending on these similarity parameters and their weightings, similar cases are retrieved by the *Subcontractor Selection* module. These similar cases are accumulated over time as the system is used on successive occasions. It therefore follows that the more the system is used the more accurate it becomes. The retrieval process is performed using a nearest neighbour retrieval mechanism (Kolodner, 1993). A list of subcontractors used in similar past tenders and the degree of success of those tenders is provided to estimators for consideration. When data comparable to the current case has been selected, and estimators have found the solution and outcome to be

acceptable, they can apply this 'case' to the new

tender project. If suitable case data are not available, estimators will need to adapt data to suit the distinctive characteristics of the new tender. Further details on this process are provided in the next section.

The selected subcontractors are then reported to estimators through the output module. All data (including the project similarity parameters and their importance weightings) are presented for checking. Details of the new case and the adopted or adapted solution(s) are stored in the CBR database for future reference and retrieval.

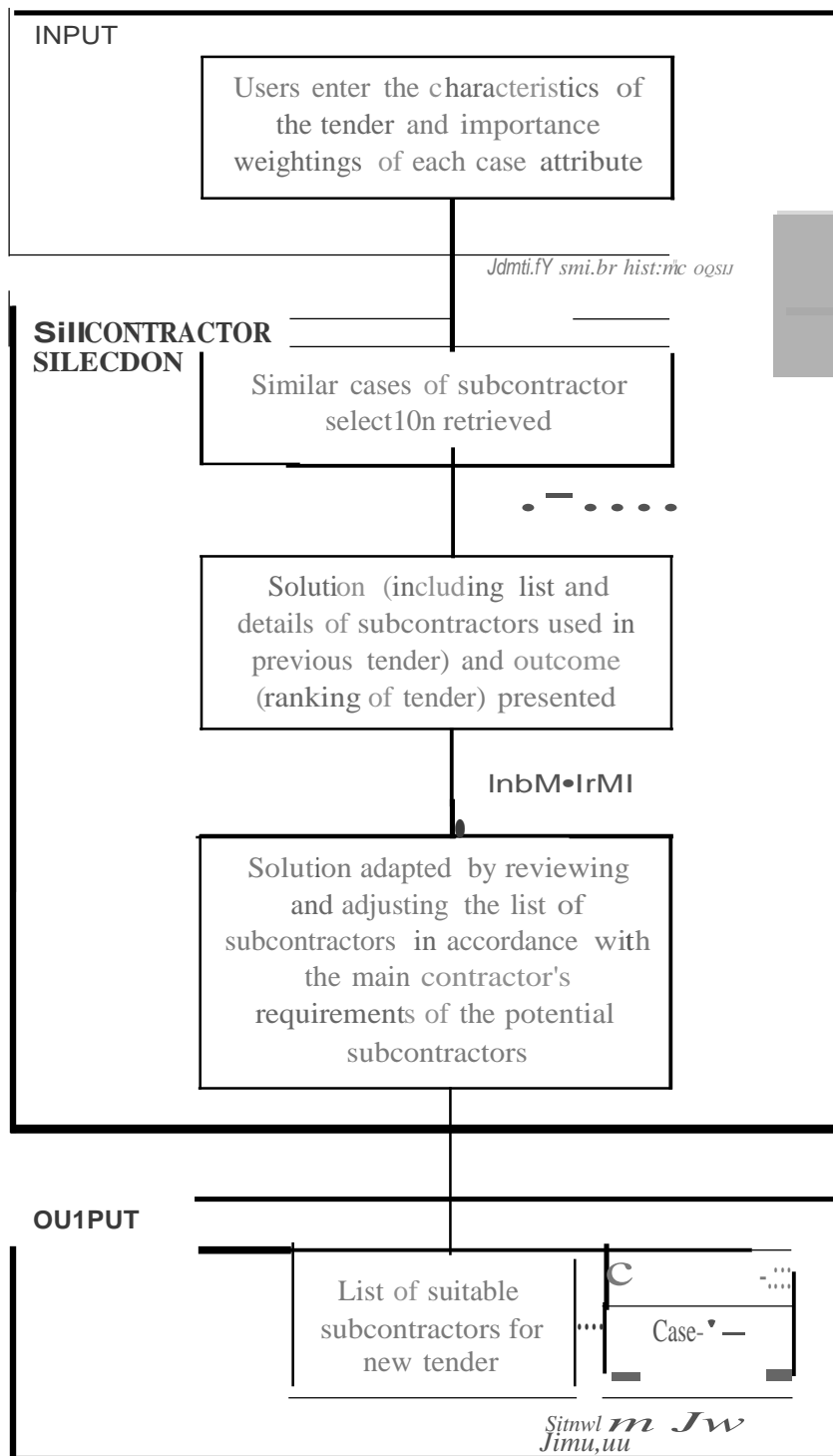


Figure 2: Conceptual framework of the case-based system for selecting subcontractors

## ARCHITECTURE OF THE CBR SUB-CONTRACTOR SELECTION MODEL

To establish the suitability of CBR approaches in this domain, the conceptual framework described above was developed into a CBR prototype using ART<sup>®</sup>Enterprise™ version 10.

## CASE REPRESENTATION

A robust CBR system is largely dependent on a clear representation of constituent cases and an appropriate structure for describing their contents (Aamodt and Plaza, 1994). CASSS comprises three main constituents: problem, solution and outcome (Table 2).

| Case Attributes             | Values   | Characteristics                                       |
|-----------------------------|--|---|
| <i>Problem Part</i>         |  |   |
| Project Category            | Administrative and civic; commercial; educational; hospital; industrial; recreation; residential; civil engineering; others  | Categorical data with no implied logical relationship |
| Construction Type           | New construction; refurbishment; combination of both   | Categorical data with no implied logical relationship |
| Size                        | < \$0.3M; \$0.3M-\$0.5M; \$0.5M-\$3M; \$3M-\$20M; > \$20M  | Quantitatively measurable                             |
| Location                    | Sydney; Wollongong and Illawara region; Newcastle and Hunter valley region; Mid North Coast; North Coast; North West NSW; South West NSW   | Categorical data with no implied logical relationship |
| Complexity                  | High, medium, low  | Categorical data with implied logical relationship    |
| Procurement Type            | Construct only; Design and construct; Construction Management; Management Contracting  | Categorical data with no implied logical relationship |
| <i>Solution Part</i>        |  |   |
| Project Name                | Name of Tender   | Text  |
| Date Submitted              | Date   | Date  |
| List of Subcontractors Used | Details of each subcontractor for each category including contract details, areas of operation, experience in certain type of works, track record of competitive pricing, track record of performance during construction, financial stability and record of current disputes with main contractor | Various types   |
| <i>Solution Part</i>        |  |   |
| Ranking of Tender Submitted | 1, 2, 3, 4, etc.   | Quantitatively measurable                             |

Table 2: Characteristics of case attributes

The *problem* part is represented by a collection of tender similarity parameters. The solution part contains a list of subcontractors used in a past tender whereas the outcome provides feedback detailing the degree of success of the tender. The degree of success is measured by the client's ranking of the contractor's tender submission provides a snapshot of case representation in CASSS. As the case attributes for CASSS contain both numerical and linguistic values various case representation schema were adopted to ensure case details were meaningfully encapsulated for future retrieval, comparison and reuse. Some of the schemas used are presented below.

**Quantifiable data:** To reduce computational effort and time, ranges were defined for quantifiable data. For instance, in CASSS, "project size" is divided into five ranges: (i)

"less than \$0.3M"; (ii) "\$0.3M-\$0.5M"; (iii) "\$0.5-\$3M"; (iv) "\$3M to \$20M"; and (v) over \$20M". The values of new and historic cases are considered equal if both are within the same range.

**Categorical data with no implied logical relationship:** Linguistic data is best captured through a precise and consistent categorical representation scheme, as this reduces the likelihood of misunderstanding and typing errors. Data of this type are codified as linguistic categories that best describe their characteristics may include such values as "commercial", "industrial", "residential" and so on. In addition, data with Boolean values (i.e. yes or no) belongs in this category too. As no logical relationship exists between the values, they can be regarded as discrete points where an exact match is required.

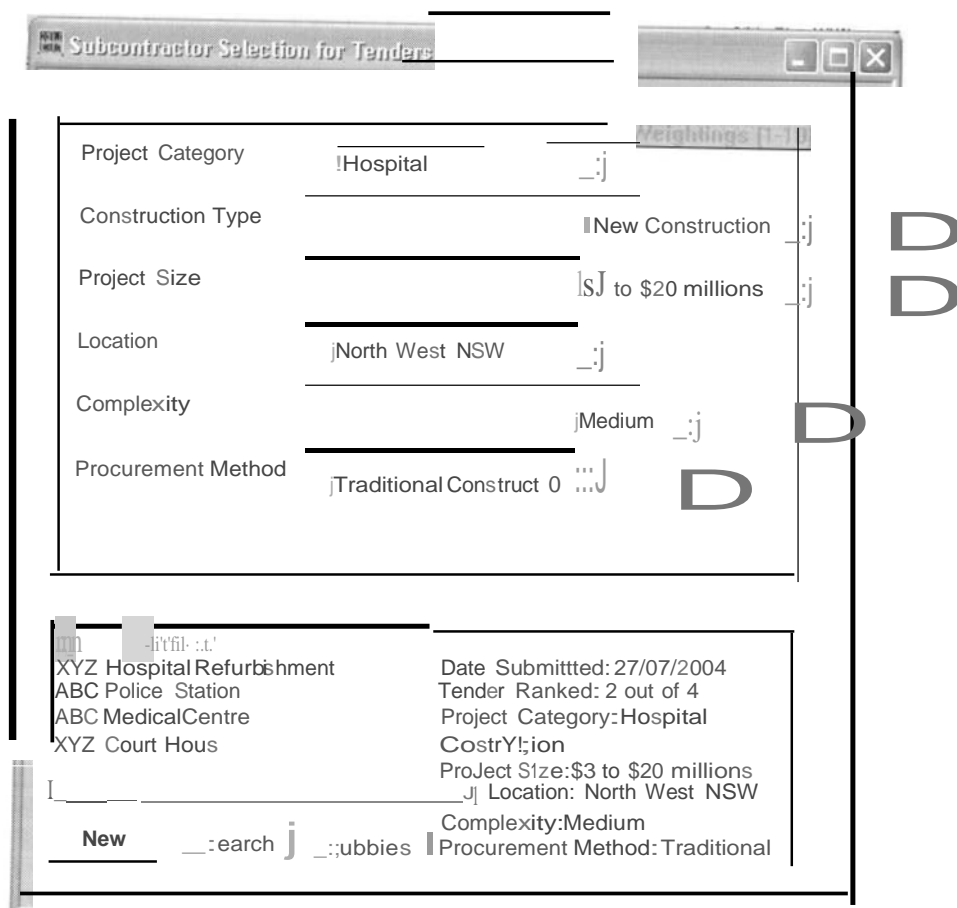


Figure 3: Case Representation in CASSS

**Categorical data with an implied logical relationship:** It is not uncommon to describe

a concept using linguistic terms. For instance, "high", "medium" and "low" are

used to describe various levels of market competitiveness, with the implication that "high" is better than "medium" and so on. The intrinsic relationship between these terms can be represented by a taxonomy tree. By defining the logical relationship

through such a structure, the distance between two related values can be measured and a similarity score computed (Figure 4).

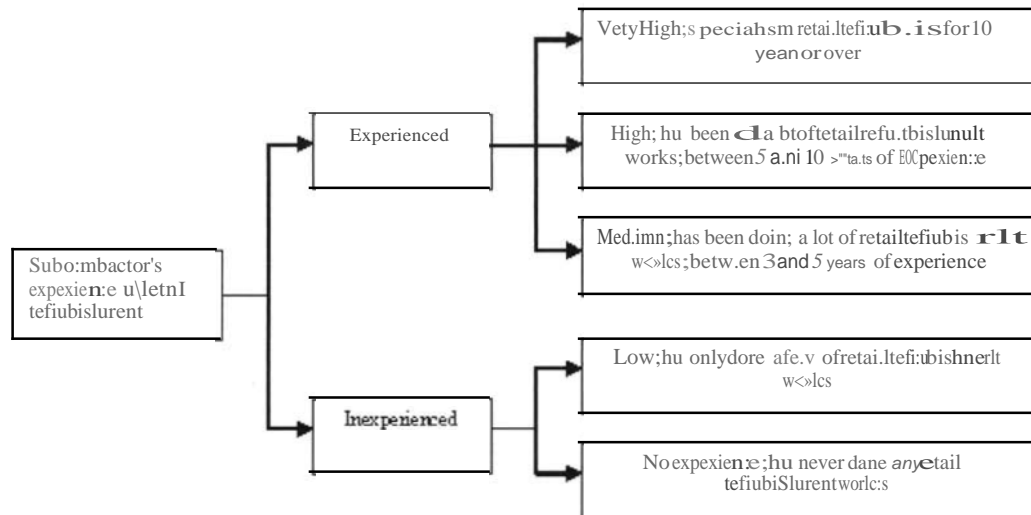


Figure 4: Taxonomy structure for reflecting the relationships of categorical data

In ART\*Enterprise™ case attributes are represented as non-hierarchical. The major advantage of this organisation is that entire case libraries may be searched during the case matching and retrieval process. As a result, the accuracy of case retrievals is a function of how reliable the matching mechanisms are, whilst adding new cases to the case library is relatively cheap and easy compared to CBR systems which use hierarchical structures (Kolodner 1993).

#### MATCHING AND RETRIEVAL

Since flat organisational structures do not justify the use of inductive approaches, CASSS uses a nearest neighbor retrieval mechanism. Similar cases are retrieved from the case library on the basis of the global similarity value (total case score) which ranges from 0 to 100; with 100 representing an exact matching and 0 a total mismatch. The global similarity value is determined by the following formula:

$$\text{Global similarity value} = \sum_{i=1}^n f(T_i, S_i) w_i \times 100$$

where:

$T$  = target case

$S$  = stored case

$n$  = number of attributes in each case

$i$  = an individual attribute from 1 to  $n$

$w$  = importance weightings of attribute  $i$

$f$  = local similarity between attribute  $i$  in cases  $T$  and  $S$

The local similarity value (i.e. attribute score), on the other hand, ranges from 0 to 1. For attributes composed of categorical data with no implied logical relationship, the local similarity value is either 1 (when the two values are similar) or 0. However, if there is an implied logical relationship between the data values or in the case of quantifiable data, the local similarity value is calculated in accordance with the positions where the data values of the two cases appear in the taxonomy tree. Thus the proximity of shared common index nodes indicates higher similarity values. Once similarity scores have been generated for all cases, they are ranked and the five cases with the highest similarity scores are presented for further consideration.



## ADAPTATION

A combination of different adaptation strategies was adopted for CASSS. For instance, if users are satisfied that a retrieved case closely resembles the current case (i.e. the tender being worked on), they can employ a *null adaptation* strategy by simply adopting the matching solution to the new case without any modification. However, when the intrinsic characteristics of the two cases differ, modifications to the historic solutions might be desirable. *Critic-based adaptation* (Brown and Lewis, 1993)

and *parameterised adaptation* (Schank et al, 1994) strategies are provided to help decision-makers arrive at more appropriate solutions.

In the solution part of each retrieved case, a list of subcontractors used in past tenders is presented to users. To facilitate detailed assessment of the suitability of the proposed subcontractors, the details of each subcontractor including area of operation, experience, performance, financial stability, etc. are provided (as shown in Figure 5).

The screenshot shows a software interface with the following elements:

- Window Title:** SUBBIES LIST: ABC MAIN HOSPITAL
- Dropdown Menu:** Mechanical Services
- Table:**

|                              |   |
|------------------------------|---|
| Mechanical Subcontractor 007 | 2 |
| Mechanical Subcontractor 021 | 3 |
| Mechanical Subcontractor 010 | 4 |
- Subcontractor Details Panel:**
  - Name:** Jelli Rreca
  - Contact:** jAlMife!X
  - Phone:** Doc)QOQ()
  - Fax:** [Redacted]
  - Address:** [Redacted]
  - Operating in:** 'North West NSW'
  - Suitable Experience in:** 'Hospital'
  - Competitive Pricing:** C....,aye
  - Performance:** **OUTSTANDING**
  - Financial Stability:** [Redacted]
  - Current Disputes with Main Contractor:** [Redacted]
- Buttons:**
  - Go Back to View Another Case
  - Choose the Subby for New Tender
  - Use Details to Search Similar Subbies
  - OK

Figure 5: Subcontractor Details Screen in CASSS

If users are dissatisfied with the subcontractors proposed for a certain trade, they can search for other companies from the database of subcontractors using case-based reasoning. CASSS displays an adaptation screen to guide users through this process as shown in Figure 6. Users are required to enter characteristics of the required subcontractors and their importance weightings. Another CBR engine (which is incorporated into the adaptation mechanism of CASSS) allows users to search through the system's database of subcontractors for

alternative subcontractors to the ones already proposed. Once users are satisfied with the list of subcontractors to be used in the new tender (case), a report of these subcontractors is available for the next stages of the tender process.

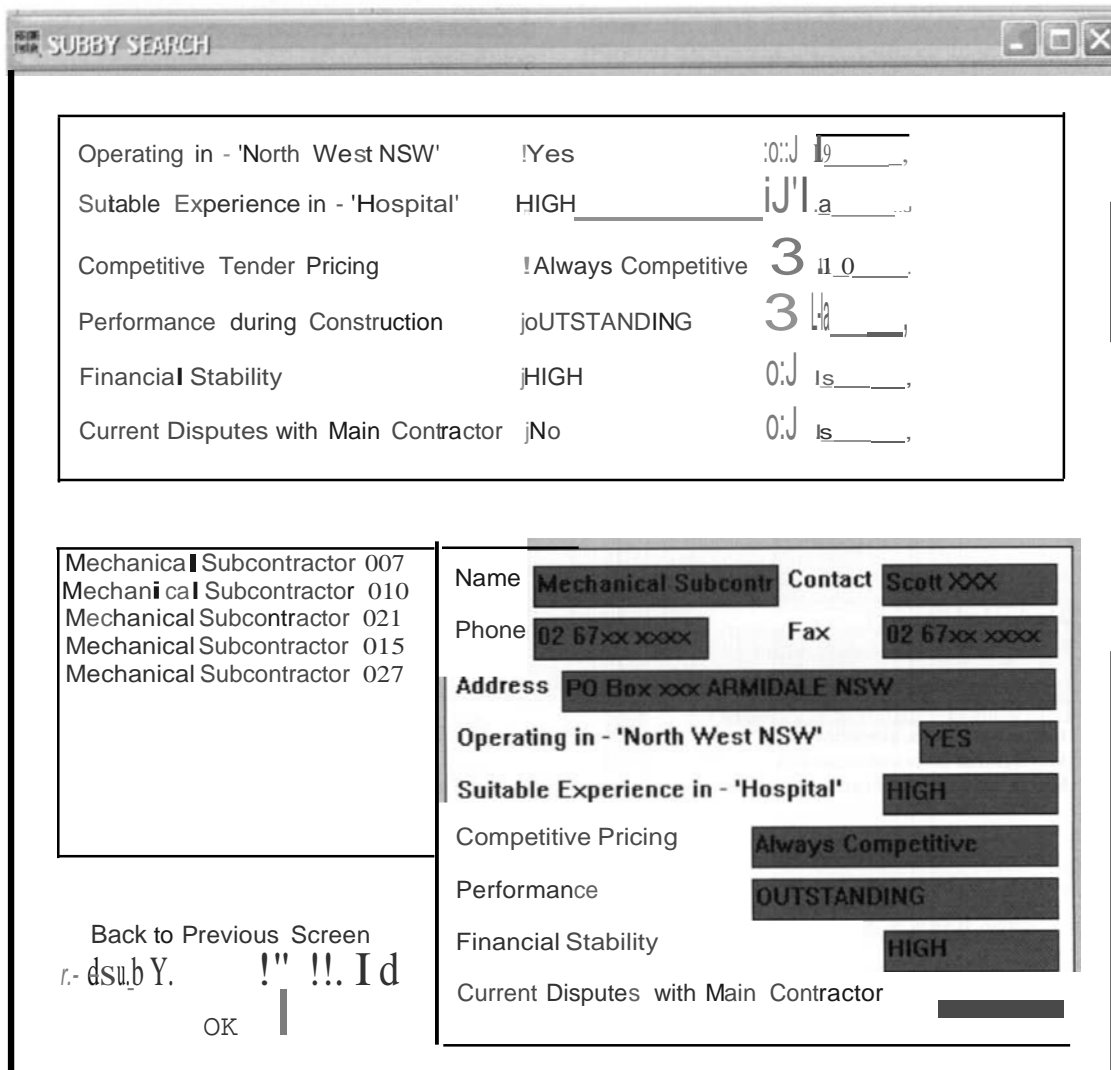


Figure 6: Critic-based adaptation using user's knowledge and CBR

### SYSTEM MAINTENANCE

As the quality of the advice given by CASSS relies heavily on the quality of the information of past tenders, system maintenance (i.e. recording and updating of subcontractor information) is an important issue. As a feature of case-based reasoning, CASSS has the ability to record information of every new tender case and automatically update its database (i.e. the case base of tendered projects). Furthermore, the system case base is also designed to link with the main database of subcontractors that is normally kept in a construction company. The system case base will automatically be updated if there is any change in the subcontractor information in the subcontractor database.

### SYSTEM PRACTICALITY

An actual tender for the construction of a new hospital (with a value of approximately A\$10m) in New South Wales, Australia was used to demonstrate the practicality of CASSS. Some details of this tender are summarised in Table 3.

| <i>Tender Details</i>          | <i>Details</i>  |
|--------------------------------|---|
| Project Category               | Hospital  |
| Construction Type              | New Construction  |
| Project Size                   | Approximately \$8,000,000   |
| Location of Site               | NSW North West  |
| Level of complexity of project | A simple structure including slab on ground, light weight steel frame, metal roof and external cladding. Services include electrical, security, data, nurse call, ducted air conditioning, water, sewer, stormwater, etc. |
| Procurement method             | Traditional Construct Only  |

Table 3: Details of test tender case

A total of 40 historic construction tenders were collected to train the CASSS model. A set of tender similarity parameters and their importance weightings were identified in accordance with the characteristics of the construction project, the external environment and the main contractor's expectation of potential subcontractors. CASSS then recommended a list of subcontractors for the tender<sup>1</sup>.

To determine whether the solution generated by the model was comparable to that produced by domain experts, four independent, experienced construction estimators with extensive local knowledge of subcontractors in the area were invited to assess the subcontractors chosen by CASSS.

As can be seen from the table above, there is generally an unequivocal agreement between the domain experts and CASSS. It is also noteworthy that the list of subcontractors selected by CASSS was quite similar to that prepared by the actual estimator of this particular tender, and that the estimator's tender was successful.

## **CONCLUSION**

This paper has presented a novel way for selecting subcontractors for construction tender projects using CBR. Since CBR is an experience-based approach, the lessons learned in previous cases can be made available to estimators to provide them with an early indication of the likely future outcomes of a tender.

Based on the information collected from experts, a conceptual framework for a case-based system for selecting subcontractors at tender time was devised. The framework was subsequently developed into a computer prototype using a CBR shell – ART\*Enterprise. The prototype, using trial data, has demonstrated that CBR can provide appropriate recommendations for the tender of a hospital. However, in order for CASSS to be fully functional, further verification and validation of the system are needed.

<sup>1</sup> The issue of confidentiality prevented the authors from publishing details of these subcontractors

| <i>Subcontractor Category</i> | <i>CASSS Recommendations</i> | <i>Expert 1</i> | <i>Expert 2</i>     | <i>Expert3</i>      | <i>Expert4</i>      |
|-------------------------------|------------------------------|-----------------|---------------------|---------------------|---------------------|
| Excavation                    | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Concrete                      | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Structural Steel              | 3 subbies                    | Agreed          | Added another subby | Agreed              | Agreed              |
| Bricklayer                    | 2 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Metal Roofing & Cladding      | 3 subbies                    | Agreed          | Added another subby | Agreed              | Agreed              |
| Aluminum Windows & Doors      | 4 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Doors & Frames                | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Agreed Gyprocker              | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Carpet & Vinyl                | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Tiling & Waterproofing        | 2 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Painting                      | 3 subbies                    | Agreed          | Agreed              | Added another subby | Agreed              |
| Metalworks                    | 2 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Electrical Services           | 3 subbies                    | Agreed          | Agreed              | Agreed              | Added another subby |
| Mechanical Services           | 3 subbies                    | Agreed          | Agreed              | Agreed              | Replace one subby   |
| Hydraulic Services            | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Medical Gas Services          | 3 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |
| Fire Services                 | 2 subbies                    | Agreed          | Agreed              | Agreed              | Agreed              |

Table 4: Results of system reliability test

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