

A Relational Case-Based Reasoning Framework for Project Delivery System Selection

Yang Cui, Yong Qiang Chen

Abstract—An appropriate project delivery system (PDS) is crucial to the success of a construction projects. Case-based Reasoning (CBR) is a useful support for PDS selection. However, the traditional CBR approach represents cases as attribute-value vectors without taking relations among attributes into consideration, and could not calculate the similarity when the structures of cases are not strictly same. Therefore, this paper solves this problem by adopting the Relational Case-based Reasoning (RCBR) approach for PDS selection, considering both the structural similarity and feature similarity. To develop the feature terms of the construction projects, the criteria and factors governing PDS selection process are first identified. Then feature terms for the construction projects are developed. Finally, the mechanism of similarity calculation and a case study indicate how RCBR works for PDS selection. The adoption of RCBR in PDS selection expands the scope of application of traditional CBR method and improves the accuracy of the PDS selection system.

Keywords—Relational Case-based Reasoning, Case-based Reasoning, Project delivery system, Selection.

I. INTRODUCTION

THE project delivery system (PDS) defines the process by which a construction project is comprehensively designed and constructed for a client. It also provides the roles and responsibilities of the parties involved in a project [1], [2]. The selection of an appropriate PDS is crucial to the success of a construction project [2], [16], [18].

Many scholars have conducted research on PDS selection, and proposed many methods to help clients (decision makers) select PDS in a systematic manner. Those methods include the analytic hierarchy process (AHP) and improved AHP [3], [4], [20], the multi-attribute utility analysis [9], [10], [12], [14], [24], the fuzzy logic approach [7], [15], [23], and the data envelopment analysis (DEA) [8], [13]. These methods attempt to rigorously structuralize the PDS selection criteria and PDS selection process. However, due to the fuzzy nature of the PDS selection problem and the multi-criteria involved, these methods are found to have difficulties in providing logical results [9]. Therefore, the instance-based approaches, represented by Case-based Reasoning (CBR), are considered to be more reasonable for solving this semi-structured and complex decision-making problem.

The CBR approach is based on the hypothesis of “similar problems have similar solutions” [21]. It is more suitable for PDS selection, because PDS selection is often based on

selections of previous similar cases [17], [22]. CBR approaches provide a technique to acquire, represent and manage previous experience, augment a set of specific experience with generalized knowledge and formalize a traditionally-informal body of knowledge [25]. Several PDS selection models are proposed based on the CBR approach [17], [19], [25].

Case representation and the similarity mechanism are the main parts of the CBR approach. It is used in PDS selection and usually presents project cases as attribute-value vectors [17]-[19], [25]. It calculates the similarity score of each attribute between two cases. However, two important points need to be considered. Firstly, there are some relations between different PDS selection criteria (attribute), so representing a project in an attribute-vector style without considering the attributes' relationships, may miss some valuable information and lead to inaccuracy when calculating similarity. Secondly, the traditional CBR method is feasible only under the assumption that the information is complete so that there are no differences among structures of the cases. However, sometimes we can't get all the information we need so that a new computational method which could take the difference in structures into consideration is in need.

Reference [5] proposed a relational CBR (RCBR) approach to improve the traditional CBR approach, representing cases with feature terms (a generalization of first-order terms) formalism and estimating similarity with a modified method. Feature terms are a generalization of first-order terms that provide a natural way to describe incomplete information where attributes are sorted and relation among attributes are represented by features [6]. By representing cases in feature terms, a more descriptive case representation can be achieved, which reflects the logical way human experts can organize their domain knowledge better. Furthermore, the modified method for estimating the similarity in RCBR uses a new distance measure to measure the similarity of the attributes having different structures [5]. Thus the RCBR was adopted in this paper to solve the problems met in PDS selection.

This paper aims to introduce the RCBR method to solve the PDS selection problem. The structure of this paper is as follows. First, the RCBR approach is stated. Then the PDS selection criteria are identified through a literature review and expert interviews. Based on the identified PDS selection criteria, a feature term to define a project case is established. With the established feature term, the mechanism of similarity calculation and a case study are shown in the next section to illustrate the PDS selection method. Some conclusions are made in the last part.

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II. THE RELATIONAL CASE-BASED REASONING APPROACH

There are three main steps to performing the RCBR approach: 1) to define the case representation with feature terms, 2) to assess the similarity of values, and 3) to assess similarity between cases.

The distance between feature terms and first order terms is identified by position. There are some main concepts related to this paper in feature terms, such as the least upper bound, depth, and anti-unification [5].

Definition -Least upper bound (lub): The lub of two sorts is the most specific sort that generalizes both.

The structure similarity mechanism between two features is based on the sort hierarchy and the definition of the least upper bound. If the lub of two sorts is more specific in the hierarchy, then the two sorts are considered to have a higher similarity value.

Definition-Depth: The depth of a feature f with root X , is the number of features that compose the path from root X to f , with no repeated nodes.

Definition- anti-unification: If a feature f appears in both case c_1 and c_2 , the set $C_{AU} = \{f \mid f \in c_1 \wedge f \in c_2\}$ represents the anti-unification of two cases.

The similarity mechanism between two case representations with feature terms is based on the concept of anti-unification. The anti-unification of two feature terms gives what are common to both and all that are common to both. A detailed definition and explanation of feature terms theory was given by Armengol and Plaza [5], [6].

To calculate the similarity between two cases, the similarity measures for features and structure of cases have to be defined. Within the anti-unification set, there are two types of features in a case - numeric and conceptual. Similarity of features with numerical values and conceptual sort are estimated first. Then the difference between the structures of the two cases is calculated by a new method. The modification through calculating similarity of structure improves the accuracy of the similarity estimate.

III. IDENTIFICATION OF PDS SELECTION CRITERIA

Because of the influence and impact of PDS on the success of a project, many researchers proposed different PDS selection criteria [8], [15], [16], [18], [27]. Based on these studies, PDS selection criteria can be categorized into three classes: the client's characteristics and objectives, the project characteristics, and the external environment. A PDS selection criteria checklist was first established based on past research, then a set of expert interviews were conducted to determine the most important PDS selection criteria shown in Table I.

TABLE I
IDENTIFIED PDS SELECTION CRITERIA FOR FEATURE TERMS

Factor	Description
<i>Client's characteristic and objectives</i>	
Type	Nature of client's organization
Experience	Experience of client in the construction domain
Financial ability	Client's ability for financing and paying
Ability of client's project manager	Ability of client's project manager to cooperate with other parties
Ability of client's employees	Ability of client's staff to cooperate with other parties
Requirement for on-time completion	Wishes for project to be completed on schedule
Requirement for building speed	Requirement of a high construction speed
Requirement for within-budget completion	Wishes for project to be completed within budget
Requirement for low operational cost	Requirement of low cost in project's operational period
Requirement for low maintenance cost	Requirement of low maintenance cost in project's whole life cycle
Acceptable degree for change	Client's attitude and tolerance towards variation
Willingness to be involved	Client's wishes to be directly involved in the project
Preference for taking risks	Client's wishes to take certain risks to improve project performance
Preference for using its own resources	Client's preference for using their own resources on the project
Trust towards other parties	Level of trust amongst other parties involved in the project
<i>Project characteristics</i>	
Project type	Type of building in the project, i.e., transportation, residential, etc.
Building construction type	Type of construction in the project, e.g., new construction, refurbishment etc.
Project size	Project scale measured by its estimated value
Design complexity	Design complexity due to the requirements of the client or a unique natural environment
Construction complexity	Construction complexity due to the design or environment
Field conditions	Various site risk factors having impact on project procurement
<i>External environment</i>	
Markets competitiveness	Level of competition in market with regards to this project
Contractor's availability	Availability of contractor and subcontractor for the project
Materials availability	Availability of materials as required for the project
Technology availability	Availability of technology to carry out certain construction techniques in the project
Financial market stability	The stability of interest rates, inflation etc.
Political stability and constraints	Impact of political activities and political instability
Regulation impacts	Impact of rules and regulations
Weather conditions	The climate and weather conditions at the project location
Geological conditions	The geological conditions of the project location

IV. THE FEATURE TERM FOR CONSTRUCTION PROJECTS

A. The Feature Terms of Construction Project Case

The development of feature terms (also called feature structure) includes varying degrees of judgment regarding classification and the balance between feature depth and coverage. There has been research into this issue using either field expert interviews [11] or competency questions [26]. Competency questions are a set of consistent questions that have been used extensively to assure consistent classification of

terms. Based on the definition of feature terms, the structure of features not only represents the conceptual logic of professional knowledge and the human decision-making process, but also has an influence on similarity calculation. The rationality of the feature structure is critical for the application of the RCBR approach. In this paper, a series of literature reviews and expert interviews are conducted to establish a structure of features identified in the previous step.

Fig 1 shows the PDS selection feature terms developed in this study. In feature term theory, each feature generally has its own value/sort, e.g. the feature “Economic environment” has its own value while having four sub-features. Such constraints

on feature term theory are necessary and applicable for the application of biology and chemistry study [6], but are not suitable nor necessary for PDS selection feature term. Latent variables which influence PDS selection do not have a clear scope and meaning in practice, it is hard to assign values to them. Different users do not share a common understanding of these latent variables, which leads to singular cases in case-based reasoning and causes errors. Therefore, no requirement is made for these features to have sorts/values and, a structural similarity mechanism was assessed to generate values for these features. The features which have conceptual values are in the feature term.

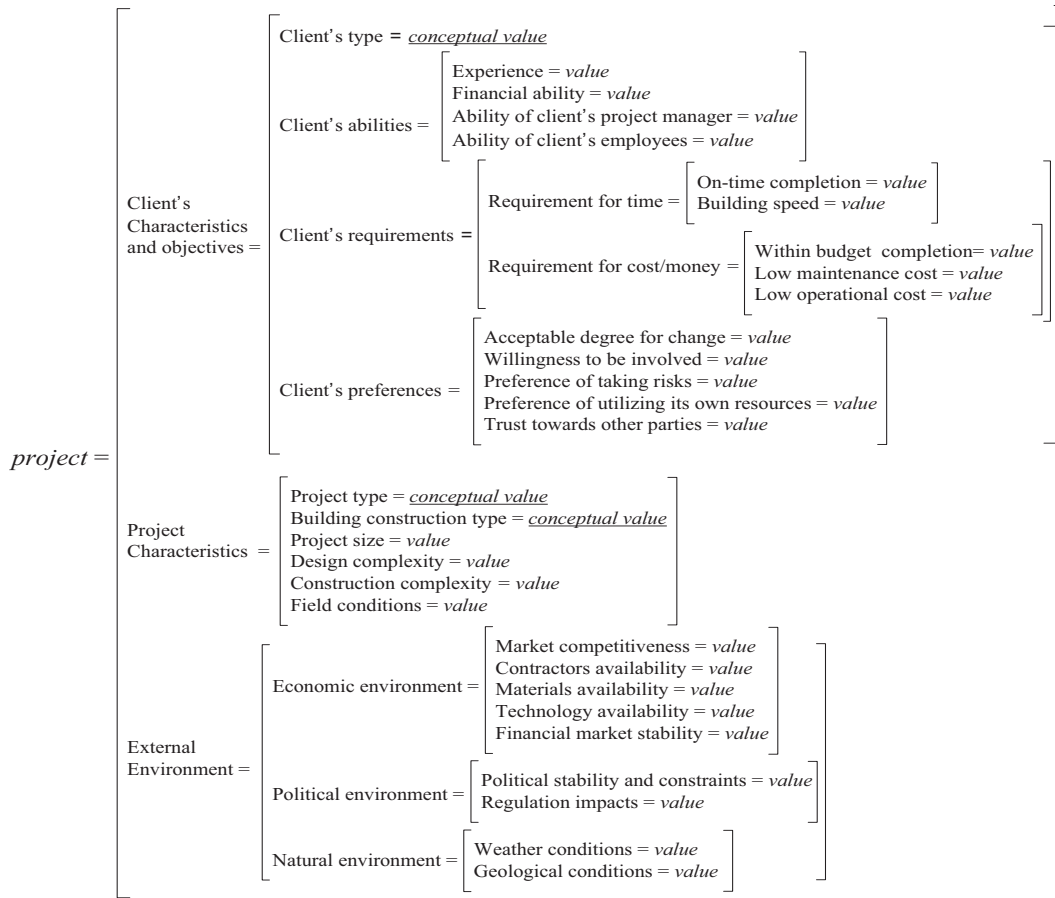


Fig. 1 The PDS selection feature terms

As no values for the latent features are assigned in this paper, the general definition of case in feature term theory is not applicable. Therefore, a PDS selection case is defined as follows: a set of paths within the PDS selection feature term, organized in the same structure as the feature term. Intuitively, a case may have part/all of the features and they have the same structure as the feature structure.

B. The Ranking of Features' Weights

The ranking of features' weights reflect the importance of each PDS selection criteria, which are gained from

investigations from 3 experts whose experience in construction projects management is more than 10 years. Considering the structure of PDS selection feature terms developed in last part, the local weights of each feature ($\omega'(f_k)$) were firstly collected, requiring the experts to compare the importance between the features in the same level and sort, such as [experience, financial ability, ability of client's project manager, ability of client's employees]. Then the global structural weight of features was calculated as follows: $\omega(f_i) = \prod_{f_k \in \pi(P, f_i)} \omega'(f_k)$, where $\pi(P, f_i)$ is the path from the root to

the feature f_i . The results shown in Table II suggest that “Design complexity”, “Construction complexity”, “Acceptable degree for change”, “Project type”, and “Project type” are the top five important criterion governing PDS selection.

TABLE II
THE RANKING OF FEATURES' GLOBAL WEIGHTS

Ranking	Feature	Global Weight
1	Design complexity	13.7%
2	Construction complexity	9.6%
3	Acceptable degree for change	6.5%
4	Project type	6.3%
5	Project size	5.1%
6	Field condition	4.9%
7	Requirement for on-time completion	4.7%
8	Ability of client's project manager	4.6%
9	Requirement for within-budget completion	4.6%
10	Experience	4.2%
11	Financial ability	3.7%
12	Requirement for low maintenance cost	3.5%
13	Ability of client's employees	3.0%
14	Requirement for low operational cost	2.8%
15	Requirement for building speed	2.8%
16	Client type	2.4%
17	Preference for using its own resources	2.4%
18	Preference for taking risks	2.2%
19	Trust towards other parties	2.1%
20	Weather conditions	1.7%
21	Geological conditions	1.7%
22	Willingness to be involved	1.7%
23	Building construction type	1.4%
24	Technology availability	1.0%
25	Materials availability	1.0%
26	Contractor's availability	0.8%
27	Markets competitiveness	0.7%
28	Regulation impacts	0.4%
29	Political stability and constraints	0.3%
30	Financial market stability	0.2%

V. THE SIMILARITY CALCULATION FOR PDS SELECTION CASES

There are three steps we need to proceed to perform RCBR on relational cases. Firstly, we calculate the similarity between the features that belong to the anti-unification set of the two cases. Second, we compute the similarity of the structures between the two cases. After all, we multiply them together to get the aggregated similarity.

A. Similarity between Anti-Unification Features

When we calculate the similarity of the feature terms in two cases with different structures, we firstly focus on what they share in common, so we calculate the similarity between the features that belong to the anti-unification set(C_{AU}) of the two cases.

There are symbolic and numeric valued features in a PDS selection case. For the numeric valued features, a nine-point Likert scale method was applied for obtaining the values. Let

v_1 be the value of feature f in case c_1 and v_2 be the value of f

in c_2 , the similarity of feature f is computed as follows:

$$sim_f(c_1.f, c_2.f) = 1 - \frac{|v_1 - v_2|}{b - a} \tag{1}$$

where a and b are the range boundary of the feature value (a=1, b=9 in this study).

For the symbolic valued features, the similarity of two feature values is computed using the symbolic value:

$$sim_f(c_1.f_i, c_2.f_i) = \begin{cases} 1 & \text{if } c_1.f_i = c_2.f_i \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

After calculating the similarity of each feature, we can compute the weighted sum of similarity of the features that belong to anti-unification set.

$$sim_f(c_1, c_2) = \frac{\sum_{f_i \in C_{AU}} W_i \times sim_f(c_1.f_i, c_2.f_i)}{\sum_{f_i \in C_{AU}} W_i} \tag{3}$$

B. Similarity between Structures

The similarity between cases has to be computed as an aggregation of the similarity of the feature values. However, cases can be incomplete in practice, so we should take similarity between structures of the cases into consideration as well.

When structure is different between two cases, the similarity of values of C_{AU} only takes the shared features into account, ignoring the difference between the structure of cases and the relations among the features. Therefore, a modified method based on RCBR is introduced.

Firstly, the similarity of the location of two features will be estimated by the following equation:

$$sim_s(c_1.f_i, c_2.f_j) = \begin{cases} 1 & \text{if } f_i = f_j \\ 1 - \frac{1}{M} level(\text{lub}(f_i, f_j)) & \text{otherwise} \end{cases} \tag{4}$$

where M is the maximum depth of the hierarchy, and the level of a feature is defined as follows: $level f_i = M - depth f_i$. For example, “lub (on time completion, building speed)=requirement for time” is at level 2, whereas “lub(on time completion, willingness to be involved)=client’s characteristic and objectives” is at level 4. This means that “building speed” is more similar to “on time completion” than “willingness to be involved”. It is proved that the measure $sim_s(c_1.f_i, c_2.f_j)$ satisfies the three conditions of distance [6], [21].

Here we compute all the similarity of all pairs in the set S as follows:

$$S = \{(f_i, f_j) | f_i \in c_1 \wedge f_j \in c_2\} \tag{5}$$

We take $p_1 = (f_i, f_j) \in S$ with maximum similarity in S . Then we remove p_1 and all the pairs that is incompatible with p_1 from S , and we get S_1 . Next, we take p_2 with maximum similarity from the remaining pairs in S_1 . We continue in this way until we get all pairs in $P_{\min} = \{p_1, p_2 \dots p_{\min(m,n)}\}$ that have a maximum similarity. Intuitively, features included in C_{AU} have the priority to be considered because similarity of these features is 1. We define the similarity between structures as follows:

$$sim_s(c_1, c_2) = \frac{\sum_{(f_i, f_j) \in P_{\min}} sim_s(c_1, f_i, c_2, f_j)}{|\gamma(c_1, c_2)|} \quad (6)$$

where $\gamma(c_1, c_2)$ is the set that contains features of the anti-unification of two cases, and the function $|\gamma(c_1, c_2)|$ returns the element number of the set.

C. Aggregated Similarity

Finally, we take both the similarity of value and structure into consideration and the aggregated similarity between two cases is calculated as follows:

$$S(c_1, c_2) = sim_s(c_1, c_2) \times sim_f(c_1, c_2) \quad (7)$$

VI. SIMULATION EXAMPLE

In this section, two PDS selection cases are represented by the feature term developed in this study, and the similarity between the two cases was calculated using the similarity mechanism previously introduced.

Figs. 2 and 3 show the two cases. The values for each feature in both cases were obtained from data of a former study [8]. Case1 was a public subway project whose client was a local government in China, and case2 was a privately-financed residential project.

A. Similarity between Anti-Unification Features

For similarity between values, there are two symbolic values. The similarity between “Local government” and “Individual”, according to the sort hierarchy of the “Client’s type”, the similarity is calculated as follows:

$$\begin{aligned} sim_f(c1.Client Type, c2.Client Type) &= 0 \\ sim_f(c1.Project’s Type, c2.Project’s Type) &= 0 \end{aligned}$$

The similarity of numeric valued features is easily calculated using the equation. Then the similarity of features is summed as follows:

TABLE III
THE SIMILARITY OF FEATURES

Features	Weight	Similarity
<i>Symbolic Features</i>		
client type	2.40%	0
project type	6.30%	0
<i>Numeric Features</i>		
experience	4.20%	0.25
financial ability	3.70%	1
requirement for on-time completion	4.70%	0.625
acceptable degree for change	6.50%	0.75
willingness to be involved	1.70%	0.875
project size	5.10%	0.5
field condition	4.90%	0.875
markets competitiveness	0.70%	0.625
materials availability	1.00%	1
financial market stability	0.20%	0.875

Therefore, the outcome of similarity between anti-unification features is calculated:

$$sim_f(c_1, c_2) = 0.225 / 0.414 = 0.543$$

B. Similarity between Structures

There are 12 features included in C_{AU} . So we should only consider the remaining features in case1 [Ability of client’s project manager, within-budget completion, low maintenance cost, Preference for using its own resources, Contractor’s availability, Political stability and constraints, Geological conditions] and case2 [building speed, Trust towards other parties]. According to (4), the maximum similarity pairs are $sim_s(c1.within budget completion, c2.building speed)$ and $sim_s(c1.preference of utilizing its own resources, c2trust towards other parties)$.

$$sim_s(c1.within budget completion, c2.building speed) = 1 - 3/4 = 0.25$$

$$sim_s(c1.preference of utilizing its own resources, c2trust towards other parties) = 1 - 3/4 = 0.25$$

Then we can calculate the similarity between the structures of case1 and case2:

$$sim_s(c_1, c_2) = (12 + 0.25 + 0.25) / 21 = 0.595$$

A. Aggregated Similarity

Finally, the global similarity between the two cases is calculated as follows:

$$S(c_1, c_2) = 0.543 \times 0.595 = 0.323$$

As shown in the example, the feature term representation allows conceptual valued features, the relations among features and the structure of features are considered in the global similarity algorithm. The similarity defined under the representation considers both the structural similarity and the feature similarity between cases, making the similarity measure more reasonable and understandable to the human user and better suited to the CBR logic.

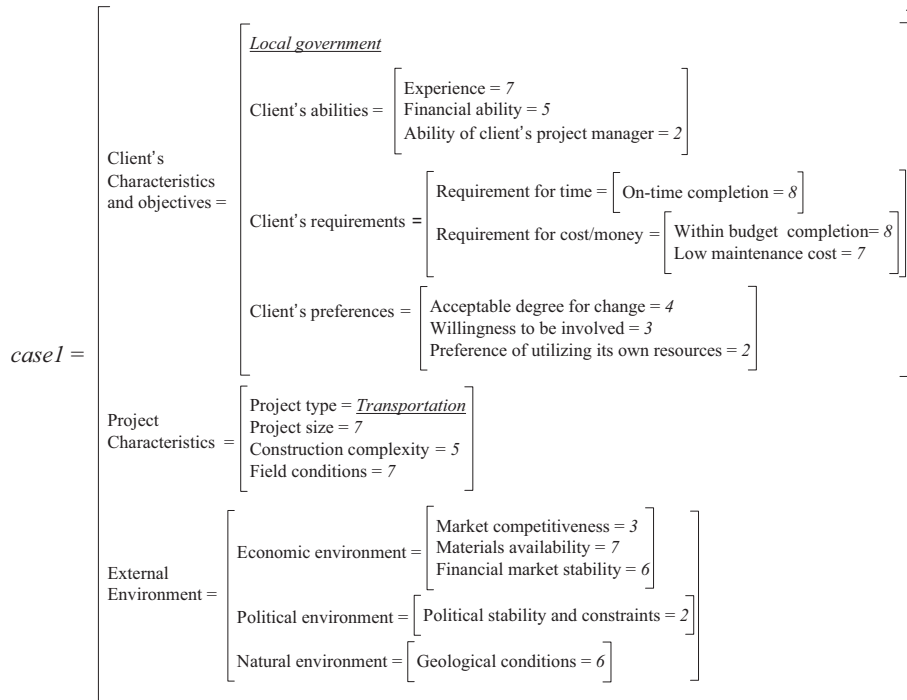


Fig. 2 Case 1 as example

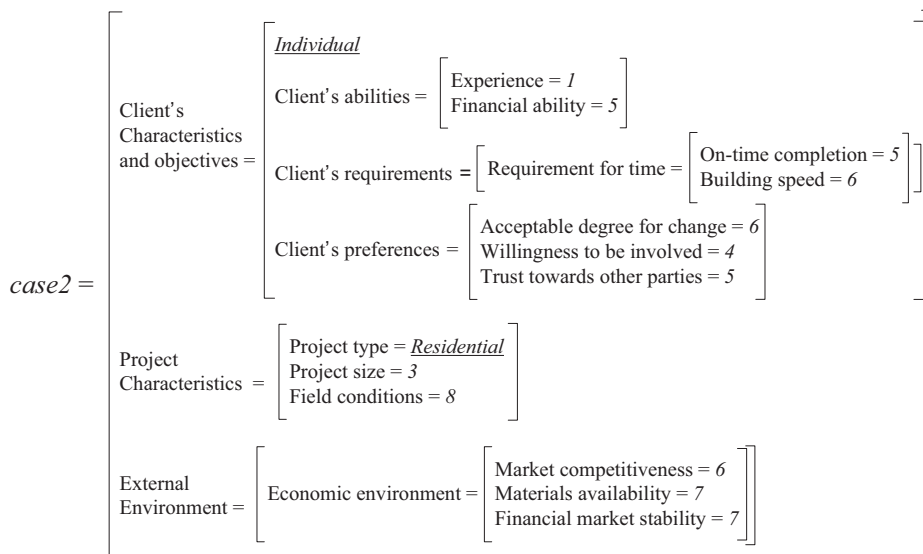


Fig. 3 Case 2 as example

VII. CONCLUSION

The main purpose of this paper is to introduce a Relational Case-based Reasoning approach for PDS selection, modifying the shortage in traditional CBR approaches. A framework of feature terms for construction projects is put forward to model the RCBR approach and the weight of each feature is obtained through questionnaires from experienced experts. The similarity measure for structure allows the modified method to be used when there are differences among the structures of the cases, which is much more suitable for practice in construction

industry.

Much work remains in order to achieve a practical application of Relational Case-based Reasoning in PDS selection. Future work may include: examining the validity of the framework of feature terms; comparing the effect and reliability of RCBR with traditional CBR by collecting PDS selection data; establishing a data base and a decision support system for decision making in PDS selection.

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