Towards a Case-Based Reasoning Framework for Construction Project Planning and Control

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Abstract

The work presented in this paper is aimed at investigating the extent to which both ‘user and system decision-making’ in construction project planning and control can be captured and stored for future use. This paper presents work being conducted to establish a framework for the application of CBR to construction planning and control. Due to the high variability in the type, size, and complexity of construction projects the work concentrates on the use of the technique for information re-use in project planning and control for highway bridge construction. Object models for a bridge and its components have been developed, and used to develop a prototype application, CBRidge. The application takes bridge information from databases and adds it to cases bases which can then be used for case matching. Once a suitable case has been found it can be adapted to more closely match the new project, and following this the adapted case can be linked to a planning model, enabling the plan for the matched case to be adapted for use with the current project. It concludes by discussing the benefits of the approach and the limitations of the system, together with future directions.

Keywords: construction planning, bridges, object modelling, databases, case-based reasoning.

Introduction

Although there is a proliferation of software purporting to provide construction project planning and control facilities, they have failed to meet the needs of project managers. These systems are primarily founded on principles and methodologies derived from operational research developed in the 1950's. They require a considerable amount of effort in data input from the project manager which is both time consuming and to some extent error prone. Some systems allow previous plans to be archived. However, they do not have the ability to capture and store the problems that were encountered and the decisions that were taken to solve those problems as a complete historical database for future use.

Whilst current research in the area of construction project planning and control is concentrating on using more advanced techniques of knowledge representation, through the use of object-oriented programming techniques, blackboard architectures, and fuzzy logic, the problem of capturing and storing knowledge of experiences and decisions made as a historical database for future use, remains to be addressed.

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The problem of building and maintaining plans is a problem of the interaction between a planner's knowledge-base and the real world. The main goal of planning is to ensure that the final product arrives on time, within budget, and with high quality. In practice, construction planners use knowledge gained from previous plans to make decisions and to produce new plans. They manage a project by using information about its status to make incremental adjustments to a preconceived work programme, schedule, and budget, checking projections against reality. The lack of a systematic approach to storing past plans and problems that were encountered together with the solutions that were used to overcome these problems means that plans have to be produced from scratch every time a new project is to be planned. Even with computer systems that allow previous plans to be archived, a great amount of effort is needed to modify such plans for use in new situations. The power of the computer to facilitate system decision making is under-utilised.

We are investigating the potential offered by a new approach termed case-based reasoning (CBR) to address this problem. Cased-based reasoning is a technique of solving new problems by adapting solutions that were used to solve previous ones. The characteristics of the planning and control domain on the surface, seem to suggest that CBR is a natural method for knowledge acquisition. However, the application of CBR to the entire planning and control problem is very difficult task. The main challenge is to determine what constitutes a case and what the case indices should be. The obvious answer would be to consider a whole project as a case. This approach on the surface appears attractive, because if complete project information can be transferred from a previous project to a new project, with little adaptation, then the new project will be planned and controlled with relative ease. However, because construction projects are hardly similar and because of the high degree of non-linearity of planning constraints and objectives, a very small difference between an input problem specification and problems in the case bases can result in large variations in the results both in terms of the amount of modification needed and the quality of the resulting project plan. The primary aim is to investigate how much of the information used in construction planning and control can be captured and stored away for possible future re-use. The extent to which it is feasible to store whole, or parts of, construction plans, together with other pertinent information for use in the planning and control of future projects needs investigating.

This paper presents work being conducted to establish a framework for the application of CBR to construction planning and control. The framework covers the following goals in the construction planning domain: generation of work-breakdown structures; determination of durations of phases, work packages, work packets, and units of work; determination of resources; logical sequencing of work; determination of budget costs; identification of performance deviation causes; determination of effects of causes; and application of control measures to repair the plan.

Due to the high variability in the type, size, and complexity of construction projects we are concentrating on structures associated with road construction projects, and in particular highway bridges. Highway bridge structures tend to be modular in design, and whilst each performs the same function they are all unique to some degree. We use the object-oriented product modelling approach to develop case memory models to represent highway bridge information. This paper will present some of the object models which form the basis of the case memory organisation structure developed to allow efficient indexing of cases and their implementation in a prototype system (CBRidge) that allows for storage, retrieval, and adaptation of project information. It concludes by discussing the benefits of the approach and the limitations of the system, together with future directions.

The Object Models

Construction projects by their very nature are complex as there are many different types of information used, and therefore potentially available. This information includes drawings, specifications, activity lists, activity durations, activity start and finish dates, activity floats, logic links, constraints, networks, bar charts, work breakdown structures, quantities and measurements, resources and costs, event logs, risks and problems, etc. This information, however, varies in relevance depending on such things as the type of plan and the people involved. Too much information inevitably results in overload, whereby the most important items are made more difficult to ascertain and locate.

A large amount of design information and construction programmes for a large number of highway bridges were collected from several sources, primarily bridge texts (BRE, 1979; Liebenberg, 1992; Pennells, 1978 amongst others), but also manuals and reports from the Highways Agency (Highways Agency, 1994a and 1994b) which commissions and maintains all structures associated with road projects throughout the country and from contractors. The information includes bridge and component outline descriptions and identities; activity lists with network planning data; dimensions and quantities; materials and resources used. A comprehensive set of object-oriented models were produced using Rumbaugh's object modelling technique (Rumbaugh et al., 1991), to represent case knowledge. Two examples of the object models are shown in Figures 1 and 2. Given that the vast majority of highway bridges developed in the UK are of a beam type, this is the only path which has been developed in the object model.

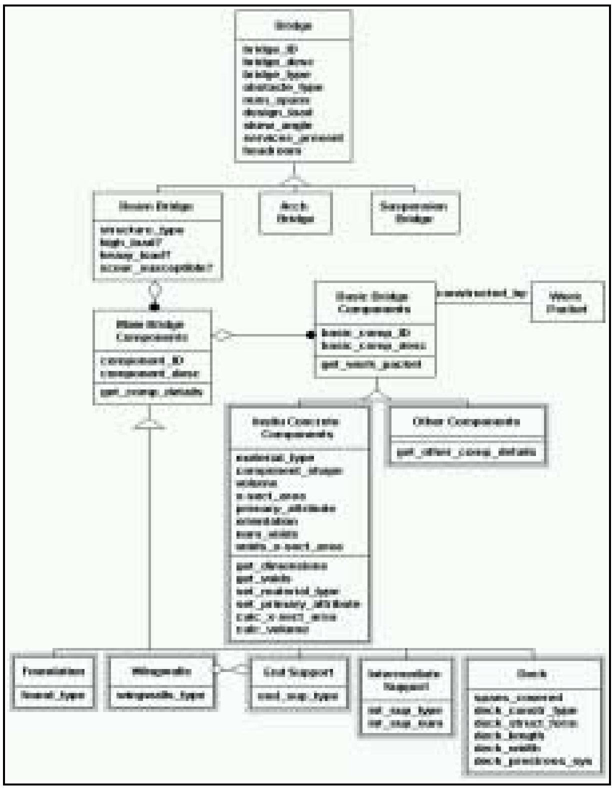


Figure 1: Bridge object diagram

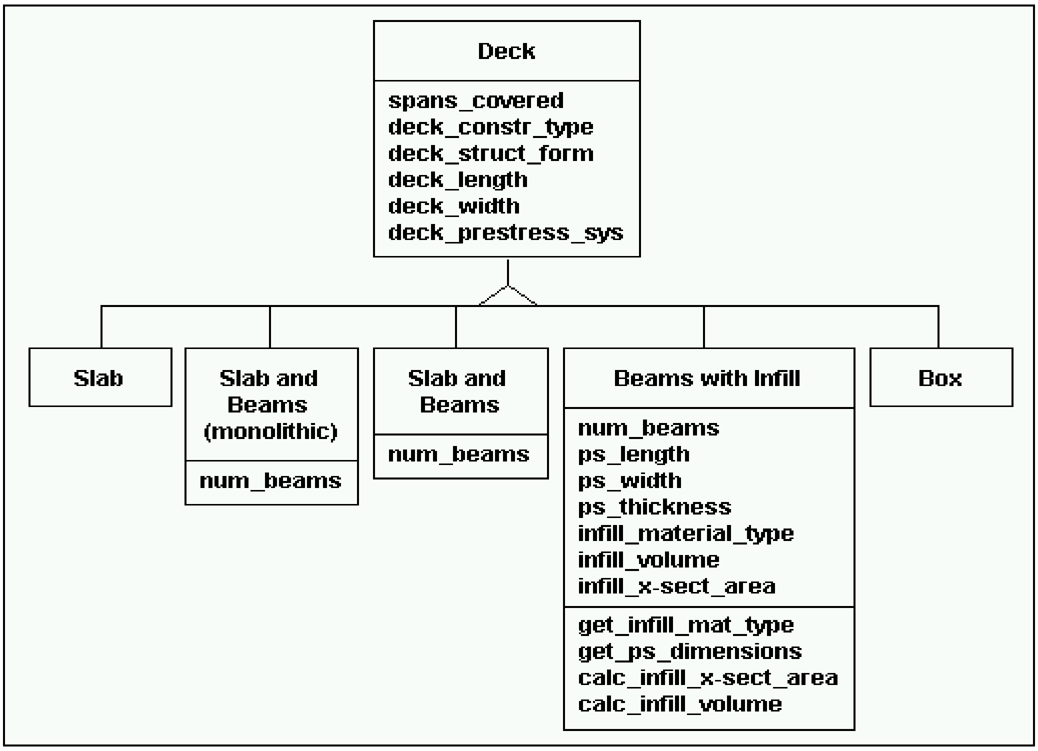


Figure 2. The deck object child diagram

The Prototype System

A prototype, termed CBRidge, has been developed to test ways in which the planning information might be stored for future retrieval and re-use. The primary influence on the software model has been simplicity, with the intention that modifications will be made to upgrade the system into something more practically applicable and usable once the core functionality have been established. The software model has been programmed using the ART*Enterprise development environment, running under Microsoft Windows 3.1 and links with the MicroSoft Project planning package.

The Project Information Repository

A large amount of information is used and also generated in planning and controlling construction projects. In practice, this information is available in paper and in computerised forms. It was therefore, a necessary pre-requisite to develop an information repository were all project information is collated and stored and subsequently used to generate case bases. A comprehensive database management system was developed to act as a project repository. The data stored included the outline information describing the physical properties of the bridge and its components; the detailed information, such as activity lists, network planning information, resources used, dimensions, risks and problems, labour, plant, material, and sub-contract resources, standard work rates, etc. The physical properties of the bridge and its components are used to populate the case base and, later, in the retrieval of appropriate cases. Once an appropriate case has been retrieved then the detailed information describing the relevant case is located and retrieved too. Once all this information has been assimilated and appropriate modifications have been made to the case, then the standard data can be used to produce a plan for the modified case.

The Case Bases

The main challenge was to determine what constitutes a case and what the case indices should be. Due to the inherent complexity, hierarchical and disparate nature of the information involved, as demonstrated by the object models, the use of a single case base was clearly inappropriate and impossible. Thus, separate case bases for the bridge information and for the main components were defined, giving a total of seven case bases. Storing the components separately from the bridge information has the advantage that they can be accessed individually, which has positive repercussions at the modification stage. Separating the different components out into their own case bases is done to maximise flexibility, due to the mechanics of the CBR algorithms used within ART*Enterprise.

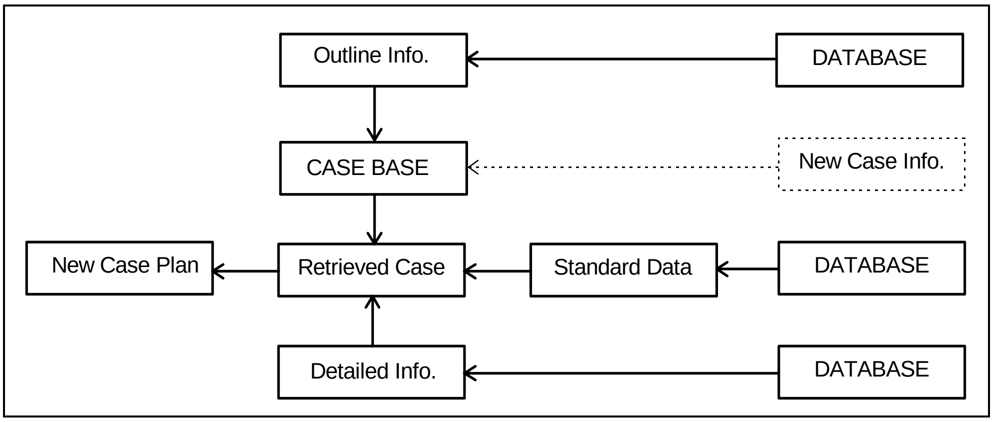


Figure 3. The relationships between the database and case base

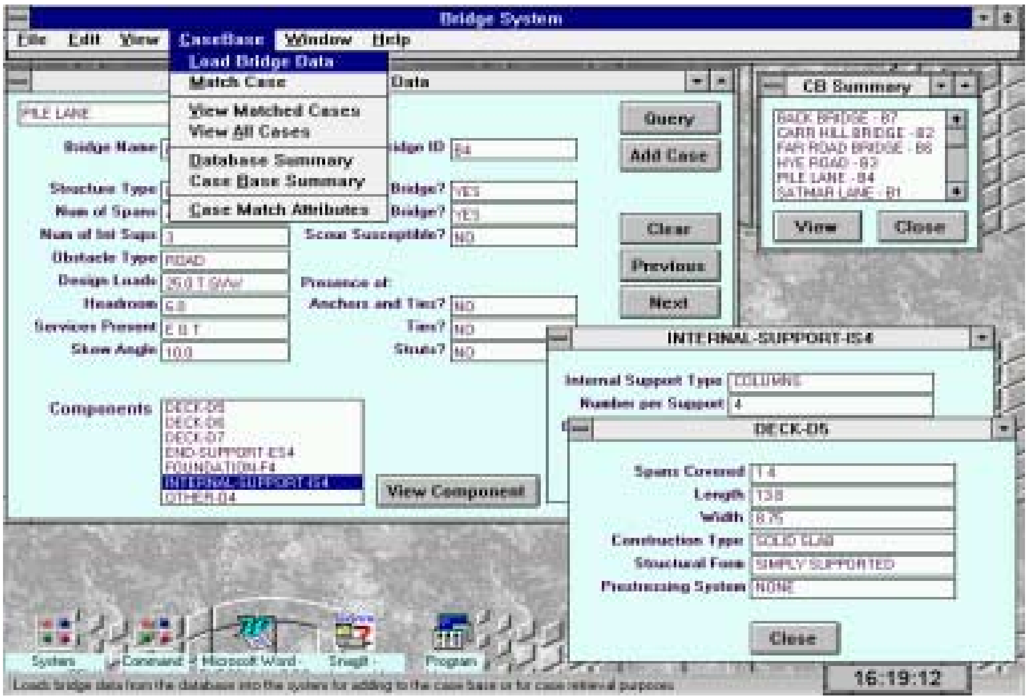
Figure 3 shows the relationships between the database and case base, and how they operate to produce a new plan from a retrieved case.

Case Representation

The selection of appropriate attributes to define the bridge and its components was of paramount importance. These describe each bridge physically and, for the most part, are used as indices for each case once it has been entered into its relevant case base. It was decided that the highway structure attributes defined by the Highways Agency (Highways Agency, 1994b) have been considered carefully, and were therefore considered to be of importance when determining the primary features of a road bridge. The features used for case matching are depicted in the object models. It is likely, depending on the planners involved and the type of output required from the system, that individuals might prefer to select different attributes to suit different contexts. It is envisaged that once the core functionality of the approach has been established it will be necessary to make this option available. In this case the files stored in the database will contain more information and individuals will be able to customise the attribute selection to their own requirements.

Prototype Implementation

A prototype software model has been developed and Figure 4 shows a running session.



PILE LANE

Bridge ID B4

Bridge? YES

Bridge? YES

Num of Int Sups 3

Scour Susceptible? NO

Obstacle Type ROAD

Design Loads 25.0 T.SVW

Presence of:

Headroom 6.0

Anchors and Ties? NO

Services Present E.G.T

Ties? NO

Skew Angle 10.0

Struts? NO

Components: DECK-D5, DECK-D6, DECK-D7, END-SUPPORT-ES4, FOUNDATION-F4, INTERNAL-SUPPORT-IS4, OTHER-O4

BACK BRIDGE - B7
CARR HILL BRIDGE - B2
FAR ROAD BRIDGE - B6
HYE ROAD - B3
PILE LANE - B4
SATMAR LANE - B1

Internal Support Type COLUMNS

Number per Support 4

Spans Covered 1.4

Length 13.0

Width 8.75

Construction Type SOLID SLAB

Structural Form SIMPLY SUPPORTED

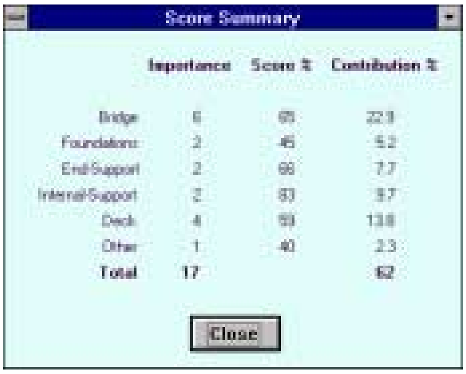
Prestressing System NONE

Loads bridge data from the database into the system for adding to the case base or for case retrieval purposes

Figure 4. The prototype bridge system

The first part of system is concerned with adding new cases to the case base. This is achieved by querying the database containing the outline bridge data, and showing all relevant cases to the user. Each of these can be viewed, by part if necessary, and added to the case base as required. Once a sufficient number of cases have been added to the case base, it can then be used for case matching. The match routine allows the current bridge to be compared against all bridges which are contained in the case base. The match itself is actually composed of six matches - the main bridge data itself, and each of the components which the bridge contains. The matching process for the main bridge data and all the components except the deck is a straightforward comparison with the relevant case bases using ART*Enterprise's scoring algorithms. The deck, however, presents more of a problem as each bridge can contain various deck spans. In this case each deck is split into three parts - the start span, the centre span(s), and the end span - and each of these parts is matched individually to produce an overall score. This deck score is then averaged over the number of deck spans to produce a final deck match score.

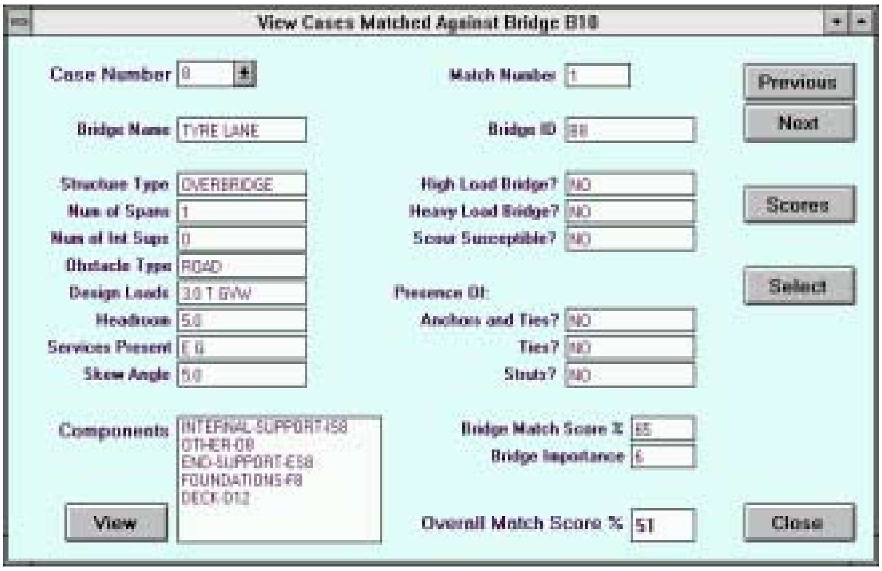
Upon completion of a particular set of matches, the overall match score for the current case can be calculated. This score is based on the match scores for the bridge and the various components it contains, and the importance rating which the user has defined for each of these parts. Each aspect of a case match has an importance rating attached to it, and this rating multiplied by the match score determines the effect each part of the bridge has on the final case score. Figure 5 shows an example of a scoring calculation.



	Importance	Score %	Contribution %
Bridge	6	65	22.9
Foundations	2	45	5.2
End-Support	2	66	7.7
Internal-Support	2	83	9.7
Deck	4	59	13.8
Other	1	40	2.3
Total	17		62

Figure 5. An Example of Score Calculation for a Matched Case

ART*Enterprise presents case match scores as a value between -1 (a perfect mismatch) and +1 (a perfect match). These scores have been converted to a percentage value for the sake of simplicity. A full set of matched cases can be viewed once the match scoring is completed. This allows the user to determine the strengths and weaknesses of each case, enabling a considered decision to be made as to which case will be selected for subsequent modification and re-use. Figure 6 shows the window used to view the matched cases. Once a matched case has been selected for re-use then modification can begin. This is the process whereby the case which most closely matches the solution to the current problem is altered in such a way as to more closely match the problem solution. The design of the current model has been done in such a way as to better facilitate the first part of the case modification process.



Case Number	8	Match Number	1
Bridge Name	TYRE LANE	Bridge ID	B8
Structure Type	OVERBRIDGE	High Load Bridge?	NO
Num of Spans	1	Heavy Load Bridge?	NO
Num of Int Sups	0	Scour Susceptible?	NO
Obstacle Type	ROAD		
Design Loads	30 T GVW	Presence Of:	
Headroom	5.0	Anchors and Ties?	NO
Services Present	E G	Ties?	NO
Skew Angle	5.0	Struts?	NO
Components	INTERNAL-SUPPORT-IS8 OTHER-O8 END-SUPPORT-ES8 FOUNDATIONS-F8 DECK-D12	Bridge Match Score %	65
		Bridge Importance	6
		Overall Match Score %	51

Figure 6. View matched cases window

The primary way this has been done is via the modular construction of the case bases. This allows a bridge model to be developed from a number of separate parts, and the match score represent the he sum of those parts. Thus, it is possible to identify the weak components and replace them with more appropriate ones from the relevant case bases. For example, a bridge match might be good in all areas except the internal supports, in which case a more appropriate internal support case might be sought to replace it. This part of the modification process is shown in Figure 7. Throughout the whole of stage one of the modification process, CBRidge continually updates the match score when component changes are made. This enables the user to immediately determine what effect the change has had on the current modify bridge.

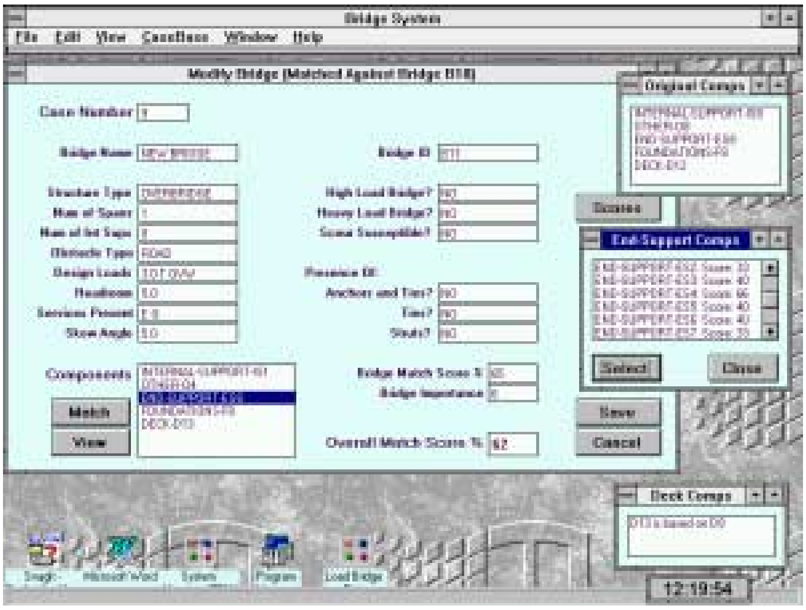
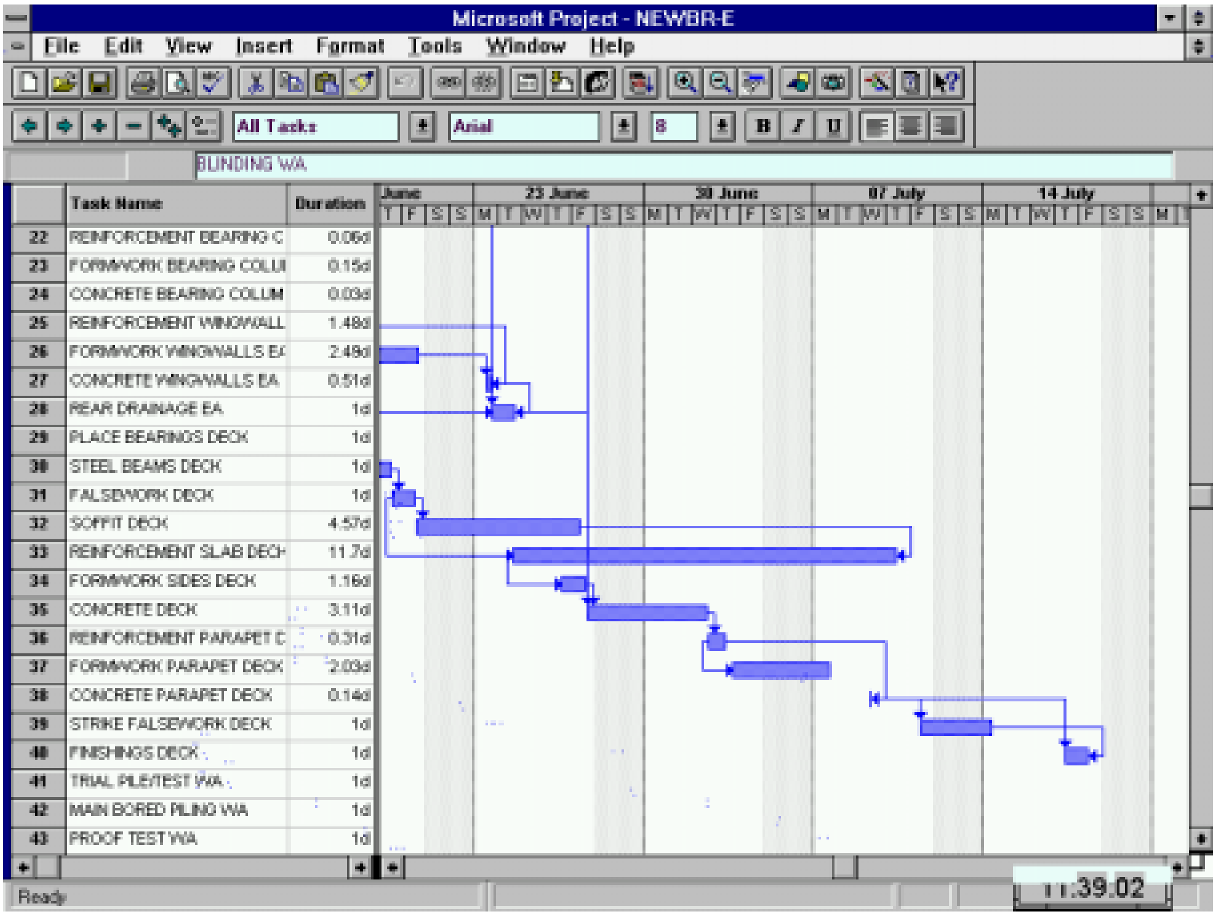


Figure 7. The first stage of case modification

The second stage of case modification is a more complex process than initial case modification. There are three parts to this: accessing the relevant database information pertaining to the modify case; defining all network links between the old retrieved case and any new components which have been added; and, calculating the resource quantities, times and costs which will be transferred to the new bridge. A number of rules and algorithms are used to perform the modifications and computations. The reason for performing many of the calculations is due to the addition of replacement components in stage one of case modification. Once a new component has been added to a bridge the project becomes a new and unique one, and therefore all data relating to it must be re-checked and calculated. Additionally, whilst some of the calculations do not strictly need to be performed within CBRidge, such as the basic component attribute values, doing them within the system helps to minimise data which needs to be expressly stored in the database. This is designed to help simplify the whole process for the user.

Once the task durations have been calculated, CBRidge can perform a critical path analysis (CPA) on the full-precedence network as defined. This is done in a standard way, and allows the system to calculate the earliest and latest starting dates, the earliest and latest finishing dates, and the total float for all tasks. As with other calculations, the CPA is performed for both target and actual data. This means that the user is able to see what was planned and what actually happened, and compare the two to determine their differences and hence any unforeseen events which may have occurred. The final step is the propagation of the calculated data back through the bridge project. This allows CBRidge to calculate the total project duration and final cost value, for both target and actual data. Once the data has been calculated for the modify bridge, it is transferred over to the new bridge, that is, the one which was used as the basis for case retrieval initially. It is recognised that one of the benefits of good construction planning is the visual plan. To facilitate this a link has been produced to export data to Microsoft Project. Figure 8 shows an example of a plan produced using CBRidge and exported to MS Project.



	Task Name	Duration
22	REINFORCEMENT BEARING C	0.06d
23	FORMWORK BEARING COLU	0.15d
24	CONCRETE BEARING COLUM	0.03d
25	REINFORCEMENT WINGWALL	1.48d
26	FORMWORK WINGWALLS EA	2.49d
27	CONCRETE WINGWALLS EA	0.51d
28	REAR DRAINAGE EA	1d
29	PLACE BEARINGS DECK	1d
30	STEEL BEAMS DECK	1d
31	FALSEWORK DECK	1d
32	SOFFIT DECK	4.57d
33	REINFORCEMENT SLAB DECK	11.7d
34	FORMWORK SIDES DECK	1.16d
35	CONCRETE DECK	3.11d
36	REINFORCEMENT PARAPET D	0.31d
37	FORMWORK PARAPET DECK	2.03d
38	CONCRETE PARAPET DECK	0.14d
39	STRIKE FALSEWORK DECK	1d
40	FINISHINGS DECK	1d
41	TRIAL PILE/TEST WA	1d
42	MAIN BORED PILING WA	1d
43	PROOF TEST WA	1d

Figure 8. Microsoft Project Link

Conclusions and Future Work

Current construction project planning systems, lack a systematic approach to storing past plans and problems that were encountered together with the solutions that were used to overcome these problems as a complete historical database for future use. This means that plans have to be produced from scratch every time a new project is to be planned. The potential for the use of CBR for the planning of concrete highway bridges has been examined and appropriate object models have been developed, along with a comprehensive database repository for project information and a software prototype. It has successfully demonstrated case representation, storage, retrieval, and re-use in the planning and control domain.

The current model is intentionally simple and by definition limited. The current attributes were selected as important given the requirement of simplicity. It is recognised however that the definition of importance will vary from planner to planner, and also from the perspective of the type of plan used. Therefore it would appear to be better from the point of view of flexibility if many attributes could be defined for each structure, and each planner could select those judged to be important, and indeed the relative level of importance of each.

With regard to the use of resources, ideas are currently being developed to test the concept of storing the various resources, such as labour, plant, gangs, and materials, as individual cases in separate case bases. These cases will store such information as work rates and wastage depending on the type of projects they have previously been involved in. Hopefully, such case bases will allow for more accurate calculation of output levels and project costs than the standard use of historical data, which usually makes no reference to personal previous experience.

Acknowledgements

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