AUTOMATED BUDGETING FOR CONSTRUCTION

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ABSTRACT

The evaluation of project plans in construction is seen to be an important task which will become more so as project complexity increases and computers become used more and more, initially as aids to planners and ultimately as automatic generators of plans.This paper discusses automated plan evaluation, and in particular the evaluation of some financial aspects of a project contained in different models of a project: the Bill of Quantities and a work activity plan. It introduces a technique for comparing these models and then for automating the budgeting of construction. Discussion of some results and problems in the work so far follows.

INTRODUCTION

Planning is an essential element of project control. It is desirable to ensure that a project is completed on time, to the correct cost and the correct quality. In order to achieve these goals the project manager aims to complete the work in the correct order as efficiently as possible.

With these goals in mind, numerous planning techniques have been developed for managers to use on projects. Amongst the most common techniques are barcharts, networks, line-of-balance and time-chainage charts. Each of these techniques is preferred in different circumstances and uses a different method for the presentation of the resultant plan.

Currently, within construction the use of 'traditional', algorithmic computer programs as aids to planning and plan presentation is widespread. In construction management research there is a growing movement towards the development of 'intelligent' planning programs that utilise expert systems and other artificial intelligence computing techniques. These programs are capable of producing plans of work and function either as intelligent planning assistants or independently. Some of the most notable of these are described in the work of Sirajuddin [1], Ibbs [2], Hendrickson [3] and Levitt [4].

An area of limited but important research is the evaluation of project plans. Regardless of whether the plans are produced manually or automatically, the need for evaluation exists. If the plans are produced manually, by the more traditional methods, the growth in the size, complexity and demands of modern construction projects means that the possibility of mistakes is greater and the level of understanding of the project is reduced.

If automated planning systems are utilised, the use of evaluation may again be considered essential. For these automated planners to become true expert systems they must be capable of undertaking evaluation in order to gain from their previous experience.

Within plan evaluation a project plan may be assessed against a large number of criteria. Some of the more important criteria for evaluation may be:

- the time requirements and constraints within a project contract
- the nature of the logic connections present within a programme of work
- the demands for labour, plant and materials within a project
- the financial implications of the project
- the safety implications of the project
- the risk involved in a project.

Some research has been carried out towards using artificial intelligence techniques for the evaluation of project plans, most notably by Ibbs et al [5].

The particular work discussed in this paper relates to a continuing programme of work which is an extension of the work described in a paper presented by the authors at the 7th ISARC [6]. This work permits some of the financial constraints of the project to be evaluated and allows the automatic generation of budgets for the project. The work has been implemented on an IBM compatible 80386 computer running MS-DOS. The package has been written using Turbo Pascal.

FORMATION OF THE MODEL

This section provides an overview to the detailed methodology that has been developed. This methodology allows some of the project plan information to be converted into a structured information tree. This has been described in greater detail in the previous paper [6]. The testing has been carried out with the assistance of Tarmac Construction, Major Projects Division, a major construction contracting company based in the U.K.

An important consideration in the development of the system was that it should be capable of utilising most formats of construction project plan. In particular, the formats which are frequently used by Tarmac are:

- barcharts
- networks
- time-chainage charts
- simple lists of the work involved in the project.

To fulfil this consideration, the system had to be designed to accept project information that would be common to all these formats of project plans, namely a list of the elements that together describe the work contained in the project. Two types of such lists are regularly produced for use in British construction projects:

- a list of the activity names
- a list of the Items from a Bill of Quantities.

These lists are normally produced independently, one by the contractor, the other by the client, and are used for different purposes. Both should contain all the work necessary to complete the project. Owing to the differing formats of these lists and the nature of construction projects the task of certifying the completeness of these lists is difficult. If the two representations of the project can be mapped over one another, areas of incompleteness or errors should be identifiable.

This mapping process is achieved by generating a tree-like structure containing the project information which is contained within a plan such as one of the lists mentioned above. The tree structure is generated by placement of elements from the plan.

An element of work from the plan, an activity name for instance, is parsed. Parsing is the process by which the sub-elements from the element are identified. For example, an activity name, 'Bridge One North Abutment Excavation' which may be written as 'Br 1 N/A Exc' would be divided into the following sub-elements: 'Br', '1', 'N', 'A' and 'Exc'. Each of these sub-elements is then searched for within a knowledge base, which contains information such as *'Br' usually means 'Bridge'*. Any unrecognised elements are highlighted and the user is asked to provide an identification.

The elements of the plan of work are then placed into the tree structure. In order to reduce the number of user interactions in this placement process the sub-elements are placed into a number of classifications. These classifications allow the sub-elements to be separated into a hierarchy of types of element. This permits the sub-elements to be automatically placed in the tree structure, providing no ambiguities exist.

The classifications are of the user's choosing and can hold any significance the user requires. The system has default classifications from which the user can start, and it is envisaged that little change to these would be necessary. The default classifications are:

- Major structures - such as buildings and bridges
- Minor structures - such as structural elements within the major structures
- Work types - such as placing concrete or bricklaying
- Elements that may be discarded - such as 'and' or 'the'
- Elements that are identifiers to other elements - such as '1' in 'Bridge 1'.

Once classified the sub-elements may be placed into the tree structure. If a new tree representation is being developed the user is required to specify the order in which the tree should be built. For instance it is possible with the default classifications to create a tree where the highest nodes are major structures and the next levels down are minor structures followed by work types. This is a *structure* orientated tree, showing primarily the number and type of structures contained in the project.

If the ordering of the tree were reversed, that is the priority of selection being work types followed by minor structures followed by major structures, a *work* orientated tree would be created. This would show primarily the types of work being carried out and, at a lower level within the tree, their locations.

An illustration of the placement process is shown below in Figure 1. An activity name, 'Bridge One North Abutment Reinforce Base', which may be written as 'Br 1 N/A Reinf Base', is placed within the tree structure, as indicated by the shaded nodes. This activity is part of an example project which is used throughout this paper. This project is a simple road bridge that was built as a small section of a larger scheme.

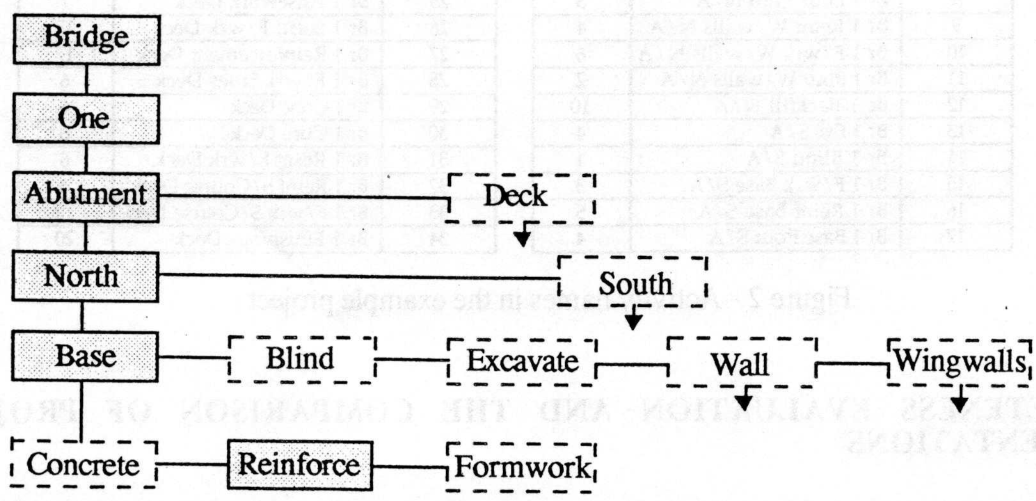

Figure 1 - Placement of an activity name within a project tree

On placement of an element within the tree, if the path created by the element fails to produce at least one new node within the tree, some degree of duplication must have occurred.

The example project, whose activity names are shown in Figure 2, was processed to produce a tree structure. No duplication of work was found.

The system also permits time and financial information, if it exists, to be carried with its associated element through the placement procedure. This allows various calculations to be performed. For instance, the dates for each activity were carried through the generation of the tree for this example project, and the period of working for each node was automatically calculated by the system.

A small section of the complete tree structure is shown in Figure 1. The following information can be related from the complete tree structure:

- 48 nodes in tree
- 1 node at the first level (Bridge)
- 1 node at the second level (1)
- 2 nodes at the third level (Abutment and Deck)
- 9 nodes at the fourth level
- 17 nodes at the fifth level
- 18 nodes at the sixth level
- 34 leaf nodes
- the working period for the bridge was from 18th March 1991 to 15th October 1991
- the working period for the bridge deck was from 4th July 1991 to 15th October 1991.

A leaf node is where the bottom of a path through the tree occurs. This equals the number of activities in the plan. In Figure 1 the leaf nodes are 'Concrete', 'Reinforce', 'Formwork', 'Blind' and 'Excavate'.

Job No.	Description	Dur.
1	Br 1 Exc N/A	4
2	Br 1 Blind N/A	1
3	Br 1 F/wrk Base N/A	3
4	Br 1 Reinf Base N/A	5
5	Br 1 Base Pour N/A	4
6	Br 1 Reinf Wall N/A	11
7	Br 1 F/wrk Wall N/A	10
8	Br 1 Pour Wall N/A	3
9	Br 1 Reinf W/walls N/A	4
10	Br 1 F/wrk W/walls N/A	6
11	Br 1 Pour W/walls N/A	2
12	Br 1 Backfill N/A	10
13	Br 1 Exc S/A	4
14	Br 1 Blind S/A	1
15	Br 1 F/wrk Base S/A	3
16	Br 1 Reinf Base S/A	5
17	Br 1 Base Pour S/A	4

Job No.	Description	Dur.
18	Br 1 Reinf wall S/A	11
19	Br 1 F/wrk Wall S/A	10
20	Br 1 Pour Wall S/A	3
21	Br 1 Reinf W/walls S/A	4
22	Br 1 F/wrk w/walls S/A	6
23	Br 1 Pour w/walls S/A	2
24	Br 1 Backfill S/A	10
25	Br 1 Falsework Deck	7
26	Br 1 Soffit F/wrk Deck	15
27	Br 1 Reinforcement Deck	17
28	Br 1 F/wrk Sides Deck	6
29	Br 1 Conc Deck	6
30	Br 1 Cure Deck	6
31	Br 1 Reset F/wrk Deck	6
32	Br 1 Reinf S/Course Deck	3
33	Br 1 F/wrk S/Course Deck	12
34	Br 1 Finishings Deck	20

Figure 2 - Activity names in the example project

COMPLETENESS EVALUATION AND THE COMPARISON OF PROJECT REPRESENTATIONS

If a similar processing is performed on a second representation of a project and the elements of this representation are overlaid onto the first representation's tree structure, a comparison may be made. This comparison will identify:

- The destination node, within the tree, of the elements of the second representation
- Those second representation elements that cannot be placed within the tree
- Areas of the tree that are untouched by the second representation overlay.

These last two points indicate sections of work where the two representations differ. This can be used to identify omissions if both representations are thought to contain all the work necessary to complete the project and they have been produced independently. This overlaying procedure also has benefits in highlighting areas of extra work that may have been generated in the completion of the project, if the two representations used were the original and the 'as-constructed' plans.

Some difficulties may arise within this overlaying process if one of the two representations has separate elements that appear in combination in the other representation. For instance, this could be shown if the first representation contained activities relating to a structural element, 'Substructure', which was shown within the second representation as a number of structural elements, 'Wall, Wingwalls, Base, etc.'.

The creation of a knowledge base to counter such problems will be undertaken in the near future. It will contain a structural tree of terms for frequently occurring structural elements. Thus it would be possible to identify that 'Substructure' and all of its constituent elements would be interchangeable.

An interesting extension to the comparative overlay process is the mapping of a financial representation of the project, such as a Bill of Quantities, to a physical representation, such as a programme of work. This mapping is discussed in the next section.

AUTOMATED BILL SPLITTING

The Bill of Quantities (B.o.Q.) is an integral part of the standard British construction contract, which is an admeasurement contract. The financial basis of this contract is the rate per unit of the quantity for any Item within the B.o.Q.

For example, an Item within the B.o.Q. may be, 'Bridge Deck - Structural Concrete - Insitu Concrete of class 40/20', and have an associated quantity of $1000m^3$. Against this, the contractor, at the time of bidding for the contract, would enter a rate for the completion of each unit (m^3) of this item and hence an amount for the completion of the total quantity ($1000m^3$). This rate, calculated by the contractor's estimators, would evolve from the materials, plant, labour, overheads and profit markup associated with the activities relating to this B.o.Q. Item. The contractor is paid for the quantity of the work completed at the time of an interim assessment. If the total quantity contained within any Item changes, the contractor will be paid according to the rate that was originally entered. The total quantities within all of the Items should contain all the necessary provision to complete the finished works.

A problem exists within this system. The B.o.Q. contains no time related information, so the production of budgets is not a simple task. For a budget forecast to be produced a mapping of the money from Bill Items on to the particular activities of work that they are involved in must be carried out. This process is known as 'Bill splitting' and is explained in greater detail elsewhere [7]. At present Bill splitting is normally performed manually and the process can be both difficult and tiresome. Four possible situations may occur:

- One Bill Item maps directly to one activity
- Multiple Bill Items map to one activity
- One Bill Item maps to multiple activities
- Multiple Bill Items map to multiple activities.

A list of the Bill of Quantities Item descriptions and the cumulative value of the Items, as entered by an engineer, for the example bridge project are shown in Figure 3. For the example project a Bill split was performed by an engineer and with only 34 activities and 98 Bill Items some 105 cross linkages between B.o.Q. Item and activity were identified. Also the B.o.Q.'s Item descriptions, with the associated total value for the B.o.Q. Items, were overlaid on the tree structure containing activity names for the project. The results of this mapping process are displayed in the next section.

Item	Description	Amount (£)
	SOUTH ABUTMENT	
1	Drainage	6160.41
2	Excavation of unacceptable material...	443.90
3	Excavation of unacceptable material...	2708.30
4	Excavation of unacceptable material...	4284.87
5	Deposition of acceptable material...	100.62
6	Disposal of unacceptable material...	4233.60
7	Imported acceptable material...fill to structures	15857.54
8	Imported acceptable material...above struct. founds.	8316.00
9	Compact acceptable material -fill to structs	1323.60
10	Compact acceptable material...above struct. founds.	869.40
11	Excavation of soft spots (Provisional)	30.70
12	Fill Soft Spots with concrete (Provisional)	122.88
13	Insitu Concrete...Blinding...	1195.52
	South Abutment Base	
14	Formwork... Class F1	2149.49
15	Structural Concrete class 40/2-	17614.74
16	Reinforcement 16mm...	3193.07
17	Reinforcement 20mm...	14406.46
	South Abutment Wingwalls	
18	Structural Concrete class 40/20	8807.37
19	Formwork...Class F1	
	...to	Total =
22	Formwork...Class F2	1575.29
23	Patterned Profile Formwork F7	2505.58
24	Reinforcement 16mm...	1596.54
25	Reinforcement 20mm...	7203.23
	South Abutment Wall	
26	Structural Concrete class 40/20	17614.74
27	Structural Concrete class 50/20	66.11
28	Formwork...Class F1	
	...to	Total =
31	Formwork...Class F2	7583.74
32	Patterned Profile Formwork F6A	6267.73
33	Reinforcement 16mm...	3193.07
34	Reinforcement 20mm...	14406.46
	NORTH ABUTMENT	
35	Drainage	6160.41
36	Excavation of unacceptable material...	443.90
37	Excavation of unacceptable material...	2708.30
38	Excavation of unacceptable material...	4284.87
39	Deposition of acceptable material...	100.62
40	Disposal of unacceptable material...	4233.60
41	Imported acceptable material...fill to structures	15857.54
42	Imported acceptable material...above structural found	8316.00
43	Compact acceptable material... fill to structures	1323.60
44	Compact acceptable material...above struc. found	869.40
45	Excavation of soft spots (Provisional)	30.70
46	Filling of Soft Spots with insitu concrete(Provisional)	122.88
47	Insitu Concrete...Blinding...	1195.52
	North Abutment Base	
48	Formwork... Class F1	2149.49
49	Structural Concrete class 40/2-	17614.74
50	Reinforcement 16mm...	3193.07
51	Reinforcement 20mm...	14406.46
	North Abutment Wingwalls	
52	Structural Concrete class 40/20	8807.37
53	Formwork...Class F1	
	...to	Total =
56	Formwork...Class F2	1768.04
57	Patterned Profile Formwork F7	2505.57
58	Reinforcement 16mm...	1596.55
59	Reinforcement 20mm...	7203.23
	North Abutment Wall	
60	Structural Concrete class 40/20	17614.47
61	Structural Concrete class 50/20	66.11
62	Formwork...Class F1	
	...to	Total =
65	Formwork...Class F2	7776.49
66	Patterned Profile Formwork F6A	6267.73
67	Reinforcement 16mm...	3193.07
68	Reinforcement 20mm...	14406.46
	DECK	
69	Drainage	329.40
70	Service Ducts	3229.40
71	Structural concrete class 40/20	23034.66
72	Structural concrete class 50/20	793.32
73	Formwork Class F2...	
	...to	Total =
76	Formwork Class F2...	12792.86
77	Reinforcement 16mm...	14080.05
78	Reinforcement 20mm...	20446.18
79	Bearings Mk 1/1	
to	...to	Total =
84	Bearings Mk 6/1	8514.62
85	Installation of Mk 1/1 bearing	
to	...to	Total =
90	Installation of Mk 6/1 bearing	3544.32
91	Expansion joint Mk 1	5260.42
92	Finishings Waterproofing	
	...to	Total =
96	Finishings Waterproofing	16423.06
97	Finishings Steel Parapet	6568.25
98	Finishings Aluminium Parapet	-

Figure 3 - A Bill of Quantities for the example project - Bridge 1

BILL SPLITTING RESULTS

The results of Bill splitting by the system are shown below in Figure 4. The Bill split performed by the Engineer is shown in column (1). This shows the value that has been assigned to each activity. The total value of the Engineer's Bill Split is £423,063.72, which equals the total value of Items in the B.o.Q. and also equals the total value of the activities. Throughout these results comparisons are made against this Bill Split.

During the overlaying of the second representation of the project a number of Bill Item descriptions matched the activity name paths to the lowest point of the tree, a leaf node. This is termed a 'Direct Mapping'. The money associated with those Bill Items was allocated to the pertinent activity. Column (2) of the table contains the difference between the Engineer's Bill Split and the directly mapped Bill Items.

Job No. (see Fig. 2)	Engineer's Bill Split (1)	Engineer's Bill Split less: Directly mapped Bill items (2)	Leaf node Bill Split (3)	Descendant Bill Split (4)	Leaf node Working Period Bill Split (5)	Descendant Working Period Bill Split (6)
1	11824.24	4325.77	1274.47	-1807.54	2636.28	2616.04
2	1195.52	0	-3082.00	-6164.01	-430.05	-435.11
3	2149.49	0	-3082.00	-2054.67	-1290.14	-1305.32
4	17599.54	0	-3082.00	-2054.67	-6020.65	-6091.48
5	17614.74	0	-3082.00	-2054.67	-2580.28	-2610.64
6	17599.53	0	-3082.00	-2054.67	-6450.71	-6309.04
7	15111.78	1067.56	-2014.44	-987.11	-4093.01	-3979.68
8	17680.85	0	-3082.00	-2054.67	-1290.14	-1261.81
9	8799.77	0	-3082.00	-2054.67	-2580.29	-2610.65
10	4273.61	0	-3082.00	-2054.67	-3440.38	-3480.85
11	8807.37	0	-3082.00	-2054.67	-860.09	-870.21
12	31560.02	31560.02	28478.02	25396.01	26399.45	26338.74
13	11824.25	4325.78	1274.48	-1807.53	2595.33	3595.33
14	1195.52	0	-3082.00	-6164.01	-440.29	-440.29
15	2149.49	0	-3082.00	-2054.67	-1320.86	-1320.86
16	17599.53	0	-3082.00	-2054.67	-3082.00	-3082.00
17	17614.74	0	-3082.00	-2054.67	-2641.72	-2641.72
18	17599.53	0	-3082.00	-2054.67	-6604.29	-6410.05
19	14919.13	1067.66	-2014.34	-987.01	-5096.35	-4915.05
20	17680.85	0	-3082.00	-2054.67	-2201.43	-2136.68
21	8799.77	0	-3082.00	-2054.67	-1761.15	-1878.55
22	4080.87	0	-3082.00	-2054.67	-3522.29	-3757.11
23	8807.37	0	-3082.00	-2054.67	-1320.86	-1408.92
24	31560.00	31560.00	28478.00	25395.99	25395.99	25395.99
25	0.00	0	-2087.82	-2319.80	-1423.15	-1402.26
26	20516.71	20516.71	18428.89	18196.91	17195.18	17244.76
27	31391.91	-3134.32	-5222.14	-5454.12	-6772.18	-6717.88
28	1400.85	1400.85	-686.97	-918.95	135.51	154.39
29	20731.19	-3096.80	-5184.62	-5416.60	-4362.14	-4343.26
30	0.00	0	-2087.82	-2319.80	-1265.34	-1246.46
31	0.00	0	-14880.68	-15112.66	-14058.20	-14039.32
32	3134.32	3134.32	1046.50	1974.42	2659.83	2617.70
33	5634.37	5634.37	3546.55	4474.47	3103.68	2879.04
34	32206.96	-13775.66	7127.83	6895.85	4786.95	4853.05

Figure 4 - A comparison of Bill Splits

It can be seen that 21 of the 34 activities (61.7%) match directly (zero in column (2) of Figure 4). The total value of Bill Items that directly map are £388,477.55, which is 80% of the total project value. During the overlaying procedure no Bill Items failed to find some level of matching within the tree structure.

Therefore 20% of the project value found only a partial match within the tree. An example of a partly matching Bill Item description is Item No. 35, 'Bridge 1 North Abutment Drainage' (Figure 3). The overlaying of this Item matches the following nodes in the tree, as shown in Figure 1:

- 'Bridge'.
- '1'.
- 'Abutment'.
- 'North'.

However the matching process fails to progress beyond the node 'North'. This is due to the lack of an activity in the first project representation (Figure 2), for this particular type of work. The sum of £6,160.41, associated with this Bill Item, is transferred to the node 'North' until the Bill splitting process can be completed.

If the sum of the activities is to match the project value the money from partly matching Bill Items must be transferred to the leaf nodes of the tree, and hence the corresponding activity. The money resting at a mid-tree node is transferred to the descendant leaf nodes (those which emanate from that mid-tree node). A number of methods of splitting the money between the leaf nodes are available, the system allows the following four:

- A *Leaf Node* split, where the money is divided equally between all the descendant leaf nodes.
- A *Direct Descendant* split, where the money is divided equally between all of the descendant nodes that exist on the next level down the tree. This process continues through the tree until all of the descendant leaf nodes are reached.
- A *Leaf Node Working Period* split, where the money is divided between all the descendant leaf nodes in proportion to the duration of the working period of that leaf node. For example, if the sum of the durations of the working periods for the descendant leaf nodes was 20 days, a leaf node with a working period of 5 days would receive 25% of the money split.
- A *Direct Descendant Working Period* split, where the money is divided between the direct descendant nodes on a working period proportioned split. This process, as with the direct descendant split, continues until all of the descendant leaf nodes are reached.

The comparative results of the Engineer's Bill Split against these Bill splits are shown in Figure 4 columns (3) to (6) respectively.

AUTOMATED BUDGET GENERATION

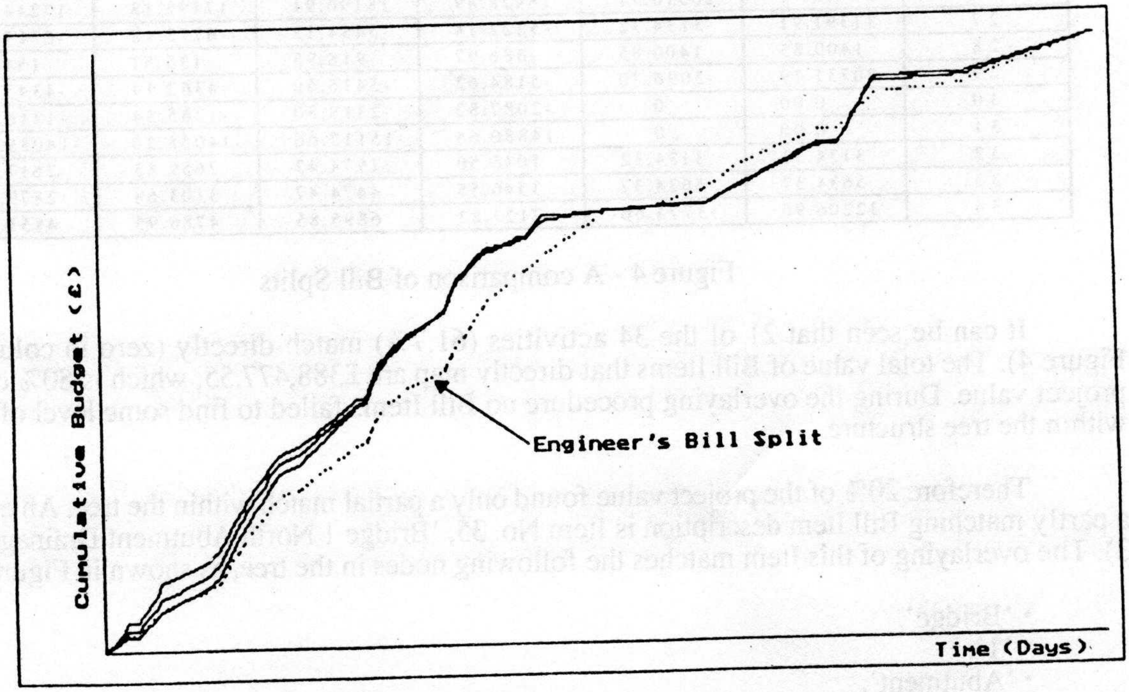

Figure 5 - A comparative budget graph for the example project

The generation of a budget for a project can be achieved by using time and financial information. Within the example project the timing information was provided by the dates for activities that were carried into the tree with their relevant activities. The financial information was provided by the mapping of Bill Items with their financial amounts on to the activities.

There are numerous methods of allocating the money associated with activities on to the project calendar. The system at present permits three methods:

- At the start date of the activity
- At the end date of the activity
- Equally over the working period of the activity.

For the example project, Figure 5 shows a comparison of the budget generated from the Engineer's Bill Split and the budgets created by the Bill splitting of the system. All associated money is spread equally over the working period for the activity.

DISCUSSION

The fundamental methodology has been shown to work on simple projects.

The parsing process allows information from any type of project plan to be represented in a basic tree structure. In terms of plan evaluation this allows duplication checks to be performed.

When applied to different models of the same project, comparability and relative completeness can be evaluated. In the examples used, this has been a helpful feature of the package. It also identifies where extra work appears in later plans of the same project, thereby indicating potential sources of extra payment or time allowances. This has not been tried out on a real project, but demonstrates the potential of the research effort.

A problem in comparing plans drawn up with different levels of detail has highlighted the need for a knowledge base to enable unmatched elements to be identified as a group of sub-elements comparable to a single element in a different model. This knowledge base development will be an important future developement in this research.

By allowing activities to carry with them information of interest to the planner (e.g. durations and financial values) a method has been devised to compare this information between different models. To do this in an automated way has meant developing various methods for splitting the information (financial information in this paper) withiout undue recourse to the user. These are possibly in need of further refinement but the results obtained so far are encouraging.

Future development work not mentioned in this paper will include a look at resources within a project. This is felt to be necessary if the package is ultimately to be a viable tool for thorough plan evaluation.

As far as this paper is concerned automated budgeting is possible and should provide a useful aid to planners.

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