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(مراجعة موضوع) ***(Subject Review)***

The State of the Art in Integration of Cost and Time Models

التقنية المتقدمة في تكامل نموذج التكلفة والوقت

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Abstract

Cost and time are interdependent by their very nature. However, cost and time are generally treated in isolation both informally and within the terms of the contract. In reality, cost and time interact throughout the construction cycle. Thus, cost and time models and modelling systems must facilitate the integration of cost with time. Recognition must also be given to the need to integrate cost and time, and suitable contractual procedures for utilising more advanced styles of modelling must be implemented. In this paper traditional and emerging models of cost and time are reviewed and the contractual context of cost and time integration is explored. This review seeks to ascertain if and why models and contracts have failed to satisfy this particular requirement, as well as the other requirements placed upon them.

Key Words: Cost Models; Time Model; Integration and Modelling System

ملخص

التكلفة والوقت ذو علاقة اعتمادية تبادلية بطبيعتيهما، ولكنهما يعاملان بمعزل الواحد عن الأخر وبشكل غير رسمي وضمن عناصر العقد. وفي الواقع يتفاعل الوقت والتكلفة طيلة حلقة الإنشاء. وعليه فإن نماذج التكلفة والوقت وأنظمة النماذج يجب أن تسهل عملية دمج الوقت بالتكلفة، كما أنه من الواجب اعطاء أهمية للحاجة الى دمج التكلفة بالوقت وتنفيذ اجراءات لاستغلال نماذج وأنماط متطورة لذلك. لقد تمت في هذا البحث مراجعة انماط من التكلفة والوقت، واستكشاف طرق دمج هذه الأنماط. تهدف هذه الدراسة الى اثبات ما اذا فشلت هذه الأنماط والعقود في عمل تكامل ما بين الكلفة والوقت، وأسباب فشلها في تنفيذ هذه المتطلبات والمتطلبات الأخرى المعتمدة عليها.

Introduction

In construction, cost and time are interdependent by their very nature [28, 33]. This interdependency is evident from estimating and planning [5] through to control on site [28]. However, cost and time are usually modelled separately. At a practical level, cost models (*e.g.* bills of quantities) and time models (*e.g.* programmes) are each subject to separate guidelines and rules for their preparation and use. Contractually, the valuation and assessment of cost and time matters is carried out independently under the majority of standard forms of contract.

It is only recently that serious attempts have been made to integrate cost and time through models and modelling systems, informally (*i.e.* out with the terms of the contract) and contractually (*i.e.* within the terms of the contract). Rather than merely trying to integrate existing models of cost and time (*e.g.* the programme activities with bill of quantity work items), effort is now being made to produce integrated models of cost and time, where the cost model work item has the same definition of work content as the activity or operation on the programme.

The most common form of cost model in Britain and many other parts of the world are the bill of quantities. It is a list of items, each of which is usually expressed in terms of the net quantity of the material component to be incorporated into the works [42]. A unit rate can be entered against each item. Adjustments to the cost of the works are then made on the basis of changes in quantities or the rates.

In the UK the bill has become the cornerstone of the lump sum contract, both in civil engineering and building. Elsewhere, around Europe, some form of the bill of quantities is used extensively [25]. The Royal Institution of Chartered Surveyors (RICS) [29-31] has carried out a number of studies over the last 10 years into contracts in use in the building (non-housing) sector in the UK (Figure 1).

Despite changes in procurement patterns and contract forms, the bill of quantities continues to play a major role. It is still used on about 50% of contracts by value [32] and some argued that its popularity is not set to dwindle this century [31]. The following figure of 50% is conservative, based on the value of contracts let on the basis of firm or approximate quantities. It takes no account of the wide use of bills of quantities when procurement options such as design and build or construction management are used.

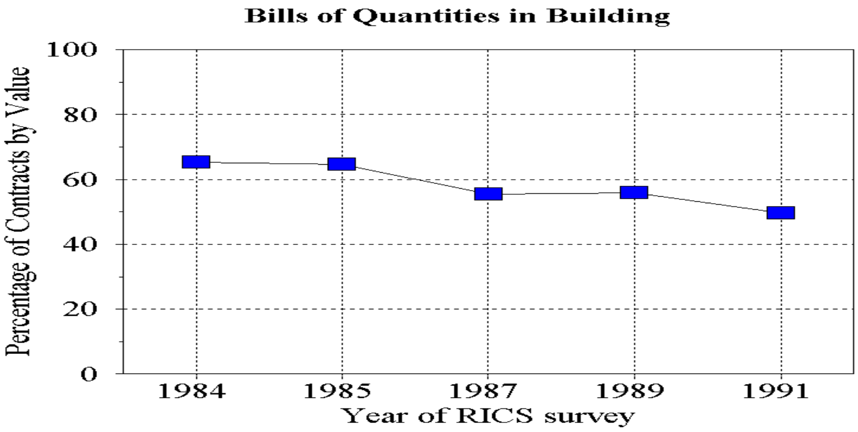

Figure 1: Results of Royal Institution of Chartered Surveyors RICS Surveys on Contracts in Use

The bill is no longer simply a means of preparing tenders from contractors on a common basis. The bill is now used for a variety of purposes. Singh and Banjoko [33] classified Bill of Quantities (BQ) uses as follows:

client:
- comparison of tenders;
- costing design alternatives;

Contractor:
- estimating and tendering;
- planning;
- cost control;
- cash flow prediction;

Contractual interface:
- interim payments valuation;
- valuation of variations; and
- work re-measurement.

Skinner [34] looked more closely at the potential use of bills of quantities by contractors. Throughout the construction process the contractor's use of the BQ extends from tendering through to production (estimating and planning, strategic planning, procurement of material, plant, quality control, payment, etc.).

Generally, two methods exist for tender stage estimating. Operational estimating and unit rate estimating [22-23]. Operational estimating consists of estimating the cost of executing the works or a section of the works on the basis of the total resources required. The resultant estimate is then distributed over the bill items. Merrifield [19, 21] regards this as the fundamental estimating technique. Unit rate estimating consists of estimating the cost of the resources for individual bill items.

In civil engineering operational estimating is common [22] and considered to be more reliable than unit rate estimates [19, 21]. Thus, when an operational estimate is used the estimate has to be spread subjectively among the associated bill items. The unit rates themselves have been criticised for the fact that quantities do not represent the buying units for materials, which contractors deal with [26]. Also, bill items are not suitable control centres, thus feedback to verify predicted productivities is practically impossible [43].

It is generally acknowledged that the accuracy of an estimate increases with the progress of design. A relatively small increase in the level of detail of information can create a large increase in the reliability of the estimate [12, 44], but as the level of detail increases, the reliability of the estimate increases at a decreasing rate (Figure 2 and Figure 3). As Harrison [14] puts it, "the higher the accuracy, the higher the cost of achieving that accuracy. The relationship is not linear".

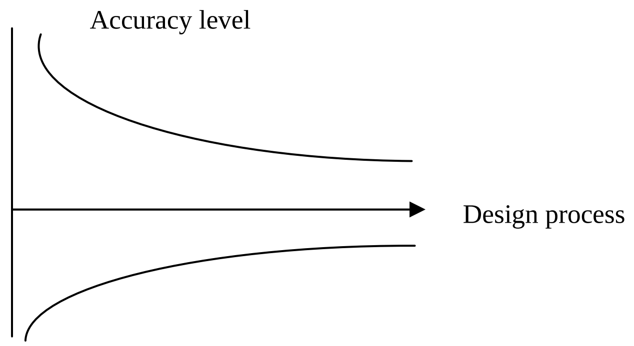

Figure 2: Relationship between accuracy and design process.

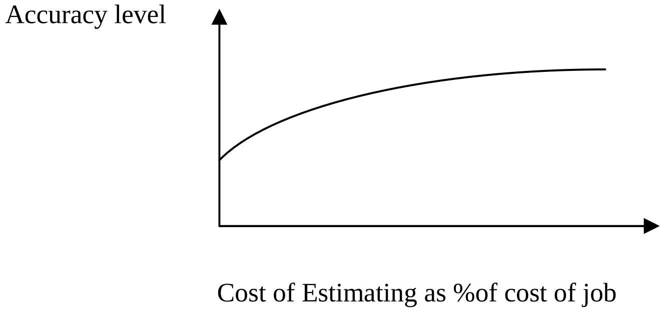

Figure 3: Level of accuracy vs. cost of producing estimate.

Researchers [3- 4] have found that the major items in a bill of quantities are generally priced to a high degree of accuracy, but as the relative value falls so does the accuracy to which they are estimated. This can be said to indicate two features:

1. low value items receive low priority; and
2. low value items often relate to abstract quantities (*e.g.*, form cavity, form arris) to which productivities cannot be assigned with confidence.

Bennett and Barnes [4] indicated that once the estimator has priced a certain number of items, there is little or no improvement in accuracy to be gained by pricing any further items. Barnes [4] concluded that the accuracy of a cost estimate can best be improved by increasing the accuracy of pricing the cost significant items, defined as those items with a value higher than the mean item value. Harmer [15] concluded that much simpler models of cost could satisfy the estimating, planning, and valuation and control functions in construction. It is clear that there is considerable scope for a reduction in the level of detail of traditional models.

Traditional forms of contract continue to treat cost and time compensation separately. Under traditional contracts the power of the engineer or architect to instruct or issue variations commonly extends to programme, sequence and method of execution, postponement, quantity, quality and performance of the works. All of these events can give rise to a change in the use of resources. Traditional forms of contract, far from encouraging agreement, are adversarial in their very nature [13]. Their failure to provide systematic procedures for evaluating the effect of changes on cost and time promote protracted dispute [2]. Time limits for the notification, submission or settlement of claims are usually ambiguous and/or inadequate.

The Link between Cost and Time

The Role of Models in the Overall Control Loop

Cost and time interact throughout the construction cycle (Figure 4). During the estimating and planning phases the contractor or client determine their best estimate of the resources required executing the works and the cost thereof. The cost model and the time model then form the baseline against which a contractor and client will monitor progress. Based on the analysis of performance, control will be initiated in order to complete the works to the optimum cost budget and duration. Ideally, the contractor will want to be able to have a complete picture of performance at any point in time.

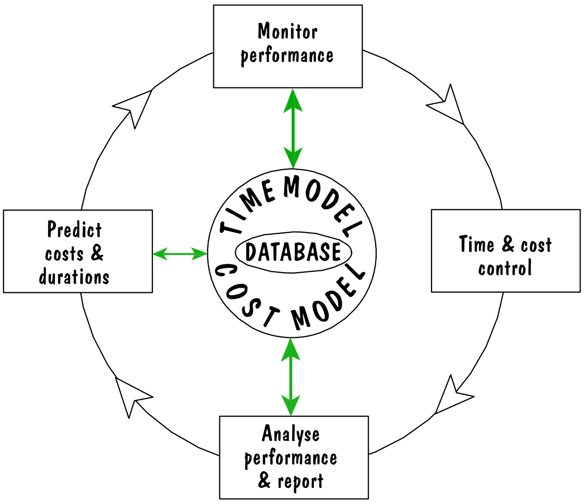

Figure 4: Cost and Time Control Loop

Estimating and Planning

The material costs of a construction project are relatively easy to predict and control. Labour and plant are a different case. There is no doubt that the quantity of work component is a major influence on the cost of these resources. Using assumed productivities the contractor will estimate the number of resource hours. The labour and plant resources are subjected to many other factors, which will influence actual productivity. The duration they are required on site will depend on factors such as timing of other work, constraints on working space, constraints on working hours, availability of resources, information availability, continuity of work, good programming, weather conditions, level of variations, interruptions, delays and soil conditions. All these matters affect the planning process as well as the estimating process.

The primary function of the planner at tender stage is to determine the optimum contract duration. He must determine whether the project can be completed within the allowed duration and what resources will be required to complete the work. To do this he must examine the drawings and specifications for constraints, in terms of time and space. He then assesses the major quantities of work, allocates resources to these operations and so derives duration for each activity on the programme. The logical sequence of activities has to be determined, taking into account location and the availability of resources.

Once a programme has been obtained the planner must confer with the estimator to ensure that they have assumed the same needed resources. Any discrepancies will be examined to determine the most efficient method of carrying out the work and either the tender or the programme will then be adjusted.

Skinner [34] observes that the unit rate and bill of quantities generally are of little use in the planning and control functions. He goes on to ask, "are the costs of production realistically represented and accounted for? A significant inability in one system (*i.e.* the bill of quantities) to reflect an observed change in the other is likely to produce dispute and dissatisfaction. Clearly there is a need to relate more closely the costs incurred to the prices charged".

Valuation and Control

Change is a fact of life in construction [2]. Change will alter the use of resources, budgets and cash flow, so it is necessary for the contractor to take account of the effect of change on budget otherwise his analysis of performance will produce incorrect results. Likewise, change will affect the client's budget and cash flow. The predictions of costs and duration will be carried out in isolation within different contracting, client and consultant organisations. Equally, the monitoring, control and reporting functions for cost and time will operate separately for internal purposes within organisations but they must also integrate/interact. As changes occur, valuations are made. It is vital that the two or more remote control loops interact in order that the effects of change are agreed, incorporated and subsequently controlled. All of this can be carried out informally with respect to historical information such as final costs and productivities. This will allow both parties to make use of the knowledge acquired by the other on future projects. However, the valuation of change is a contractual matter and thus requires incorporation into standard conditions of contract (Figure 5).

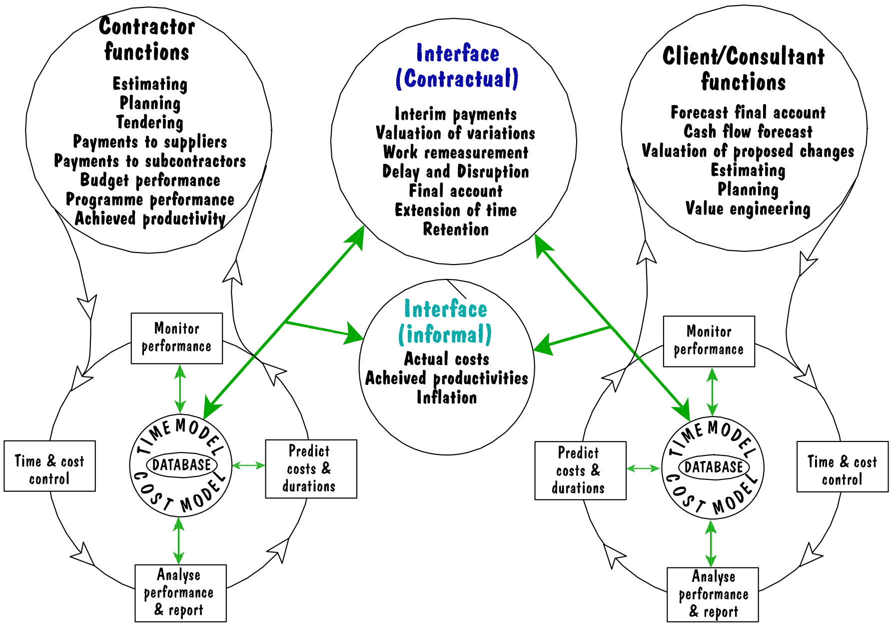

Figure 5: Control Loop Functions and Interfaces

The reality of control is clearly illustrated by Zakieh [41] (Figure 6). A barrier exists between estimating models based on work items and control systems, which can operate at a much coarser level [27-28]. Zakieh [41] looked in detail at control in construction, and in particular at the construction stage. The classical control loop in Figure 4 is an ideal situation which is, rarely, the case in practice. In particular, the provision of feedback is virtually non-existent. The main reason for this is the incompatibility of the various models, as confirmed by Mawdesley et al. [20]. The estimating model, such as the bill of quantities, must be manipulated to suit the control model. The former is based on work items and the latter on work activities or operations. Once the control function is exercised the data so collected is incompatible with the work item making it very difficult, if not impossible, to verify achieved productivities against assumed productivities. The primary reason is because work items are not suitable control items. Estimators seldom compare predicted with actual and thus seldom learn from experience. In a study of estimating practice carried out by McGowan [23] feedback was restricted to qualitative and subjective comments from site personnel.

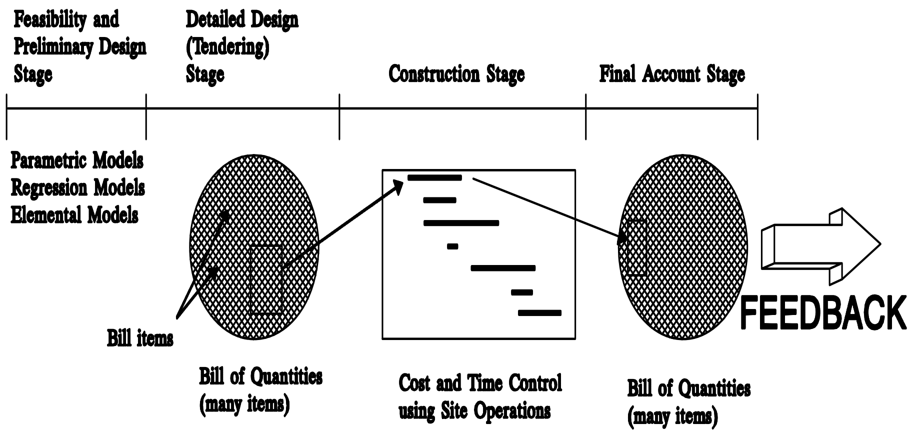

Figure 6: Conventional Control Barriers [41]

The timing of information and the level of detail at which information is collected are crucial. What is past cannot be controlled. If an activity is for example of three weeks duration and reporting is on a monthly basis, then control cannot be affected. Control items must relate to activities or operations, which have or are likely to have a sufficient duration to enable feedback to be obtained in order to effect control. Thus, major operations/activities should be concentrated on. The level of detail at which information is collected will have a profound impact on the ability to collect data quickly and accurately. An excessive level of detail will result in lengthy data collection and misallocation of costs. According to Zakieh [41] (referring to [24]), when the number of cost codes rises above 50 there is a substantial fall off in accuracy of allocation.

Integration of Cost and Time

There follows an analysis of some noted attempts by researchers and practitioners to overcome the lack of cost and time integration in construction cost and time models and modelling systems.

Operational Bills and Bills of Quantities (Operational Format)

In the 1960's Skoyles [35] developed the Operational Bill (OB). He questioned the usefulness and validity of the traditional cost model, which compounded labour and material costs into a single unit rate, which was adjusted against quantity. He particularly questioned the validity of modelling labour cost against quantity, and the use of abstract work items. He recognised the operational nature of construction and promoted the OB. An operation was defined as "the work, which can be carried out, by a man or a gang of men without interruption by other work" [36]. In practice, the OB was part of an overall process of document production based around operations. Each project was represented as a network diagram. The network then formed the basis for document production, though it was not intended to dictate the method or timing of construction. It was intended to allow the consultants to pass their "considerable knowledge" of the project on to the contractor.

The OB consisted of a schedule of materials for each operation, and labour costs were expressed as a lump sum. The OB attracted a mixture of positive and negative comments.

Positive Comments on the Operational Bill

The following are representative positive comments on the OB [1]:

1. It was a step towards rational modelling of costs based on the factors affecting them; "many new construction methods entail considerable mechanisation and the integration of the building process from design to construction" making the traditional bill of quantities an inappropriate form of communication for cost and production and operational information;
2. Contractors were able to tie control and incentive schemes directly to activities;
3. Administration was eased;
4. Direct feedback was facilitated;
5. The accuracy of estimates could improve;
6. It was a useful tool for preparing interim valuations;
7. It did not present any further difficulty in valuing variations and some felt that the operational bill enabled more efficient valuation of variations as the labour element of a contractor's bill was directly allocatable to the programme, so disturbances to a programme could be more easily assessed.

Negative Comments on the Operational Bill

The following are representative of negative comments on the OB [1]:

1. The new bill layout led to perceived new estimating techniques and lengthier estimating periods [37] and it became unpopular among estimators.
2. It was perceived and felt strongly that there was a need for a standard operational model which avoided the perceived inflexibility of the predetermined network for the operational bill.
3. There was a perception that the valuation of variations was not necessarily straight forward when using the current forms of contract and conditions, which governed the valuation of variations at the time.
4. Skoyles himself suggested that the demise of the Operational Bill be due to the general resistance to change in the industry. Others felt that 1966 was too early for its introduction. Conceptually it was good but practically the new concepts needed to be introduced gradually.

Because of the negative aspects of the OB, the Bill of Quantities (Operational Format) (BQOF) was introduced as a halfway house. Essentially the BQOF was a BQ, measured to an existing Standard Methods of Measurement (SMM) but split on the basis of work operations as well as trade sections. In hindsight the BQOF compounded many of the problems associated with the OB. It was more complex than conventional bills, containing more items than even elemental bills [36], which were they considered to produce a lot of repetition of items. The Bill of Quantities Operation Format (BQOF) removed the one major innovation, the billing of all labour costs for an operation as one lump sum. Skoyles [3] was forced to admit, "it will be impractical to feedback costs at the level of an individual item and any cost reconciliation can only be made to the activity heading". Thus, one of the primary aims of the OB was defeated. Also, the form and content of the activities in the BQOF were still tied to the network produced by the consultants, rather than the contractors.

Method Related Bill

Barnes constrained himself considerably by acknowledging the conservative nature of the industry [3, 33] when developing the method related bill (MRB).

The underlying philosophy of the method related charges (MRC) is the fact that cost is not proportional only to quantity. Considerable proportions of cost can be committed based on the method and timing of the work rather than the quantity of work executed. In these circumstances it is important that the cost of these resources is isolated so as to avoid unnecessary splitting of rates at the time of variation. Under the MRC there are two cost types; the fixed cost and the time related cost, designed to model costs, which are not to be considered as quantity proportional.

The research, which led to the development of the Method Related Charges (MRC), spawned the Civil Engineering Standard Methods of Measurement (CESMM), which is now in its third edition. Despite the continued promotion of the MRB it has not gained wide acceptance [33]. Many reasons exist:

The MRB is "an inaccurate model of the pattern of construction costs, it compounds material costs and some plant-labour costs and represents the remaining plant-labour costs as if they were independent of quantities and output rates" [33]; it is not developed sufficiently to avoid exploitation by either party to the distinct or continual disadvantage of the other party; its use is not sufficiently developed in the contract; and the use of the MRC is not mandatory.

The result is that it is abused. In a study of the work of a major civil engineering contractor's estimating department the author noted [23] that the MRC was not used properly, except once, in 4 tenders. This was not company policy but rather the unwillingness of estimators to relinquish the small advantage they could gain with unit rates compared with MRC's. The use of MRC was perceived as a client device. Despite the fact that the contractor was expected to expose his proposed method of working and use of resources, he felt that it was just another means for the client to avoid paying the true value of variations. The terms of the contract and procedures relating to valuation remained unchanged after the introduction of the MRC. More often than not the MRC was a "pot" into which adjustment items were put.

The "Rational" Bill of Quantities

Singh and Banjoko [33] set out to develop an alternative to the conventional and method related bills using scientific methods. They categorised construction costs into four groups (Figure 7):

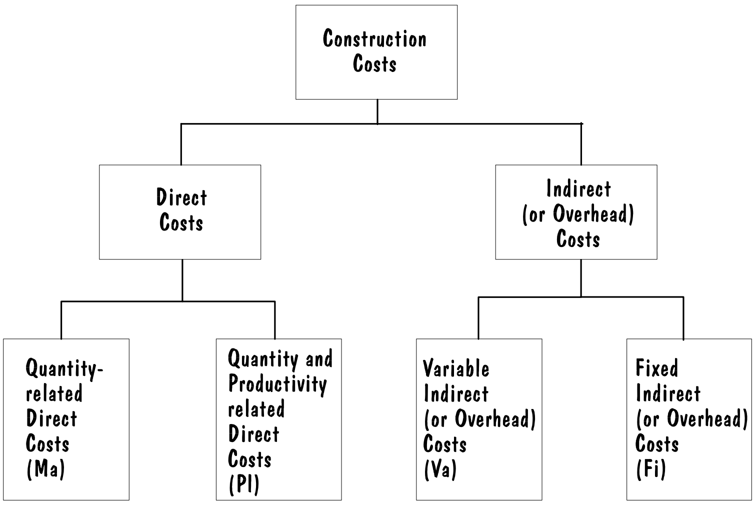

Figure 7: Singh and Banjoko's Classification of Costs [33].

Quantity related direct costs (Ma);

Quantity and productivity related direct costs (Pl);

Variable indirect costs (Va' and Va"); and

Fixed indirect costs (Fi).

The proposed format of the "rational" bill of quantities that they developed is shown in Figure 8, where:

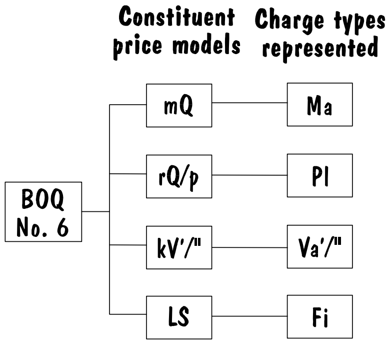

Figure 8: Structure of Costs in the "Rational" Bill of Quantities [33].

m is materials cost per unit quantity;

Q is quantity of a work component;

r is hire rate of plant-labour team;

p is output rate of the component;

k is a proportion;

V' is sum of materials charges;

V" is sum of labour-plant charges; and

LS is lump sum.

For example, Figure 8 shows that variable indirect costs (Va' or Va") are either a proportion of the sum of materials charges on a project (kV') or a proportion of the sum of labour-plant charges on a project (kV").

Their analysis concentrated on cost components, which were modelled independently of the time model, the programme. Thus, no consideration was given to the development of work item content or definition so that it would be compatible with programming activities. From the valuation point of view, they restricted their developmental work to the following functions:

1. Interim payments;
2. Valuation of variations; and
3. Work re measurement.

Singh and Banjoko [33] were looking for forms of bills of quantities, which could reproduce the structure of costs for financial control. According to them, "the core of the measurement contract with quantities is the contractor's efficiency, the individual permanent work components which he/she has to do for the client; and their quantities; and the need to allow them to be re measured within reasonable limits without contract rate adjustment". Thus, they rejected the concept of time related direct costs, as they felt that they did not model costs in terms of the permanent work components. The form of this bill for permanent work items is shown in Figure 9.

Criticisms

Their structure and classification of costs was too rigid because they restricted the use of variable and fixed costs to the indirect works and quantity and productivity related costs to direct works. As a result, the possibility of having fixed or variable costs for direct works was ignored;

Item Number	Item Description	Unit	Materials Charge			Plant-Labour Charge Rate per day		
			Quantity	Rate	Amount(£)	Hire	Output	Amount (£)
	Brought forward				17988.94			9663.00
407	Provide and fix wrote shuttering to headwalls and wingwalls of pipe culverts	M2	50	1.72	86.00	276.00	120	115.00
408	Provide and fix wrot shuttering to vertical faces of box culverts	M2	14552	1.72	25029.44	276.00	120	34469.60
409	Provide and fix in position all dimensions MS reinforcements in box culverts in wingwalls of pipe and box culverts and side drains	T	3.90	506.00	1973.40	196.92	1	767.99
Total of Part No. 4 – carried to summary of permanent work parts				**45077.78**				**45015.59**

Figure 9: The form of the "Rational" Bill of Quantities for permanent work items (Direct Charges) [33]

A limited set of objectives was identified against which the ability of a bill to model the structure of construction costs would be evaluated; The need to integrate cost and time was explicitly ignored; and no consideration was given to the form of model or work item content against which cost was to be modelled.

Activity Schedule

The Activity Schedule (AS) was first introduced under the BPF system [8]. It was an attempt to find an alternative to the bill of quantities. "In the schedule of activities, the contractor specifies a priced list of separate activities within his total programme, for which he will be paid as each is completed. The number of activities in the schedule will depend on how the contractor plans his work and wishes to be paid". Stated reasons for the adoption of the AS were:

1. simpler to prepare;
2. the conventional bill is over detailed;

3. simplify interim payment calculations;
4. direct link to the programme;
5. facilitates progress monitoring;
6. facilitates site cost control; and
7. facilitates feedback for future estimates.

Such a system allowed the cost and time models to be prepared on a common basis, and the models would match the contractor's intended method of execution of the works. However, noted disadvantages of such a system are:

1. like the "rational" bill above, the work item content of the AS is not standardised and this can lead to problems in database generation and application to future estimates [7] (The lack of standardisation led Pasquire to note . "The form of the AS was left to the contractor. But contractors were still preparing BQ's. A need for some measurement rules or guidelines was identified for use with the BPF system for the preparation of the activity schedule");
2. Because the contractor prepared it it was not available for pre-tender estimates [26];
3. There was duplication of effort in preparation, even if it matched each contractor's method;
4. The comparison of tenders was made much more difficult; and where the content or structure of the model is discretionary it may often be
5. Inadequate and require further time-consuming clarification.

Integration and the Standard Forms of Contract

Much of the movement towards rational modelling, introducing causality into cost-time relationships and flexibility of modelling to accord with construction methods has altered the way we treat cost and time contractually. If the move away from the conventional bill continues then so must the move away from bill of quantities based contracts and valuation mechanisms. As noted earlier, one of the failures of both the methods related bill and the operational bill has been a failure of the contract procedures to reflect the changed standing of rates and charges. Some developments on the contract front are worth noting.

Other Examples of Cost and Time Modelling

The Integrated Performance Evaluation System (IPES) [27] addressed the issue of effective modelling for control purposes. IPES was developed to provide a link between the estimating and planning functions and then in turn link these through to the monitoring and control functions and finally feedback for future estimates and plans. In addition the cash flow implications of a contract programme were considered. The whole system is based on the concept of work elements being used as the basis for expressing the estimate (often derived on the basis of the BQ) in a format suitable for planning and cash flow prediction. Using significance theory the operations, which consume the majority of resources, or are vital for the logical representation of the construction project programme, are identified. These are then used as the basis for integrating the various control functions. Subsequently, the significant work elements form the basis for the collection of performance data and the analysis of contract performance including productivity, earned value, programme efficiency and other measures.

As Mawdesley et al. [20] point out, "true control cannot be exercised on a project without the integration of (time and money)". By linking the estimating, planning, site evaluation and cash flow prediction functions a powerful management tool is created, provided the system is quick to report and accurate [27-28]. Thus, the system permits management control decisions to be made in time to enable control to be usefully applied so that performance can be improved [27, 45].

The use of Information Technology (IT) to integrate cost and time is blossoming. Recent publications note the many instances of links between estimating and planning packages [6, 11, 20]. There are no doubts that the barriers to integration are coming down. However, much of the effort of IT developers and innovators has been directed to integration using inappropriate cost and time models. Mawdesley et al. [20] note that "the fundamental problem in integrating time and money for construction is that the two models are incompatible". The complexity that IT can handle has perhaps fuelled the continued reliance on traditional complex cost models. Multiple bill items can be assigned to individual activities [6, 20], and thus the use of complex bills of quantities continues. Computerisation of manual processes only propagates use of inappropriate models.

Discussion

Clearly, effective measurement, valuation and control require integration of cost and time. These three functions are carried out within and between client, consultant and contractor organisations. They may be carried out informally or contractually. There is no requirement for a contractor to analyse performance, but it is an unwise one who doesn't. Equally, there is no reason why a form of contract must include formal procedures for valuing payment or variations or claims. One could argue that if the contract allows for payment and variations then the parties could work out the mechanics of how that should be done. However, lack of pre-agreement is a recipe for dispute and conflict on a large scale. Equally, inappropriate mechanisms are a recipe for dispute and conflict. Unfortunately inappropriate mechanism appear to be the norm. Cost and time are modelled separately using incompatible models, the bill of quantities based on work items and the programme based on activities and operations. The problem starts in the pre-contract stage where contractors struggle to price a complex document and relate it to a much simpler time model. Work items are often abstract making their cost estimation difficult and of suspect accuracy. The collection of meaningful feedback for such a cost model is impossible, particularly if it is to be done as part of the contractor's overall site control function whereby he is seeking to analyse performance accurately enough and in enough time to be able to effect control that will be of use.

The Role of the Programme

Zack [40] observes that "a schedule should be nothing more than a list of all activities required to complete the work in accordance with the requirements of the contract documents". For some the programme is not a tool for planning and co-ordination but a means to help build claims. It is only prepared because the contract says so. Under Institution of Civil Engineers (ICE6) the programme is to show "the order in which (the contractor) proposes to carry out the works" (Clause 14(1)). The Chartered Institute of Building (CIOB) [9] states "there is no doubt that inadequate programming and information are the cause of many claims which could and should be avoided". Ruppal [46] and Clayton [10] both stress the importance of the programme in monitoring and dealing with delays. Thus, the programme should be used in claims management but not as merely a tool to enhance recovery in claims situations [40], but rather primarily as a tool to drive the project and to aid the identification and settlement of claims as the work progresses [38].

Delays and Disruption

There is a strong relationship between the ability of cost and time models to display this inherent integration, be it with the MRB or the "rational bill", and the ability to deal with change (*i.e.* variations, delays and disruptions). The preparation of claims for delay and disruption is often based on the application of planning techniques. Planned execution, and estimated expenditure and use of resources are compared against actual in the light of relevant accepted risk events. The power of the programme in this regard is mentioned by many. The developed cost models have strived to either:

take account of factors which influence cost that have a direct overlap with time factors (*e.g.* the Rational Bill of Quantities); or

create cost models on the basis of equivalent site operations or programme activities (*e.g.* the Activity Schedule).

The valuation of delay and disruption has so far evaded systematic consideration. Some of the reasons are:

1. The conventional bill of quantities is an irrational model of construction costs;
2. The programme is given little standing contractually;
3. The principles of method related charges have had a failure of implementation, which may be considered to be symptomatic of:
    a. The failure to clarify the new status of the MRC vis-a-vis the programme (which continues to be the clause 14 programme, which has little contractual status); and
    b. The failure to create a new contractual climate, commensurate with the more open handed principles of exposing the factors to which cost is sensitive, so that the value of the MRC and the unit rates are adjusted rationally in accordance with these principles (the terms of Institution of Civil Engineers (ICE5) and ICE6 did not change on the introduction of the Method Related Bill (MRB)).

Other developments such as the Rational Bill of Quantities remain committed to traditional concepts. Time and cost models remain isolated and they are operated within traditional contractual frameworks. As a result, they restrict themselves to systematic valuation of re measurement and variations, though only a small proportion of these are carried out systematically, equitably and accurately.

Clearly, some advances need to be made in setting up a suitable contractual framework for the advancement of sound programmes as a management tool. Recognition must also be given to the need to integrate cost and time. Suitable contractual procedures for utilising more advanced styles of modelling must be implemented in order that the scope for systematic, equitable and accurate valuation of delay and disruption claims, as well as variations and work re-measurement, can be increased. Additionally, as was discussed earlier, the cost and time models need to fulfil wider functions within the overall control loop.

Things are changing. Developments of simpler and more realistic cost models are being made (*e.g.* the method-related bill and the rational bill). Equally, cost and time models are being prepared on a more common basis (*e.g.* the activity schedule). Contractually, the programme is gaining more weight and the use of the unit rate in isolation for valuing changes is decreasing; Government Form of Contract (GC/Works/1) and New Engineering Contract (NEC1). The problems of claims are being addressed in a number of ways. Delay and disruption are valued with variations and cost and time models are being updated frequently (*e.g.* GC/Works/1, NEC1). The parties are motivated or forced to deal with claims promptly (*e.g.* NEC1).

Conclusions

1. The bill of quantities is the most common form of cost model in the UK, and in many other countries.
2. The bill of quantities is now used for a wide variety of functions within and between the organisations involved in construction.
3. The bill of quantities is a complex, detailed and irrational model of construction costs.
4. The bill of quantities is not suited to many of the functions for which it is used.
5. Cost and time are interdependent throughout the control cycle, from estimating and planning through to valuation and control.
6. Traditional conditions of contract fail to integrate cost and time in the evaluation of risk.
7. The operational bill failed to gain wide acceptance because it was perceived to be too radical and inflexible.
8. The method related bill was developed to model costs on the basis of factors to which they were sensitive, but it is still considered to be an

irrational model and its contractual use has not been developed sufficiently.

9. The "rational" bill is constrained in its development to the traditional valuation and work re measurement roles rather than the wider context of delay and disruption.
10. Recent proposals such as the activity schedule seek to relate cost model items to programme activities to provide a common basis for estimating, planning and control.
11. Both the activity schedule and the "rational" bill use non-standard model items, which mitigate against effective feedback and database generation for application to future projects.
12. Recent developments in conditions of contract and contractual mechanisms seek to integrate cost and time and to enhance the role of the programme but not to the extent that systematic valuation of variations, delays and disruptions is increased.
13. The power of IT can aid integration of cost and time at a practical level but inappropriate models continue to be used.
14. The Problem of claims for changes in the use of resources needs to be addressed by integrating cost and time effectively through contractual models and modeling systems.

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