Resource Significant Models for Estimating, Planning and Control in Construction

P H McGOWAN, C W RANDALL and R M W HORNER*

ABSTRACT

The production of acceptably accurate estimates and programmes in any contracting organisation is a function of the reliability of the estimating and planning data, the soundness of judgement applied by the estimators and planners, and the ability of the organisation to manipulate and process the data.

By applying the lessons learnt from historical projects, the estimator or planner hopes to minimise the risk associated with the current project. In order to gain access to this vital information the historical data should relate to a realistic and measurable yardstick to which productivities, gang compositions, *etc* can be assigned. This should in turn dictate the format of the estimating or planning model issued by the client. Equally, it is vital that the resources expended on site can be efficiently and conveniently allocated against the requisite yardstick, ideally as a part of the control process.

The authors have used the philosophy of resource significance to produce rational models for the generation and maintenance of a comprehensive and realistic estimating and planning database for construction projects. The models reflect the level of detail necessary for the production of acceptably accurate estimates and programmes by encompassing the significant labour, plant and material resources of a project. A factor is applied to the value of the significant resources to calculate the total value. The work packages of the resulting resource significant models relate to site operations and activities, thus ensuring that the database can form the basis of the site control and feedback system, as well as the tender models.

Key Words

resource significance; cost modelling; control; feedback; programme

INTRODUCTION

The success of any construction venture relies on the organisation, management and control of resources. This, in turn, relies on the ability of the various parties to communicate effectively at the inter- and intra-organisational level. The communication process suffers without the requisite data to back it up.

* *Department of Civil Engineering, University of Dundee, Dundee DD1 4HN, Scotland.*

Data density, a term to denote volume and detail of the transmitted data, is probably at its highest from detailed design through to completion of construction. During this time data pertaining to cost and time is usually transmitted in very small packets, typically bill (work) items or similar material based measurements. These work items generally represent the bottom level of the work breakdown structure at the client/contractor interface. Developments in Information Technology (IT) have in many respects only served to promote the level of detail. In the race to computerise, IT developers have found many more ways of analysing and splitting these small packets of information without ever really questioning their suitability for the functions to which they are put.

This paper concentrates on the estimating, planning and monitoring functions in construction. In the next section of the paper, the authors demonstrate the need to rethink the basis upon which construction participants model the resources employed in construction projects and consequently the basis upon which databases are maintained. The level of detail at which data is processed is called into question. Ultimately cost and time data must be collected, analysed and acted upon at the site level, economically and quickly. Furthermore, the lessons of one project are important when considering future work and therefore feedback in a suitable format is required.

The authors then go on to examine resource significant modelling. Pareto's 80/20 rule forms the basis for the identification of the important work items for individual projects or categories of projects, whether it is in terms of cost (cost significant items) or resource content (resource significant items). The cost and resource significant items number approximately 20% of the number of items in traditional cost models and yet they contain around 80% of project value. Resource significant items are packaged to represent the work content of site operations or activities. These resource significant work packages are formed into standard models of cost and time for certain categories of projects. These models are offered as a basis upon which IT can advance the ability of estimators, planners, surveyors and construction managers to effectively control resources from inception to completion of a project, and maintain the knowledge gained on one project for application to the next. The processes described can be applied to repetitive and non-repetitive contracts alike.

DATA STRUCTURES IN CONSTRUCTION

The construction process passes through a number of stages from inception through to completion on site. At each stage, processes will be initiated which will use a variety of cost and time data formats. In general, the level of detail of data, and the models to which it is applied, increases as the design process progresses. Also, manipulation of data, and its structure, between the various estimating and planning processes and functions is high (Zakieh, 1991).

Classical Control Loop

Figure 1 shows a classical control loop for cost and time on a construction project (McGowan et al, 1992). Any IT solution needs to facilitate the feedback of factual site data in order to satisfy the control function (Randall, 1991). Equally, knowledge gained on one project can aid future estimating and planning functions (Mair, 1991). To make use of this knowledge, data must flow to a central historical database.

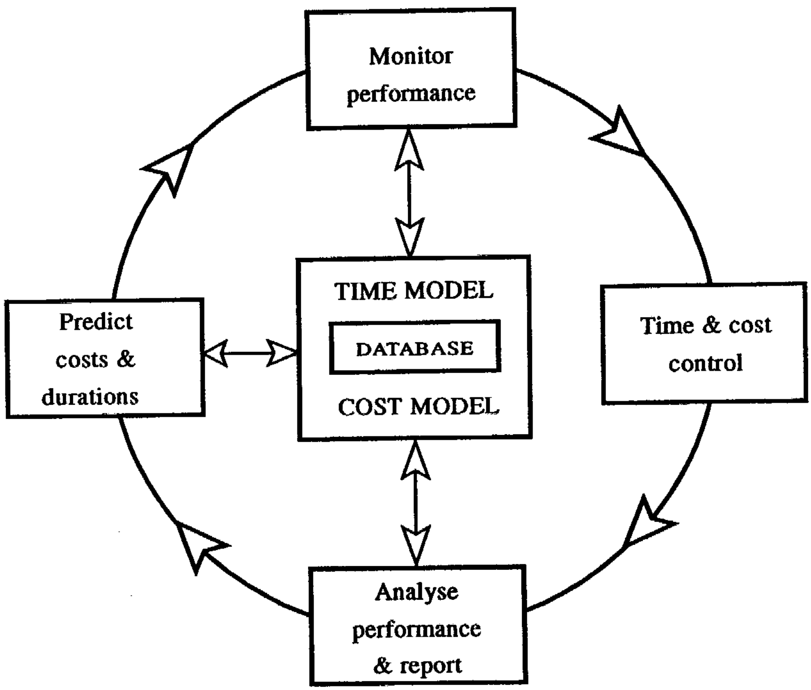

Figure 1. Classical Control Loop (Derived from Asif, 1988)

Standard Models

Standard models need a set of rules for specifying the form and content of the model items. Standardisation facilitates communication and the comparison of specific models and their items with suitable historical or other sources. However, site data is collected and analysed at a coarser level than that with which estimates of cost are traditionally prepared. It tends to equate more with the level of detail of a programme.

Measured work items are generally material led. The measurement rules and the work items are arranged into trades (representing skills) or work sections (representing subcontracting patterns) (CCPI, 1987). However, standard elements, which are used for design stage estimates, relate to the functional characteristics of buildings rather than the specific construction solution and are thus unsuitable for detailed estimating and planning.

Planning is carried out at a lower level of detail than the work item, possibly at sub element or work section level (CCPI, 1987). The criterion for deciding the level of detail of the programme are generally arbitrary or, at best, organisation specific. Often the particular circumstances of the project will dictate the programme format.

Cost and Time Integration

In construction, cost and time are integrated by their nature (Barnes, 1971). Planning and estimating decisions are linked through productivity, quantity and other factors. However, there is a conflict between cost models prepared on the basis of numerous material led items and a plan which is based upon operations and activities. Despite the need for integration of cost and time, where attempts have been made to do so in the past they have generally failed. Reasons include the perceived inflexibility of imposed planning structures (McGowan et al, 1992). Operational bills (Skoyles, 1965) did not address these criticisms and failed to gain widespread support from industry.

Feedback

We need to feed relevant data back to a database (Figure 1) so that we can place confidence in future cost and time predictions. Feedback is often ad hoc and qualitative, whereas Randall (1992) notes that gang composition and time, locational and other characteristics are necessary to maintain a coherent database. The volume and structure of the data which is fed back is dictated by the economics and realities of the construction site, and yet we continue to prepare estimates using databases of productivities which cannot be verified, and all in the name of accuracy.

Generic Model

A generic model for use throughout the prediction, analysis, control and feedback functions is required and yet there appears to be an imbalance between the level of detail necessary to produce estimates and programmes and between the prediction and site control functions. Equally, standard formats tend to be inflexible in planning terms.

Accuracy Versus Level of Detail

It is generally acknowledged that the accuracy of an estimate increases with the progress of design (Mair, 1991). A relatively small increase in the level of detail of information can create a large increase in the reliability of the estimate (Vergera and Boyer, 1974) , but as the level of detail increases, reliability increases at a decreasing rate.

As the design process develops the level of information available increases. Early stage methods of prediction reflect the limited information available and concentrate on simple parametric models. As design develops the detail with which cost and time models are produced increases. At the tender stage and beyond, the cost models are prepared in a variety of formats (*eg* bills of quantities). Time models are prepared using a variety of logical and graphical techniques.

Researchers (Barnes, 1971 and Saket, 1986) 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 (*eg*, form cavity, form arris) to which productivities cannot be assigned with confidence.

Bennett and Barnes (1979) 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. Saket (1986) 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. It is clear that there is considerable scope for a reduction in the level of detail of traditional models.

Models for the Control Process

Once construction starts, the level of detail with which data is processed tends to fall. Control centres tend to be at a coarser level more akin to site operations or activities than work items.

The multitude and form of work items mitigates against their use as both estimating packages and planning and control packages (Figure 2). Many work items relate to tasks for which it is impossible to monitor the actual cost, duration or productivity. Also, the sheer number of items precludes economic, swift or accurate collection of data. As a result, the work items are manipulated into packages suitable for monitoring and control purposes.

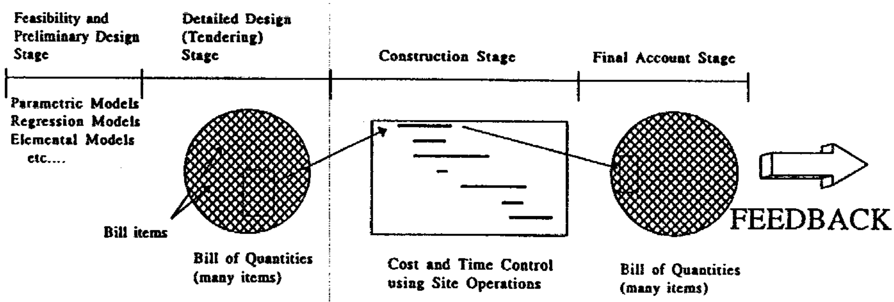

Figure 2. Conventional Estimating and Control Process (Source: Zakieh, 1991)

Construction as a Series of Operations

Construction costs are a function of the labour and plant content of a project, as well as the material content. Labour and plant productivities are sensitive to a number of factors, both controllable (*eg,* materials management) and uncontrollable (*eg,* weather). Consequently, productivity predictions remain difficult to estimate to a high degree of accuracy.

On site, labour and plant resources are generally formed into gangs which in turn execute work in a series of operations using a number of material types and/or grades. It is these operations (or work packages) which often form the basis of the control system.

Towards a Rationale

A picture emerges of the need for generic models which contain a small proportion of high value, or significant, work packages which relate to site operations. Estimating and planning data sets can then be integrated with control data sets. If work packages relate to site operations, participants in the construction process can communicate and process data effectively at all stages, using IT as the interface.

Significant items can be identified on an ad hoc or arbitrary basis but this may result in a unique data structure for each project. We cannot maintain an effective rational database on such a basis.

There is a clear need for a standardised data structure which we can use in conjunction with IT to access and present data to the various management levels, and in particular to site. This will facilitate the interface between site and the various site control processes and enable the collection of data in a format which will be suitable for the pre-contract estimating and planning functions.

SIGNIFICANCE MODELLING

From the foregoing, the ideal model must be sufficiently simple for use in effective control, yet sufficiently accurate to generate confidence in the predictions of cost and duration. At its heart must be a set of work packages which relate to realistic site operations and which are capable of site measurement for monitoring, control and feedback. They must lie within a standard framework, yet provide sufficient flexibility for the contractor to identify and implement the optimum construction solution. There must be a close correspondence between the elements of the cost model and the activities in the programme to provide the link between cost and time control.

The 80/20 Rule

It is well known that approximately 80% of the cost of a project is contained in approximately 20% of the work items in a bill of quantities. These cost significant items are those items which have a value greater than or equal to the mean item value. Saket (1986) confirmed that estimating accuracy can be maintained at or improved upon current levels by concentrating on the cost significant items. The other insignificant costs are represented as a constant proportion of the significant costs. Thus:

$$V_T = \frac{V_{CSI}}{MF} \tag{1}$$

Where:

V_T	=	Total project value
V_{CSI}	=	Value of cost significant items
MF	=	Model factor (approximately 0.80)

Cost Modelling

Further work by Asif (1988) showed that projects could be categorised in such a way that the same cost significant items applied to each project within the category. In this manner, Asif was able to produce a standard model for specific project categories (*eg*, roads (flexible construction)) whose small number of items contained 80% of a project's value. For each project within the category he used the same model factor to convert the value of the significant items to the total value. These simplified models can be used to predict the cost or value of appropriate projects to a degree of accuracy comparable with more detailed models. In addition, the removal of so many insignificant items focuses attention and increases the time available with which to improve the accuracy of prediction for the remaining items.

Resource Significance Modelling

A model which is applicable to both time and cost must be sensitive to both. The primary link between cost and time is through the labour and plant resources. The determinants of the cost of labour and plant are usually factors in determining the programme for the works (*eg* productivity, gang composition, timing, etc).

Quantity is the major variable factor in determining material cost. It is also a factor in determining labour and plant cost. In conjunction with the other factors, and not in isolation, it determines the programme for the works. A model for cost and time which ignores the inherent interdependency of cost and time is thus an incomplete model.

The philosophy of resource significance has spawned a method of analysis which allows us to identify the work items whose labour, plant and material resources are cost and time significant for a particular project. The 80/20 rule holds true for the individual resources. Within defined categories projects exhibit the same resource significant items.

Once identified, the resource significant items are used to define the work packages comprising the standard resource significant cost and time model, or database.

Work Package Content

Cost significance opened the way for simplification, but there still remained an apparent conflict between the ability to define a model in terms of work packages while retaining enough detail to allow sufficiently accurate estimates to be prepared. It is important to describe a work package so that its cost and duration can be estimated to an adequate level of accuracy.

According to Lanford and McCann (1983), work packages occur at the intersection of the lowest level of detail of the work breakdown structure with the organisational breakdown structure (Figure 3). The work package forms the lowest level of breakdown for:

1) estimating or planning either performance, time required or costs,
2) tracking progress in attaining performance, monitoring time budgets, living within estimated costs, and
3) controlling performance, time and costs.

This coincides with the concept of a generic data structure built around work packages rather than work items.

A work package should be capable of site measurement within a suitable timescale for the available manpower. It should also relate to site operations so that a single measurement yardstick can be applied. A work package is thus only capable of site measurement if it is a separately identifiable portion of work. A single measurable yardstick generally indicates that the work package should relate to a single material type, or a collection of material types which have a single identifying unit of measure (McGowan, 1992). The work package should be measurable in terms of the input from each crew type.

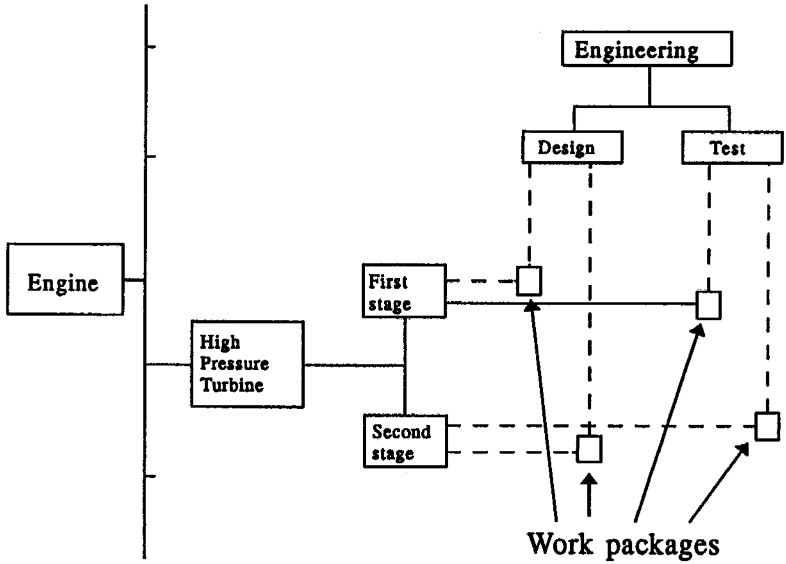

Figure 3. Work Breakdown Structure and Work Packages (Source: Lanford and McCann, 1983)

Describing a Work Package

Work items tend to be created under traditional methods of measurement so that a single productivity or rate can be applied. Changes in factors such as access to the work face or the grade or type of material usually results in the creation of a new work item.

Zakieh (1991) showed that while the cost of an operation (*eg*, steel fixing) may be spread over a number of work items, in many cases there is a strong linear relationship between cost and quantity (Figure 4). He showed that a work package can be developed to represent a realistic site operation while having only one unit rate. The unit rate is invariably the unit rate of the work item with the greatest proportion of total work package quantity. In Table I an example illustrates the power of this approach.

Predominant Productivity

Some operations relate to the same material type (*eg*, fill) but the quantity of new material (*eg*, imported fill) may not represent the total quantity of the work package. We use resource significance to analyse the individual resources of labour, plant and materials. The material content of a work package can then be modelled separately. In this way, the productivity of the operation is defined by the productivity of the largest quantity, the predominant productivity. The work package contains two yardsticks, one for labour and plant productivity and one for material quantity (Table II).

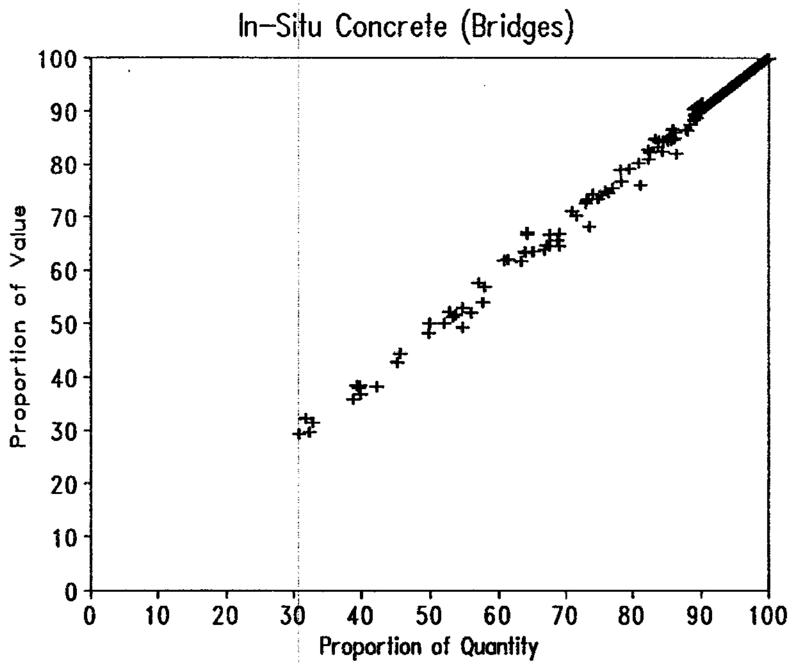

Figure 4. Relationship Between Cost and Quantity (Source: Zakieh, 1991)

This facility allows us to model cost and time data relating to site operations and activities. The work packages are at a level of detail commensurate with that required to collect site data swiftly while being able to place confidence in it.

Table I Pricing a Work Package Using the Unit Rate of the Largest Quantity

BOQ item	Rate	Qty	Value
Mild steel reinforcement in bars of 16mm nominal diameter or less in bars of less than 12m in length	296.00	1.26	372.96
Mild steel reinforcement in bars of 20mm nominal diameter or greater in bars of less than 12m in length	270.00	2.10	567.00
High yield steel reinforcement in bars of 16mm nominal diameter or less in bars of less than 12m in length	316.00	17.20	5435.20
High yield steel reinforcement in bars of 20mm nominal diameter or greater in bars of less than 12m in length	305.00	4.05	1235.25
Actual Value			**7610.41**
Total work package quantity		**24.61**	
Rate of predominant quantity	**316.00**		
Estimated value (24.61 t * £316.00)			**7776.76**
Accuracy			**+2.18%**

Flexibility

The work package forms the last level of detail of the standard model. It is thus the last defined level of detail within the work breakdown structure or any other model format, such as the SfB set of elements. An example work breakdown structure for a reinforced concrete bridge is shown in Figure 5.

Ideally, a direct link between cost model packages and the programme of activities is desired. In practice, the project may dictate changes to the form or content of the programme of activities. Any modelling system which lacks flexibility will ultimately fail to achieve its goals. The work package structure can be changed due to locational reasons or other logic considerations but a link is maintained with the central database. It is a fact that any ideal modelling system must strike a balance between flexibility and the capability of producing data for application to future projects. Work packaging theory and the correct use of the predominant productivity can allow us to ensure that the work packages chosen for particular project categories strike that balance.

Table II Predominant Productivity of a Work Package

<u>BOQ items</u>

	Description	Qty	UoM	Rate	Total
a)	Deposit suitable material around foundations	100	CM	3.46	346.00
b)	Deposit suitable material adjacent to structures excluding around foundations	580	CM	2.92	1693.60
c)	Imported granular material deposited around structural foundations	275	CM	7.69	2114.75
d)	Imported granular material deposited adjacent to structures excluding around foundations	1590	CM	7.10	11289.00
e)	Compaction of fill material around foundations	375	CM	-	-
f)	Compaction of fill material adjacent to structures excluding around foundations	2170	CM	-	-
Total					£15443.35

<u>Estimate using predominant quantity</u>

	Description	Qty	UoM	Rate	Total
	Filling in or around foundations with any material	2545	CM	7.10	18069.50
Accuracy					+17.00%

<u>Estimate using predominant productivity</u>

	Description	Drn	Per	Rate	Qty	Uom	Total
	Filling in or around foundations with any material						
	Labour and plant gang rate and productivity of item d.	0.15	H	19.13	2545	CM	7304.15
	Material	-	-	4.23	1865	CM	7888.95
Total	Cost						15193.10
	Hours						1527.00
Accuracy	Cost						-1.62%
	Hours (Actual total = 1579.6)						-3.32%

Non-repetitive Contracts

Resource significant work packages are formed into standard models for particular project categories. In this way it is possible to maintain a single model factor for application to other projects which fall into the same category in the future. The work packages themselves can also be used as the basis for modelling non-repetitive contracts which do not fit into easily identifiable categories. This is especially true when used as the basis for planning and control packages. Estimates can be prepared from the database of work package productivities and locational and other characteristics, but the model factor, which accounts for the insignificant work items, must be chosen carefully.

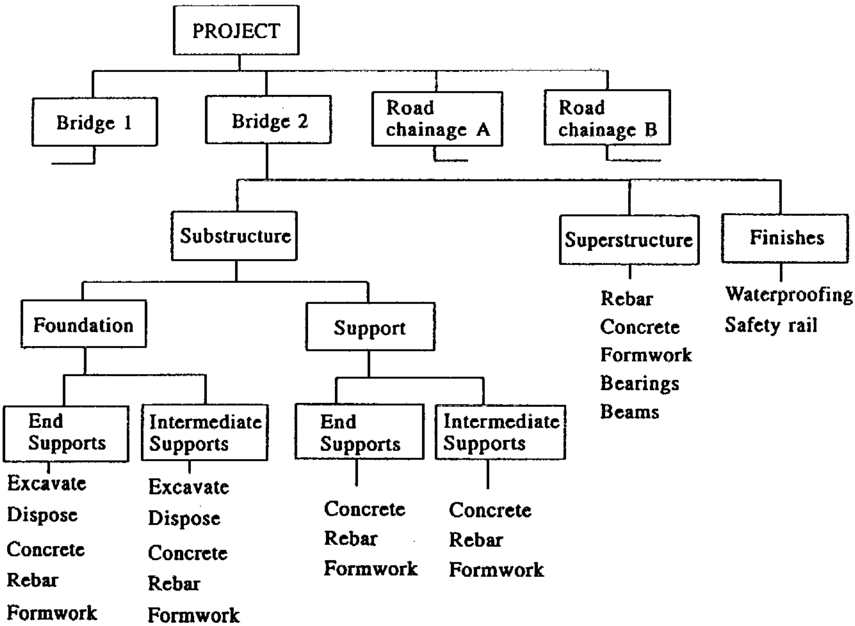

Figure 5. Work Breakdown Structure for Reinforced Concrete Bridge Model

CONCLUSIONS

IT developments seem to proceed at an ever increasing pace. With such powerful tools it is little wonder that fundamental questions regarding the way in which we model cost and time have been bypassed in the race to computerise.

Traditional detailed models of cost and time dictate much of the form and content of IT solutions. The software developer rarely questions the basis of these data structures. Very often the industry is relying on established procedures which have a firm footing in traditional practice. The operational nature of construction and progress in modelling theory indicates that we should now begin to question the whole basis of industry practice in order that IT solutions in the future can best deliver the data in a format suited to the purposes to which it will be put.

Resource significance modelling is offered as a credible basis for future database development around which IT can operate to the benefit of all involved in the construction process. It has been developed to match the organisation, estimating, planning, control and feedback process relating to the resources employed in a construction project. At the core of the resource significant cost and time model for any particular project category is a set of work packages which satisfy the requirements of estimating and planning through to control. Simplified models whose work packages reflect realistic site operations can offer an effective rational basis for the collection, analysis and application of data across the various functions.

Future IT development will only operate to the long term benefit of the industry if we are willing to recognise the need for change in the way we model and use cost and time data. Resource significance modelling is a rational approach to the integration of the various construction processes and functions which utilises the realities of collection and use of cost and time data on the construction site and in the client, consultant or contracting organisation. Resource significance modelling will allow IT to maximise its potential.

References

Asif, M (1988), *Simple generic models for cost-significant estimating of construction project costs.* PhD Thesis, University of Dundee, UK.

Barnes, N M L (1971), *Civil engineering bills of quantities.* CIRIA Research Project No. 98, Dept. of Civil and Structural Engrg., UMIST, UK.

Bennet, J and Barnes, M (1979), Six factors which influence bills: Outline of a theory of measurement. In *Chartered Quantity Surveyor.* Vol. 2, pp 53-56.

CCPI (Co-ordinating Committee for Project Information) (1987), *Co-ordinated project information for building works, a guide with examples.* CCPI, UK.

Lanford, H W and McCann, T M (1983), Effective planning and control of large projects - Using Work Breakdown Structure. In *Long Range Planning.* Vol. 16, 2, pp 38-50.

Mair, A J (1991), *Estimating and control of construction projects using cost significant work packages.* PhD Thesis, University of Dundee, UK.

McGowan, P H, Horner, R M W, Zakieh, R, Jones, D and Thompson, P A (1992), The role of integrated cost and time models in conflict resolution. In *Construction conflict: Management and Resolution* (ed P Fenn and R Gameson). E & FN Spon, London.

McGowan, P H (1992), *Derivation of resource significant cost and time models.* Internal Report CMRU-PH-4-92, Dept. of Civil Engineering, University of Dundee, UK.

Randall, C W (1991), Development of an integrated management control system. In *Proc. first Civil Engrg. Teaching Company Seminar.* Teaching Company Scheme, UK.

Randall, C W (1992), *Private correspondence.* Dept. of Civil Engineering, University of Dundee, UK.

Saket, M M (1986), *Cost-significance applied to estimating and control of construction projects.* PhD Thesis, University of Dundee, UK.

Skoyles, E R (1965), *Introduction to operational bills.* Design Series 32, Building Research Station, UK.

Vergera, A J and Boyer, L T (1974), Probabilistic approach to estimating and cost control. In *ASCE Journal of the Construction Division.* Vol. 100, pp 543-552.

Zakieh, R (1991), *Quantity-Significance and its Application to Construction Project Modelling.* Ph.D. Thesis, University of Dundee, UK.

ACKNOWLEDGEMENT

The work described in this paper has been financed in part by the Science and Engineering Research Council, whose support is gratefully acknowledged.

---

c. 1993, Management of Information Technology for Construction, K. Mathur et al (Eds), World Scientific Publishing Co., Singapore.