Simple computer models of the construction process

Autor(en): **Horner, R. Malcolm W. / McKay, Kenneth J. / Saket, Munther M.**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **53 (1986)**

PDF erstellt am: **26.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-41113

Simple Computer Models of the Construction Process

Modèle informatique simple dans le processus de la construction

Ein einfaches Computermodell für den Bauprozess

R. Malcolm W. HORNER
Head of Department
University of Dundee
Dundee, Scotland, UK

Malcom Horner, born in 1942, obtained his BSc and PhD from University College London. After 11 years in the construction industry, he joined Dundee University in 1977. His research interests embrace all aspects of Construction Management, with special emphasis on labour productivity and project control systems.

Kenneth J. McKAY
Research Student
University of Dundee
Dundee, Scotland, UK

Ken McKay, born in 1963, obtained his BSc in Civil Engineering from the University of Dundee in 1984. He is currently researching into computerised cost models for construction management control.

Munther M. SAKET
Research Student
University of Dundee
Dundee, Scotland, UK

Munther Saket, born in 1959, obtained his BSc in Civil Engineering from Manchester University in 1982 and his MSc in Construction Management from Birmingham University in 1983. He is currently researching into simplified models of the construction process.

SUMMARY

An accurate cost model of the construction process is a pre-requirement for optimising designs and controlling project costs. British bills of quantities are too long and complex to serve this purpose effectively. Our research has shown that on average, 80% of the value of a bill is contained in that 20% of items whose value is greater than the mean. We have therefore been able to derive simple models of the construction process which are as accurate as but far shorter than conventional bills of quantities. Their use drastically reduces the resources needed for cost estimating and project control.

RÉSUMÉ

Un modèle précis des coûts dans le processus de construction est nécessaire afin de réaliser une conception optimale et de contrôler les coûts du projet. En Grande-Bretagne, les bordereaux de prix sont trop longs et complexes pour atteindre ce but efficacement. Notre recherche a démontré qu'en moyenne 80% de la valeur d'un bordereau de prix est englobé dans les 20% des articles ayant une valeur supérieure à la moyenne. Nous avons donc établi des modèles simples pour le processus de construction, aussi précis mais plus rapides que les devis conventionnels. Leur usage réduit considérablement les ressources requises pour l'estimation des frais et le contrôle du projet.

ZUSAMMENFASSUNG

Ein genaues Kostenmodell für die Bauausführung ist eine Voraussetzung für eine optimale Projektierung und die Kostenkontrolle. Die heutigen britischen Leistungsverzeichnisse sind zu detailliert, um dieses Ziel zu erreichen. Umfangreiche Untersuchungen haben gezeigt, dass ungefähr 20% der Leistungspositionen mehr als 80% der Baukosten abdecken. Aufgrund dieser Erkenntnis wurde ein einfaches Modell des Bauprozesses entwickelt, welches mit bedeutend weniger Leistungspositionen auskommt und trotzdem eine ausreichende Genauigkeit bei der Kostenerfassung gewährleistet. Damit konnte der Aufwand für die Kostenkalkulation und die Projektkontrolle erheblich gesenkt werden.

1. INTRODUCTION

Designs cannot be optimised, and costs cannot be controlled, without an accurate model of the construction process. If project costs and durations cannot be predicted, there is no means of evaluating alternative design solutions, and no yardstick against which to measure actual performance. To be effective, models ought to be easy to understand, simple to use, and should provide relevant information quickly.

In the UK the most commonly used model is the bill of quantities (boq), a document frequently containing several thousand items, most of which relate more to the material content of the project than to the method of construction. Such models, even when computerised, make pricing time-consuming and cost or duration control almost impossible. Their use probably stems from confusion between accounting and control systems. The purpose of an accounting system is to monitor profit or loss, and to identify where costs are incurred. It is necessary, therefore, to record the source of every incidence of expenditure. In order to evaluate alternative designs or to effect project control, however, we are interested not in every cost, but only in those items where variances would have a significant effect on the outcome.

For the past two years, the Construction Management Research Unit at Dundee University has been seeking ways of deriving simpler cost models of the construction process which can be used for predicting and controlling project costs and durations. Our work is based on the philosophy that a project can be modelled adequately without incorporating every item in the boq. Instead, it is necessary to consider only a relatively small number of highly priced items which constitute the majority of the cost.

2. IDENTIFICATION AND DISTRIBUTION OF COST-SIGNIFICANT ITEMS

2.1 Identification

It has for long been known (1,2,3) that 80% of the value of a bill of quantities is contained in only 20% of the items. Short of arranging every item in order of value and calculating the cumulative sum, no simple method has been found to identify those which are cost-significant.

Analysis of more than 50 bills of quantities, ranging in value from £10 000 to £2 000 000 and as diverse in character as nurses homes and motorways, has revealed that the cost-significant items are all those whose value is greater than the mean. The mean is simply the total bill value divided by the total number of items, and is easily calculated. The sum of all items identified in this way is consistently greater than 70% and averages 80% of the total bill value. They number between 12% and 26%, and average 19% of the total number of items. Typical results are presented in Table 1.

Project Description	Value V^o (£)	No. of items N^o	V^o/N^o (£)	Sum of all items $>V^o/N^o$ (£)	% of V^o	No. of items $>V^o/N^o$	% of N^o
Factory	54,955	586	94	44,402	81	111	19
Supermarket	564,950	1,324	427	468,824	83	199	15
School Building	230,762	871	265	193,951	84	164	19
Housing Project (20 Units)	196,918	3,756	52	156,911	80	736	20
Bridge	2,160,272	369	5,854	1,801,962	83	75	20
Bypass	1,954,572	469	4,169	1,698,696	87	69	15

Table 1 Identifying cost-significant items from priced bills

The 80/20 rule is ascribed in a different context to the 19th century Italian economist, Vilfred Pareto, who found that 80% of a nation's wealth was vested in 20% of its population. It has since been found to apply to a wide variety of circumstances as different as particle size distribution, stock control, and purchasing policy (4,5). Whether the mean value theorem applies equally widely is the subject of further study.

2.2 Distribution

Previous attempts to characterise the distribution of prices in bills of quantities have proved unsuccessful. Log normal and Pareto distributions have both been tried.

What we have found, however, is that the distribution of the prices of those items whose value is higher than the mean can be closely approximated by a Pareto curve (Fig. 1). This has allowed us to develop a new, more efficient way of predicting project value from a bill of quantities.

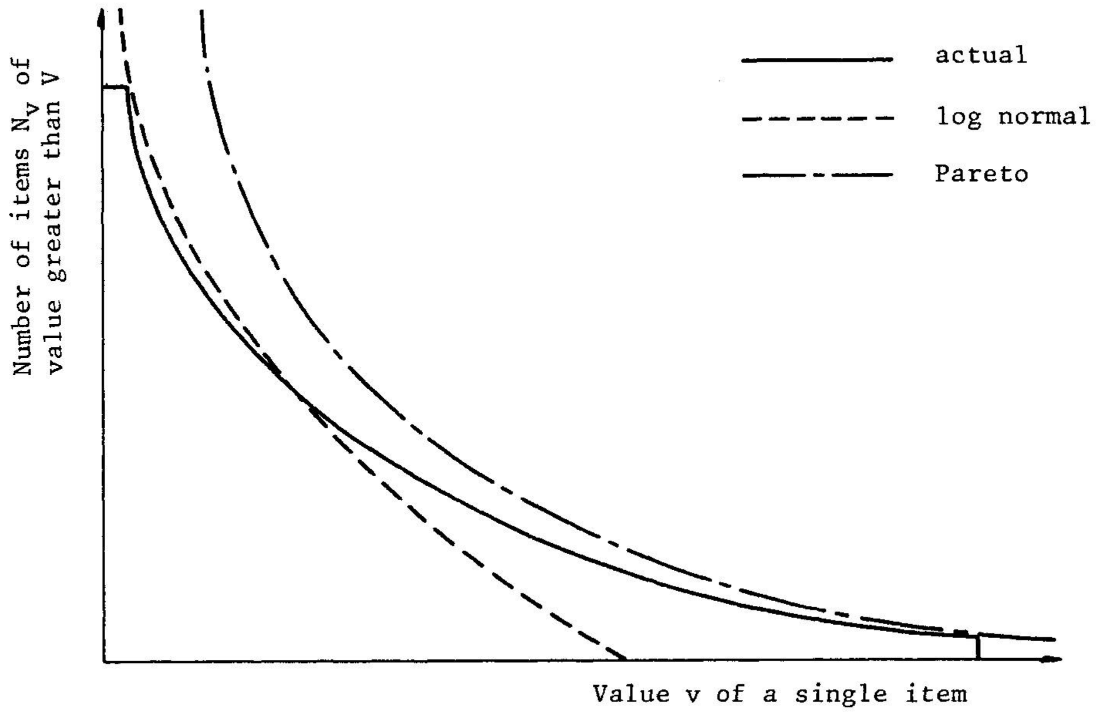

Fig. 1 Log normal and Pareto distribution fitted to bills of quantities

3. ITERATIVE ESTIMATING

3.1 The Pareto distribution

Pareto's first equation is

$$N^{v} = Kv^{-\alpha} \tag{1}$$

where v is an item value
N^v is the number of items having a value greater than v
and K,α are constants.

From our previous discussion however,

$$V^{\bar{v}} \cong 0.8\ V^{o} \tag{2}$$

where $V^{\bar{v}}$ is the sum of all items whose value is greater than the mean, $\bar{v}$, and V^o is the total bill value.

It can be shown that combining Eqns (1) and (2) gives

$$V^o \cong \left\{1.25 \frac{\alpha K}{(\alpha - 1)} N^{o(\alpha-1)}\right\}^{-\alpha} \qquad (3)$$

where N^o is the total number of bill items.

3.2 Solution of the equations

If α, K and N^o in Eqn (3) were all known, V^o, the total bill value could be calculated. Unfortunately, the values of α and K vary from bill to bill. However, it is possible to solve Eqn (2) and a derivative of Eqn (1) using an iterative technique which is outlined below.

1) Guess the total bill value V^o_i.
2) Calculate the resulting (guessed) mean value $\bar{v}_i = \frac{V^o_i}{N^o}$.
3) Identify and price all items in the bill whose value is expected to exceed $\bar{v}_i$.
4) Calculate the sum $V^{\bar{v}i}$ of all items whose value is greater than $\bar{v}_i$.
5) Obtain a second approximation V^o_{i+1} to the total bill value by multiplying $V^{\bar{v}i}$ by 1.25.
6) Repeat steps 2 to 5 until the difference between V^o_i and V^o_{i+1} is acceptably small.

The procedure is easily computerised.

3.3 Results

Bill Number	True value (£)	First approximation (£)	Max. number of items used (% of N^o)	Final iterated value (£)	Final iteration as a % of true value
1	19,788	9,894	27.4	19,832	100.2
		59,364	25.9	19,832	100.2
2	31,349	15,674	22.8	30,484	97.2
		94,047	22.8	30,484	97.2
3	352,823	176,412	19.1	375,460	106.4
		1,058,469	19.1	375,460	106.4
4	23,837	11,918	29.1	22,962	96.3
		71,511	26.8	22,962	96.3
5	11,320	5,660	28.3	11,156	98.5
		33,960	28.3	11,156	98.5
6	43,352	21,676	24.8	44,357	102.3
		130,056	24.2	44,357	102.3
7	76,177	38,088	25.8	78,189	102.6
		228,531	16.9	78,189	102.6
8	47,470	23,735	27.1	47,368	100.2
		142,410	29.2	47,368	100.2
9	1,972,690	986,345	20.9	2,125,380	107.7
		5,918,070	14.9	2,129,810	108.0
10	73,817	36,908	24.3	75,739	102.6
		221,451	23.0	75,739	102.6
11	3,029,960	1,514,980	23.8	3,156,900	104.2
		9,089,880	20.9	3,156,900	104.2
12	54,598	27,299	24.0	54,921	100.6
		163,794	22.5	54,682	100.4

Table 2 Results of iterative estimating on 12 priced bills of quantities

Table 2 shows some typical values for V^o obtained by iterative estimating compared with the value obtained using conventional techniques. We have tried the procedure on over 20 bills, and although the maximum theoretical error is ±12½%, the range of error we have found in practice is only -4% to +8%.

The value of the initial guess is not critical. The procedure works well provided $0.01 < V_i^o/V_o^o < 10$. We have never needed more than 6 iterations to converge on the solution and the number of items we have had to price has always been less than a third of the total.

3.4 Consequences

We are confident that it is possible to predict consistently the total value of a bill of quantities whilst pricing not more than 30% of the items. Since the accuracy of predicting the value of a bill of quantities by traditional means is ±12% (6,7), the error induced by iterative estimating is not unacceptably large. Moreover, because with our method there are so few items to price, it is not unreasonable to expect that the pricing accuracy of each individual item will improve.

Thus, the Engineer is provided with a simple model which can be used both to evaluate the merits of alternative designs, and to control the subsequent progress of the project.

Perhaps of even greater importance, however, the philosophy causes us to question the very nature of bills of quantities. If only 30% of the items are needed to form the basis of an adequate cost model, why cannot their length be reduced? This question is addressed in section 5.

4. SIMPLE COST MODELS

4.1 Background

It is clear that the principle of cost-significance lends itself to the design of simple project control systems. A local steel fabrication company agreed to collaborate with us in the production of a suite of micro-computer programs which integrates the functions of estimating and controlling durations, cost, productivities and material wastage. The study was limited, in the first instance, to the fabrication and erection of farm buildings whose value ranged between £6000 and £70 000.

4.2 Derivation of the model

Bills of quantities for farm buildings typically contained about 130 items. Analysis of the tenders for some 40 jobs spanning 4 years of operation revealed that in all the bills only 34 items were cost-significant and that their contribution to the bill value ranged between 82% and 92%. Thus by pricing only the cost-significant items (csi) and dividing their sum by 0.87, the total bill value could be predicted to an accuracy of ±5%.

Further investigation of the sensitivity of the model to the omission of certain items indicated that grouping the buildings into 3 categories, large (> 1300 m²) floor area), ordinary (< 1300 m²) and insulated, allowed the identification of 3 similar but distinct cost models, none containing more than 24 items, yet each with a predictive accuracy of better than 5%. The cost-significant items for each group are shown in Table 3.

The resulting cost models are:

large buildings: $V^o = \frac{\Sigma csi}{0.834}$

ordinary buildings: $V^o = \frac{\Sigma csi}{0.750}$

insulated buildings: $V^o = \frac{\Sigma csi}{0.852}$

Item	Ordinary jobs	Large area jobs	Insulated jobs
Rafters	*	*	*
Rafter fabrication	*	*	*
Columns	*	*	*
Column fabrication	*	*	*
Gable columns	*	*	*
Gable column fabrication	*	*	*
Wind/side braces	*	*	*
Eaves/brace ties	*		*
Brace/ties fabrication	*	*	*
Galvanised eaves beams		*	*
Doors			*
Gable rails	*	*	*
Side rails		*	
Purlins	*	*	*
Paint	*	*	*
Painting	*	*	*
Roof cladding	*	*	*
Side cladding	*	*	*
Gable cladding	*	*	*
Insulation			*
Erection	*	*	*
Crane	*	*	*
Travel	*		
Journeys	*	*	*
Delivery	*	*	*
Calculations	*	*	*
Total number of items	22	22	24

Table 3 Components of cost models

4.3 Software design

For the purposes of control, it was decided that the output from the system should include:

- list of csi's
- actual and predicted cost of each csi, both total and per unit quantity, broken down into labour and material
- actual and predicted total cost
- actual and predicted profit or loss
- actual and predicted labour productivity on each csi
- actual and predicted project duration
- quantity of materials required
- quantity of materials used
- record of the multiplier required to convert the sum of costs actually incurred in cost-significant items into total project costs

This would require the following inputs:

- identification of the model to be used
- unit hourly labour costs and productivities (obtained from the rolling mean of previously completed jobs)
- unit material costs
- wastage factor to be applied
- quantities of materials received and invoiced costs
- amount of labour used and hourly cost

- predicted cost of transport, craneage and calculations
- all other undifferentiated (not cost-significant) costs
- multiplier to be applied to cost-significant activities (derived from the rolling mean of historical data)

In addition, the software was designed to compute most of the quantities automatically from leading dimensions forming part of the data input.

4.4 Discussion

The system is extremely easy to operate. Computer users are confronted with a series of unambiguous, simple questions to answer. Engineers have the option of using the average values of the historical data stored in the computer memory, or of using their own data sources. The time required to produce a tender is about 10 minutes, compared with the four hours previously required. The effort needed to collect progress data is expected to reduce by 70%, and a significant improvement in accuracy is anticipated. Financial accounting is now accomplished under only 25 cost headings - the csi's plus one "all other costs" category. At the same time management has available at the press of a button all the up-to-date information needed to control the outcome of the project.

5. GENERALISED COST MODELS FOR INTEGRATED CONTROL SYSTEMS

5.1 Work packaging

The derivation of a simple cost model for a limited range of similar projects is fairly straightforward. To develop a procedure which can be applied to any project is more difficult. However, the technique of iterative estimating provides the means of identifying cost-significant items in a bill of quantities without pricing more than 30% of the bill. It has proved possible to collect together items similar in character to produce meaningful "cost-significant work packages" which correspond much more closely to site operations than do the individual bill items. These work packages can themselves be combined to produce cost-significant activities which correspond closely to activities on conventional critical path networks.

Preliminary guidelines for defining work packages have been evolved. A package must represent an identifiable site operation which involves no more than one trade, or which can be described in a way that positively discriminates against the inclusion of bill items that are not cost-significant. It must incorporate a defined quantity of work, to which one productivity figure can be applied, and which can be accomplished without interruption. A cost-significant activity combines work packages involving the same trade into a meaningful, uninterrupted site operation. An example of the item - work package - activity hierarchy is shown in Table 4. It appears so far that the number of work packages is likely to be significantly less than 5% of the number of bill items.

5.2 Time control

Although the relationship between the value of the cost-significant items and the total bill value is now well established, the relationship between total project duration and the duration of the cost-significant activities is less clear.

Pioneering work by Robertson (8) suggests that critical path networks based solely on cost-significant activities yield project durations 80% as long as those derived by traditional means. This is an area where considerable further study is required.

Cost-significant activity	Cost-significant work package	Cost-significant items
1. Earthworks	1.1 Excavation	1.1.1 Excavate unsuitable material in cuttings and excavations in bulk in the open
		1.1.2 Excavate rock in structural foundations 0.3m deep
	1.2 Disposal of material	1.2.1 Disposal of unsuitable materials in tips off site
	1.3 Imported fill	1.3.1 Imported granular fill and deposition adjacent to structures excluding around structural foundations
		1.3.2 Imported crushed rock and deposition adjacent to structures excluding around structural foundations
	1.4 Soft spots and other voids	1.4.1 Filling of soft spots and other voids below structural foundation with concrete (grade 22.5/20)

Table 4 Example of project breakdown levels - bridge project

5.3 Integration of time and cost control

The ability to define cost-significant items simply, to predict project costs and durations from them, and to group them into operational packages provides an exciting opportunity to simplify the model of the construction process. If the same hierarchical model can be used to estimate both costs and durations, then the amount of effort required to predict project outcome can be reduced by some 80%. This is a considerable advantage, not only when comparing alternative design solutions, but also when implementing data collection systems for project control. An improvement in accuracy and effectiveness can be anticipated, since the system should both be easier to use and produce useful results earlier.

5.4 Consequences for bills of quantities

Work is now proceeding to determine whether or not rules can be derived which would allow cost-significant work packages to form the basis of bills of quantities. Two major questions arise.

1) Can projects be classified in such a way that cost-significant work packages can be defined without recourse to the list of several thousand items demanded by current UK standard methods of measurement?

2) If so, can variations be priced fairly, and can the value of the final account be calculated accurately?

In view of the conventional European and American practice of producing short bills of quantities which successfully fulfill all the roles of their British counterpart, the answer to both questions must emphatically be "yes".

6. CONCLUSIONS

1. Conventional UK bills of quantities are lengthy and complex documents ill suited to serve as the basis of project control systems.
2. Cost-significant items in bills of quantities are all those whose value is greater than the mean. Their sum is approximately 80% of the total

bill value, and they number about 20% of the total number of items.

3. The distribution of cost-significant items is closely approximated by a Pareto curve.
4. Combination of conclusions 2 and 3 leads to a system of iterative estimating which requires less than 30% of the effort of conventional procedures, yet which produces an acceptably accurate prediction of total bill value.
5. For jobs of a similar nature, the principle of cost-significance can be used to derive simple models which successfully predict both project costs and durations, and which can form the basis of effective project control systems.
6. In the general case, it is possible to conceive guidelines for consistently defining cost-significant work packages which are much more closely related to site operations than are bill items.
7. It seems likely that the principle of cost-significance could be applied to the derivation of a new standard method of measurement which would generate bills of quantities similar in length and complexity to those commonly used in Europe and America.

ACKNOWLEDGEMENTS

The financial support of the Science and Engineering Research Council of Great Britain and of Reekie Engineering Ltd, Forfar, is gratefully acknowledged.

REFERENCES

1. BARNES, N M L and THOMPSON, P A, Civil Engineering Bills of Quantities. CIRIA report No 34, London, 1971.
2. MOYLES, B F, An Analysis of the Contractor's Estimating Process. MSc thesis, Loughborough University of Technology, 1973.
3. SHEREEF, H A, Measurement and Control of Labour Productivity on Construction Sites. MSc thesis, University of Dundee, 1981.
4. DAND, R and FARMER, D, Purchasing in the Construction Industry. General Press, London, 1970.
5. JOHANNSON, H and PAGE, G T, International Dictionary of Management. Kogan Page, London, 1975.
6. HARRIS, F and McCAFFER, R, Modern Construction Management. Crosby Lockwood Staples, London, 1977.
7. BENNETT, J, Construction Cost Data Base. Second Annual Report, University of Reading, Department of Construction Management, 1980.
8. ROBERTSON, M P, Cost Significance and Time Control. Honours Dissertation, Department of Civil Engineering, University of Dundee, 1985.