Pricing and Controlling Construction Projects Using the Significant Philosophy

التسعير ومراقبة التكلفة باستخدام نظرية الرزم الأكثر أهمية

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Received: (19/3/2001), Accepted: (17/12/2002)

Abstract

Recent research has demonstrated the feasibility of identifying, within any category of project, a small number of cost significant work packages whose value represent a consistently high proportion of the total bill value. Using the allied principle of quantity significance, it proved possible to build simple models, which could predict both the cost and the duration of a project. In the course of that work, a surprisingly linear relationship between value and quantity was noted. This paper reports the background to and consequences of that finding. Quantity-significant work packages are formed by aggregating those items within a trade for which a linear regression of value against quantity yields a correlation coefficient greater than 0.99 and an intercept insignificantly different from zero. The price of packages formed in this way can be determined simply by applying to all the items within the package the rate associated with the largest quantity, the so-called "characteristic item". Application of the concepts of quantity-significance and characteristic items is expected to lead to simpler estimating and more effective control procedures, because there is no longer any need to allocate cost and resources to each individual item contributing to a work package.

Keywords: *Cost estimate, cost control, significance, cost modeling*

ملخص

أثبتت الأبحاث الحديثة إمكانية تحديد عدد من الرزم الأكثر أهمية في أي مشروع والتي تمثل قيمتها نسبة ثابتة من التكلفة الكلية للمشروع. أن استخدام نظرية الكميات المميزة أثبت إمكانية عمل نماذج بسيطة تمكن من تقدير الكلفة والفترة الزمنية للمشروع، وقد لوحظ أن هناك علاقة خطية مدهشة بين التكلفة والكمية. يقدم هذا البحث خلفية أثر هذه النتائج . لقد جمعت الرزم الأكثر تميزاً من عدة مشاريع ومعامل الارتباط ما بين الكمية والتكلفة كان بنسبة تزيد على ٩٩% ، كما يمكن تحديد أسعار الرزم بضرب سعر الوحدة الأكثر كمية بالكميات الكلية للرزم. إن استخدام هذه الطريقة يمكن من حساب الكلفة ويسهل مراقبة المشروع دون الحاجة لتوزيع الموارد على كل بند من بنود الاتفاقية.

Introduction

The research in the Construction Management Research Unit (CMRU) at Dundee University has shown that about 80 % of the value of measured items in a traditional Bill of Quantities, which are used in civil engineering projects, is contained within 20% of the items [2]. These items are called "Cost Significant Items". Each item has a value greater than or equal to the mean item value. This finding led to the development of simple cost models that can be used for estimating the contract cost. An estimate of the total cost of the contract is obtained by dividing the value of the significant work-packages by the cost model factor. The model factor is the ratio of the value of the significant work-packages to the total value of the contract. Work-packages may vary in size, but must contain measurable and controllable units of work to be performed. Therefore, a project could be planned, estimated, scheduled and controlled using work-packages.

In civil engineering and building projects, a major proportion of the cost is contained in a small proportion of the work items. It is well known that about 80% of the value of a project is contained within about 20% of the number of items in a bill of quantities [1-3],[5],[8-11],[16]. This is known as the 80/20 rule. There is a growing awareness that estimating efficiency and accuracy can be improved by focusing attention on the small number of “cost-significant’ items which represent the majority of the cost [4], [11], [13]. More recent research has shown how the 80/20 rule can be applied to the development of new, unconventional ways of estimating and controlling the cost of construction projects. One important result has been the discovery that those bill items whose value is greater than the mean consistently account for 80% of the project value, but represent only 20% of the total number [7]. This finding has allowed the development of two important techniques: iterative estimating, whose use allows the value of a bill of quantities to be predicated to an accuracy of ±5% without pricing more than 30% of the items in Bill of quantities, and cost -significant models which can be used both to estimate and to control construction projects, yet which contain only 10-20% of the items in a conventional bill of quantities [14]. The cost models were developed by categorizing projects in such away that the cost-significant items recurred significant in all bills of quantities within one project category. Using some of the techniques described in this paper, it is possible to aggregate cost significant items into cost-significant work packages which represent a consistent and high (close to 80%) proportion of the total value of any project in the same category. The ratio of the value of the cost-significant work packages to the total project value is known as the cost model factor. The total value of a project can therefore be determined by pricing the relevant cost-significant work packages and applying the appropriate cost model factor which accounts for the value of the non-cost-significant items and work packages [2].

A natural development of this work was to determine whether or not the new models could be used to estimate and control project duration as well as costs. Since, for any work package:

Cost = Quantity x Rate,

It seemed possible that a link might be forged through quantities. Accordingly, a comprehensive analysis of the quantities and rates in bills of quantities was undertaken. The resulting integrated cost and time model for reinforced concrete bridges has been reported elsewhere [12].

During the analysis, which is described in this paper, we were struck by the notion that the total value of some categories of work, such as concrete or formwork, was dominated by a few items of large quantity. We were also struck by the large number of items of smaller quantities to which were applied a wide variety of rates. The variables, which appeared to effect the estimator’s choice of rate, were material type; size; location; orientation; and units of measurement.

We hypothesized that much effort went into estimating the rates associated with this plethora of bill items representing relatively small quantities of work, and that if a way could be found of safely “lumping’ them together with larger quantity items, considerable gains in estimating efficiency might be achieved without compromising the accuracy. This paper describes the results of the investigations and the refinement of previous approaches to estimating and controlling construction costs.

Data Description

The study was limited to two quite different categories of project: reinforced concrete bridges and steel-framed supermarkets. The reinforced concrete bridges (public sector projects) have been prepared using the Standard Method of Measurement for Road and Bridge works [6], while the steel framed supermarkets (private sector) have been prepared using the Standard Method of Measurement for Building Works [15]. All projects were constructed in the United Kingdom (UK). The data used in developing and testing the models consist of twenty bills of quantities for reinforced concrete bridges and fourteen bills of quantities for steel-framed supermarkets. Each bill of quantity consists of tens of work packages.

Distribution of Prices and Quantities

In any analysis of quantities, it was clearly going to be necessary in the first instance to group together bill items for similar types of work measured in the same units. For this reason, bills were analyzed on a trade by trade basis. Figures 1 and 2 show the plots of cumulative quantities and cumulative value versus cumulative number of items plotted in descending order of value for in situ concrete in twenty reinforced concrete bridges. Table 1 shows a typical set of data from which they were derived.

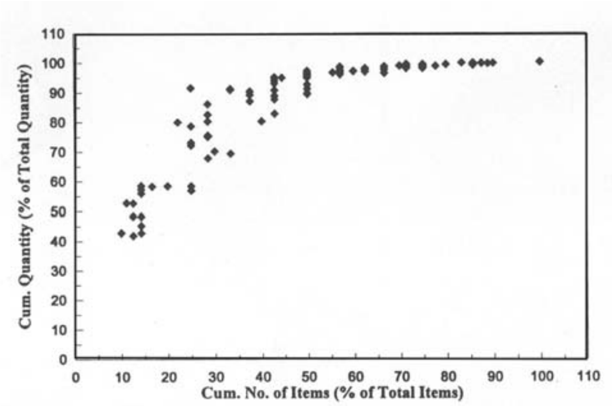


Figure 1: Cum. quantity vs. cum. no. of items (in situe concrete)

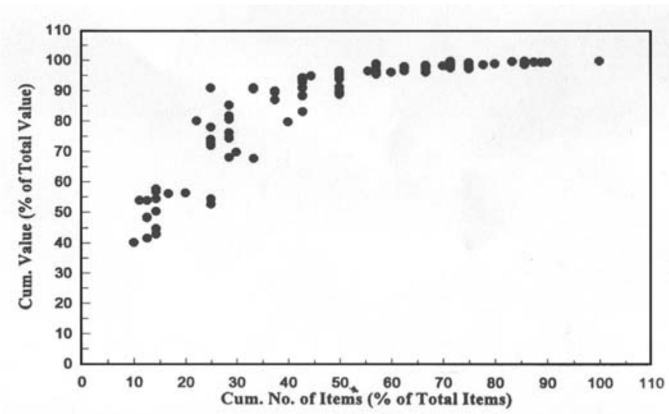


Figure 2 : Cum. value vs. cum. no. of items (in situe concrete)

Table 1: Cumulative value, quantity and number of items for one in situ concrete bridge project.

Item No	Quantity (m^3)	Rate (£)	Cumulative Quantity (m^3)	Cumulative Value (£)	% Total Numbers of items	% Total Quantity	% Total Value
1	468	57.84	468	27069.12	10	40.84	39.93
2	284	54.25	752	42476.12	20	65.62	62.65
3	187	60.75	939	53836.37	**30**	**81.94**	**79.41**
4	59	57.65	998	57247.72	40	87.09	84.42
5	51	60.75	1049	60225.97	50	91.54	88.99
6	48	67.48	1097	63575.01	60	95.72	93.77
7	29	91.75	1126	66235.67	70	98.25	97.70
8	13	82.80	1139	67312.16	80	99.39	99.28
9	4	73.15	1143	67604.76	90	99.74	99.71
10	3	64.54	1146	67798.47	100	100	100

It is immediately clear from table 1 that 30% of the items account for about 80% of the value and about 80% of the quantity. Moreover, the "quantity significant" items (qsis) for any trade may be simply defined as those whose quantity is greater than 1146/10= 114.6m^3 (see Table 1). Items whose quantity is greater than 114.6m^3 account for 81.94% of the total concrete quantity. They also account for 79.41% of the total value of concrete. The stability of the value, quantity and numbers of quantity significant items in 20 bridge bills is shown in Table 2.

Table 2: Stability of quantity significant items for concrete in reinforced concrete bridges.

Bill No.	Total Quantile	% No. Of Items	% Total Quantile	% Total Value
1	3466	25	78.17	78.12
2	1166	29	82.84	83.31
3	673	29	75.33	74.72
4	812	29	82.51	81.95
5	1961	25	87.05	87.22
6	562	25	73.13	72.88
7	524	33	91.22	91.14
8	1095	29	75.07	76.34
9	1076	30	80.30	79.99
10	1278	25	91.55	91.09

… Continue table (2)

Bill No.	Total Quantile	% No. Of Items	% Total Quantile	% Total Value
11	617	25	78.12	76.78
12	339	33	84.52	87.53
13	2029	33	79.94	80.19
14	576	29	85.93	85.48
15	1540	29	80.26	80.71
16	1733	29	75.48	74.48
17	1350	25	89.24	91.38
18	1492	25	83.42	81.63
19	1097	25	89.24	89.68
20	1146	30	81.94	79.41

Table 3: Stability of quantity significant items for various work types.

Type of project Trade			The contribution of qsis to the total quantity and value of all items	
Bridges			**Mean (%)**	**Standard deviation (%)**
	Form work	% of total number	30.75	1.74
		% of total quantity	80.11	6.07
		% of total value	81.17	5.32
	Concrete	% of total number	31.44	5.67
		% of total quantity	82.26	5.54
		% of total value	82.20	5.92
	Bar	% of total number	31.84	3.92
	Reinforcement	% of total quantity	76.89	4.76
		% of total value	75.48	5.03
Supermarkets				
	Formwork	% of total number	22.75	5.28
		% of total quantity	86.53	3.89
		% of total value	83.48	5.99
	Concrete	% of total number	24.50	4.77
		% of total quantity	82.55	5.33
		% of total value	82.20	4.65
	Bar	%of total number	28.04	7.07
	Reinforcement	% of total quantity	79.18	5.09
		% of total value	78.56	5.47

… Continue table (3)

Type of project Trade			**The contribution of qsis to the total quantity and value of all items**	
Bridges			**Mean (%)**	**Standard deviation (%)**
	Brick and block work	% of total number	24.32	2.92
		% of total quantity	80.43	3.29
		% of total value	79.01	4.35
	Steelwork	% of total number	28.65	3.46
		% of total quantity	73.74	4.84
		% of total value	72.80	5.13

The results in Table 3 shows that for concrete, on average, the quantity represented by these items is 82.26% of the total quantity with a standard deviation of 5.54% and the value of these items is 82.20% of the total value with a standard deviation of 5.92%. The results for other work types in both reinforced concrete bridges and steel framed supermarkets are also shown in Table 3.

Relationship between Quantity and Value

Of even greater interest was the relationship between percentage cumulative quantity and percentage cumulative value. The results for all twenty reinforced concrete bridges are shown in Figure 3.

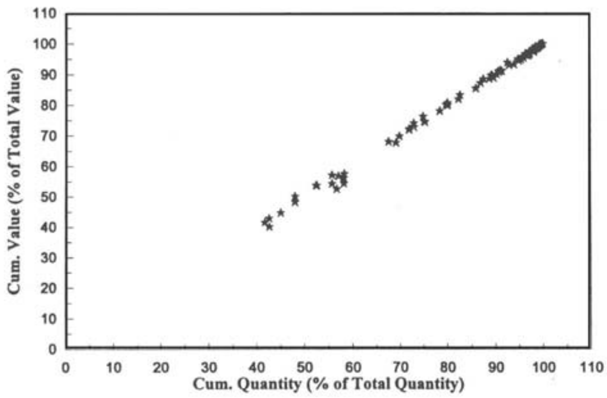
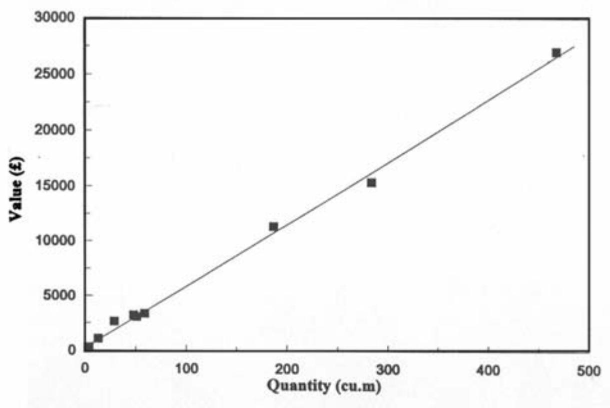


Figure 3: Cum. value vs. cum. quantity (in situe concrete)

The linearity is striking. The coefficient of correlation from a linear regression analysis was 0.993, representing a greater than 99% confidence in the linearity of the relationship. Not only is the relationship between cumulative quantity and cumulative value linear, but the slope of the line is 45°. This means that any marginal increase in quantity (by adding the quantity of the next item) causes a similar marginal increase in value, at least for the large quantity items. In other words, the unit rates of the larger quantity items were insignificantly different, one from another. Although the rates, for smaller quantity items were not necessarily similar, the effect of any differences was over shadowed by the weight of the larger quantity items. This relationship was immediately apparent for three trades in both bridge and supermarket projects: in situ concrete, bar reinforcement and formwork, and for structural steel work in supermarkets.

The relationship between the percentage cumulative quantities and values of items automatically means that the relationship between the quantities and values of these items is also close to linear. This is illustrated in Figure 4 for the in situ concrete items listed in Table 1.



Figur 4: Value vs. quantity for in situe concrete data in Table 1

In this Figure, the coefficient of correlation was better than 0.99 and the *t*-test revealed that the intercept of the best-fit line was not significantly different from zero.

None-Conforming Work Types

Not all work types immediately exhibited this linear relationship. For example, Figure 5 shows the graph of value versus quantity for brick and block work in supermarkets. At first sight, there appears to be no correlation.

However, when the items are measured in cubic meters rather than square meters (Figure 6), it is possible to distinguish between three categories of brick and block items. Atypical example of block work data is provided in Table 4.

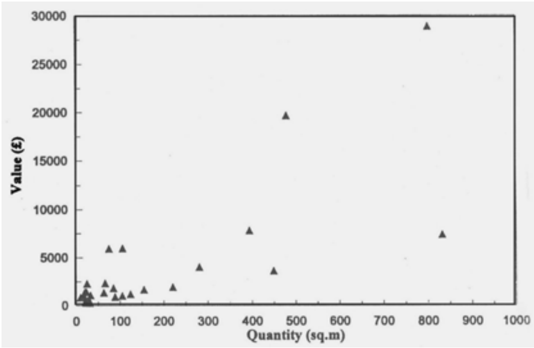


Figure 5: Value vs. quantity of brick and blockwork in supermarkets

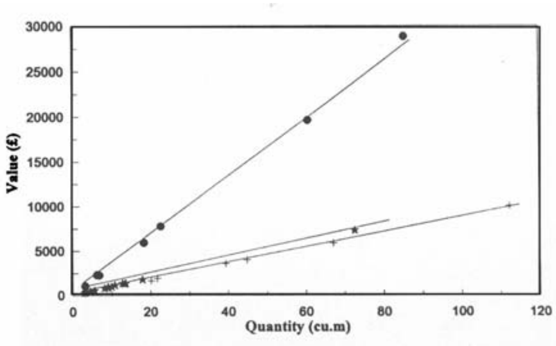


Figure 6: Value vs quantity, measured in m^3 (brick and blockwork in supermarkets)

Table 4: Quantity versus value for brick and block work in supermarkets (dense concrete blocks)

Item	Description	Quantile (m^3)	Old unit Rate(£/m^2)	New rate (£ /m^3)	Value (£)
Outer Walls					
	440 X 215mm fair faced paint Grade standard, dense concrete blocks; compressive strength10.5 N/mm^2; in cement lime mortar (1:1:6)				

…Continue table (4)

Item	description	Quantile (m^3)	Old unit Rate(£/m^2)	New rate (£ /m^3)	Value (£)
	Skins of hollow walls				
1	100 mm thick	39.4	9.15	91.50	3605.10
2	140 mm thick	112.28	12.52	89.40	10041.04
Staircases					
	440 X 215mm fair faced paint Grade standard, dense concrete blocks; compressive strength 7 N/mm^2; in cement lime mortar (1:1:6)				
	Walls				
3.	14mm thick	21.70	12.36	88.29	1915.80
Internal partitions					
	440 X 215 mm fair faced paint Grade standard, dense concrete blocks; compressive strength 7 N/mm2; in cement lime mortar (1:1:6)				
	Walls or partitions				
4.	100 mm thick	44.90	8.93	89.30	4009.57
5.	140 mm thick	67.06	12.36	88.29	4920.44
6.	190 mm thick	20.14	15.54	81.79	1647.24

Thus, the original bill rate for dense concrete blocks in skins of wall 100 mm thick was £ 9.15/m^2. This represents a rate of £ 9.15/0.1= £ 91.5/m^3. The rate for walls 140 mm thick was £12.52/ m^2 representing a rate of £12.52/0.14=£89.40/ m^3 (see Table 4). Within each type, correlation coefficients of greater than 0.99 representing confidence levels higher than 99% were obtained in all cases.

Modification to the Unit of Measurements

We found that it was possible to create a linear relationship in many more trades if one or more of the following adjustments were made. In some trades, items were described by type, or length or by thickness of materials, whilst the measurements were made in number of units, linear units or by area. In these cases the units of measurement were changed to volumetric units and the items descriptions modified to correspond with the new unit of measurement. As shown in the brick and block work example above, When the units of measurement were changed from square meters into cubic meters, the same unit rate could be applied to items, which differed only because of their thickness. Trades in which the units of measurement of items have been modified are listed in Table 5.

Table 5: Modified units of measurement

Project category	Trade	Old Unit	New Unit
Bridges	Precast concrete members	No.	m^3
Supermarkets	Excavation	m^2	m^3
Supermarkets	Up filling	m^2	m^3
Supermarkets	Sub-base filling	m^2	m^3
Supermarkets	Dense bituminous macadam	m^2	m^3
Supermarkets	Formwork	Linear m	m^3
Supermarkets	Brick and block work	m^2	m^3
Supermarkets	Gutters	Linear m	m^2

Omission of Selected Bill Items According to Description

In some trades, the quantity significant items, as identified earlier, all exhibited a characteristic set of features. For example, all the quantity significant items for dense bituminous macadam are described as "more than 300 mm thick". In this case, the insignificant items (i.e. those less than 300 mm thick) have significantly higher rates. The omission of these items, whose value is accounted for in the "model factor", combined with a change in the unit of measurement, made it possible to create a linear relationship between value and quantity. Using these techniques, it was possible to aggregate conventional bill items into a smaller number of work packages to each of which a single unit rate could be applied.

"Quantity significant work packages" were groups of items packaged in this way from which the items were not quantity significant had been omitted. The criteria for determining whether or not a series of items could be aggregated into a quantity significant work package were simply, first, that a linear regression of value on quantity should have a correlation coefficient of at least 0.99, and second, that for the sake of simplicity, a *t*-test should reveal that the intercept of the best fit line was not significantly different from zero.

The work packages defined in this way together with their characteristic items and units of measurement are shown in Table 6.

Table 6: Work packages, characteristic items and units of measurement.

WP No.	Work Package	Measurement Unit	Characteristic Item
BRIDGES			
	Formwork		
1.	Vertical	m^2	Largest quantity
2.	Horizontal	m^2	Largest quantity
3.	Inclined	m^2	Largest quantity
4.	Curved	m^2	Largest quantity
5.	Patterned	m^2	Largest quantity
6.	**Bar reinforcement**	tonne	Largest quantity
7.	**In situ concrete**	m^3	Largest quantity
8.	**Precast concrete**	m^3	Largest quantity
Supermarkets Earthwork and paving			
	Excavation		
1.	Excavation to reduce level at main buildings and external works	m^3	Largest quantity
2.	Excavating trenches to receive foundations or bases	m^3	Largest quantity
3.	Excavation to working space and filling with material ; disposal of excavated material by removing from site	m^3	Largest quantity
	Filling		
	In main building, car parks and their access roads, service yard, and the public roads and footpaths, (except in repairs)		
4.	General up filling	m^3	Largest quantity
5.	Sub-base filling	m^3	Largest quantity
6.	Sub-grade filling	m^3	Largest quantity
	Dense bituminous macadam		
	In areas as in the filling section		
7.	Over 300 mm wide	m^3	Largest quantity
	Asphalt		
	In areas as in the filling section		

…Continue table (6)

WP No.	Work Package	Measurement Unit	Characteristic Item
8.	Over 300 mm wide	m^3	Largest quantity
	Kerbs		
9.	Except to curve	m^3	Largest quantity
	Present concrete slabs		
10.	Over 300 mm wide	m^3	Largest quantity
Concrete work			
	In situ concrete		
11.	in foundations, beds of ground slabs, suspended slabs, Bases to walls and walls ground beams with area >0.25 m^2	m^3	Largest quantity
	Reinforcement		
12.	In all the above in situ concrete	tonne	Largest quantity
13.	Fabric	m^2	Largest quantity
	Form work		
14.	Edges/faces of foundations > 0.25 m high	m^2	Largest quantity
15.	Soffits of slabs and walls	m^2	Largest quantity
Brick and bloc work			
	Brick and bloc work each type with its own unit rate in		
16.	Walls or skin of hollow walls (not curved)	m^3	Largest quantity
Structure steel work			
	Columns, beams, gable posts;		
17.	Supply and fabrication	tonne	Average rate of the largest members of beams and columns
18.	Surface treatment	m^2	One rate existed
19.	Erection	tonne	one rate existed
Covering and finishing			
	Wall and roof cladding		
20.	Vertical (walls)	m^2	Largest quantity
21.	Sloping (roofs)	m^2	Largest quantity

…*Continue table (6)*

WP No.	Work Package	Measurement Unit	Characteristic Item
22.	Gutters	m^2	Largest quantity
	Slater work		
23.	Sloping Pitch for roof For each type	m^2	Largest quantity
	Title work		
24.	Ceramic tiles with backing coat (over 300 mm wide)	m^2	Largest quantity
	Terrazzo work		
25.	Precast terrazzo tiles with cement and sand (over 300 mm wide); exceeding 4 m^2 on plan	m^2	Largest quantity
	Plaster work (over 300 mm wide); exceeding 4 m^2 on plan		
26.	plaster, Carlite pre-mixed	m^2	Largest quantity
27.	Screed	m^2	Largest quantity
28.	Granolithic	m^2	Largest quantity
	Painter work (over 300 mm wide)		
29.	Painted areas except on metal	m^2	Largest quantity
	Bituminous roofing work Supply and fix of Galvanized steel sheets;		
30.	Flat or sloping	m^2	Largest quantity
31.	Felts; over 300 mm wide	m^2	Largest quantity
	Suspended ceiling work Supply and fix of suspended ceiling 300 mm wide ; with area exceeding 4 m2		
32.	Less than 20 mm thick	m^2	Largest quantity
33.	20-30mm thick	m^2	Largest quantity
34.	More than 30 mm thick	m^2	Largest quantity
Drainage work			
	Excavating trenches		

…Continue table (6)

WP No.	Work Package	Measurement Unit	Characteristic Item
35.	Inside boundary	lin.m	Longest excavation
36.	External boundary	lin.m	Longest excavation
37.	Laying pipes	lin.m	Longest pipe
38.	Drainage channels	No	One rate/type
39.	Bedding for pipes	m^3	Largest quantity

Classification of Items According to the Type or Size of Material

It was also possible to apply a single unit rate to items differing in size or type of material using the notion of "characteristic quantities" as described in the following section.

Application to Estimating

It was described elsewhere by Horner and Zakieh [12] how it is possible to identify within any category of project a relatively small number of work packages which represent a consistent proportion (typically close to 80%) of the cost and duration of a job. This allows the development of simple project models which themselves is powerful estimating and control tools. However, the findings on the linearity between value and quantity have other important consequences for estimating and control.

The equation of the best fit of quantity against value of items is of the form:

Value = Slope of best fit line x Quantity (1)

or,

Total Value = Slope of best fit line x Total quantity (2)

Equation 2 provides us with a simple means of determining the value of a group of similar items or "work package" From Equation 2.

Slope of the best fit line = $\sum v_i / \sum q_i$

Where,

v_i is the value of the i^{th} item;

and q_i is the quantity of the i^{th} item.

However: $\sum v_i / \sum q_i$ is also the weighted mean value, and by definition,

Total quantity x Weighted mean value = Total Value.

But the slope of the best fit straight line, the weighted mean value, is dominated by the rate of the largest item; the higher its contribution to the total, the closer its units rate is to the weighted mean. Thus where this relationship exists, the unit rate associated with the largest items can be applied to all items with the largest quantity within any work package the ‘characteristic item’. Table 6 provides a list of all the work packages we identified, together with their characteristic items and units of measurement.

Specific Examples

The application of these findings to estimating is illustrated using four examples. Example 1 draws on the data provided in Table 1. Figure 4 shows the regression line of value versus quantity. The slope of the line is £57.76/m^3 and a *t*-test revealed that the intercept (£241) is not significantly different from zero. The rate of the item containing the largest quantity is £57.84, which is very close to the slope of the regression line. If, rather than pricing every concrete item individually, each item is priced at the rate of the largest item, the result is 57.84 x 1146= £66284.64 which is about 2.23% different from the actual total value (i.e. £67798.47). The results for concrete in twenty bridge bills are shown in Table 7. The average difference is 0.08% with a standard deviation of less than 2.23%.

Table 7: Comparison of actual and calculated values for concrete in RC bridges.

Bill no.	Total quantity (m^3)	Actual Value (£)	Unit rat (£ /m)	Estimated value (£)	Variation (%)
1	610	30031.64	49.03	29908.30	-0.41
2	659	33675.68	50.92	33556.28	-0.35
3	1939	98334.00	50.98	98850.22	0.52
4	568	28239.24	49.03	27849.04	-1.38
5	1405	67181.60	48.50	68142.50	1.43
6	3391	172907.83	50.98	172873.18	-0.02
7	3855	160098.15	41.53	160098.15	0.00
8	308	15532.40	48.83	15039.64	-3.28
9	857	37106.28	42.96	36816.72	-0.79
10	1934	101928.11	52.88	102260.92	0.34
11	1239	51361.04	41.53	51455.67	0.18
12	545	28092.82	50.98	27784.10	-1.10
13	1143	57696.71	50.98	58270.14	0.99
14	688	35481.92	50.03	34420.64	-3.97

…Continue table(7)

Bill no.	Total quantity (m^3)	Actual Value (£)	Unit rat (£ /m)	Estimated value (£)	Variation (%)
15	1079	55608.99	53.51	57737.29	3.83
16	775	32317.64	42.44	32891.00	1.74
17	1116	45225.36	40.56	45264.96	0.09
18	997	40343.72	40.56	40438.32	0.23
19	688	27987.40	42.44	29198.72	4.33
20	1146	67798.47	59.54	66284.64	-2.23

Similar calculations were done for the block work shown in Table 4 and for the vertical formwork, bar reinforcement and bituminous macadam items shown in Tables 8, 9 and 10 and Figures 7, 8 and 9. For these and other work packages on which we tested the technique, the difference between actual and calculated values was always less than 5%.

Analysis of other bills with a larger range of bar diameters demonstrates that the principle still holds well.

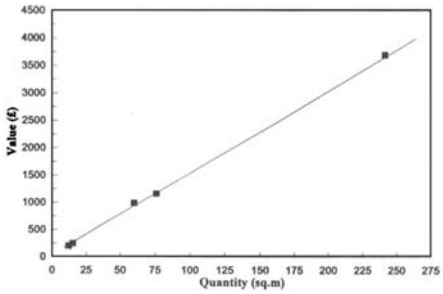


Figure 7 : Value vs. quantity for vertical formwork data in Table 8

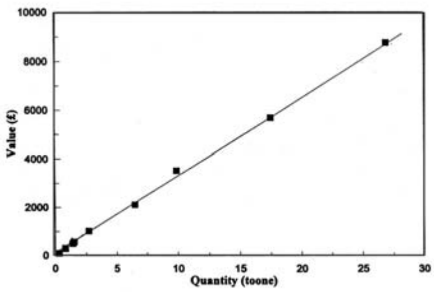


Figure 8: Value vs. quantity for reinforcement data in Table 9

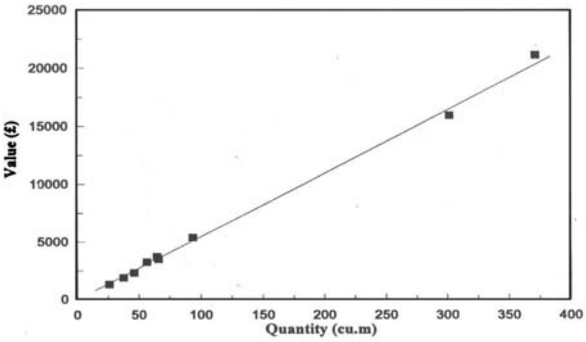


Figure 9: Value vs. quantity for dense bituminous macadam data in Table 10

Table 8: Formwork bill items for bridges.

Items Description	Quantity (m^2)	Unit rate (£ /m^2)	Value(£)
End supports			
1. Formwork more than 300 mm wide at any inclination more than 85 up to and including 90 to the horizontal Class F1	242	15.28	3697.76
2. Formwork more than 300 mm wide at any including 90 to the horizontal Class F2	15	16.19	242.85
3. Formwork more than 300mm wide at any inclination more than 85 up to and including 90 to the horizontal Class F3	60	16.53	991.80
Intermediate supports			
4. Formwork more than 300mm wide at any inclination more than 85 up to and including 90" to the horizontal Class F1	76	15.28	1161.28
5. Formwork more than 300 mm wide at Inclination more than 85 up to and including 90 to the horizontal Class F3	12	16.53	198.36
Total quantity	**405**	**Total Value**	**6292.05**
Total value using the rate of the largest quantity % difference			**6188.40** **-1.64%**

Table 9: Bar reinforcement bill items in a bridge.

Item description	Quantity (tonne)	Unit rate (£/tonne)	Value (£)
End supports			
1. Mild steel bar reinforcement nominal size16mm and under of 12 m length or less	1.5	379.69	569.54
2. Mild steel bar reinforcement nominal size 20 mm and over of 12 m length or less	0.3	319.61	95.88
3. High yield steel bar reinforcement Nominal size 16mm and under of 12 m Length or less	1.4	356.82	499.55
4. High yield steel bar reinforcement Nominal size 20mm and under of 12 m Length or less	17.5	325.73	5700.28
Intermediate supports			
5. Mild steel bar reinforcement nominal size 16 mm and under of 12 m length or less.	0.8	379.69	303.75
6. High yield steel bar reinforcement nominal Size16 mm and under of 12 m length or less	0.8	356.82	285.46
7. High yield steel bar reinforcement nominal Size 20 mm and over of 12 m length or less	6.5	325.37	2114.90
Superstructure			
8. Mild steel bar reinforcement nominal size 16 mm and under of 12 m length or less.	2.7	379.69	1025.16
9. High yield steel bar reinforcement nominal Size16 mm and under of 12 m length or less	9.9	356.82	3532.52
10. High yield steel bar reinforcement nominal Size 20 mm and over of 12 m length or less	26.9	325.73	8762.14
Total quantity	**68.30**	**Total Value**	**22889.36**
Total value using the rate of the largest quantity			**22247.36**
% difference			**-2.81%**

Table 10: Dense bituminous macadm bill items for supermarkets.

Item description	Quantity (m3)	Old Unit rate (£/ m2)	New rate Rate (£/m3)	Value (£)
Service yard				
1. 100 mm road base ; work to area on sub-base; to falls, cross falls or slopes not exceeding 15 from Horizontal, over 300 mm wide	93.7	5.75	57.5	5387.75
2. 40 mm road base; work to area on road base; to falls, cross falls or slopes not exceeding 15 from Horizontal, over 300 mm wide	37.48	2.00	50.00	1874.00
Car park				
3. 80 mm road base ; work to area on sub-base; to falls, cross falls or slopes not exceeding 15 from Horizontal, over 300 mm wide	372.00	4.54	56.75	21111.00
4. 65 mm road base ; work to area on sub base course; compacted in two layers to cross falls or slopes not exceeding 15 mm horizontal, over 300 mm wide	302.25	3.43	52.77	15949.73
Footpaths within site				
5. 60 mm base course; work to area on sub-base; to falls or slopes not exceeding 15 from horizontal, over 300 mm wide	56.40	3.43	57.17	3224.39
Car park access road				
6. 40 mm road base; work to area on road base; to falls, cross falls or slopes not exceeding 15 from Horizontal, over 300 mm wide	25.88	2.00	50.00	1294.00
7. 60 mm base course; work to area on sub-base; to falls, cross falls or slopes not exceeding 15 from Horizontal, over 300 mm wide	64.70	7.75	57.50	3720.25

… Continue table (10)

Item description	Quantity (m3)	Old Unit rate (£/ m2)	New rate Rate (£/m3)	Value (£)
Temporary car park				
8. 65 mm wearing course; work to area on base course; compacted in two layers to cross falls or slopes not Exceeding 15 from horizontal, over 300 mm wide	65.91	3.43	52.77	3478.07
Public roads and footpaths				
9. 40 mm base course; work to area on sub-base; to falls, cross falls or slopes not exceeding 15 from horizontal, over 300 mm wide	46.08	2.00	50.00	2304.00
Total quantity	**1064.40**	**Total Value**		**58343.18**
Total value using the rate of the largest quantity % difference				**60404.70** **+3.53%**

General Applicability

Clearly, more work is required to determine the extent to which this findings may be generally applicable. Nevertheless, the remarkable consistency of the results does suggest the possibility of pricing many bill items at the rate associated with the characteristic items. The effect of such procedures on the valuation of variations and claims also requires investigation, and research to shed light on both these problems has already started.

One serious question, which arises, is “How much larger than the second largest item dose the largest have to be before its unit rate can safely be applied to all items“. We have been unable to find an analytical solution to this problem because of the large number of variables involved. However, we believe that an experienced estimator using no more judgement than normal will be able to resolve this dilemma without difficulty. Referring once more to Figure 4, the problem faced by the estimator is “If I delete the largest quantity, will the gradient of the resultant straight line vary by more than ±5%? Alternatively, after determining the rate for the largest item the estimator may ask “Is this rate characteristic of the other items in the work package”. If the estimator has any doubt about the answer to either of these questions, he will determine the rate for the second largest item and price all items at the quantity weighted average rate for the largest and second largest items. He can continue this process until he feels comfortable about the rate that he has chosen. We believe that the application of this system in practice will ameliorate this problem still further.

Consequence for Control

One of the principal difficulties in effecting cost control through the bill of quantities is the need to allocate the actual costs of resources used on site (labor, plant and materials) to every bill item. This is an impossible task. The concept of characteristic items provides a potential solution to this hitherto intractable problem. It is best illustrated by reference to the bar reinforcing items shown in Table 9. Under normal circumstances, to track the actual costs of rebar for comparison with those predicated, it would be necessary to allocate resources to each different bar diameter and steel type. Although in the case of materials, this presents no particular difficulties, it is quite impractical to assign plant and labor hours at this level of detail. But with characteristic items, there is no such necessity. All that has to be done is to measure the total weight of rebar fixed, and divide this by the total steel fixer labor and plant costs. This provides the unit labor and plant costs (and productivity) for reinforcement characterized, in this case, by bars size 20 mm and over. (There is no need to distinguish between mild steel and high yield bars because they are both part of the same work package). In this way, by gathering data from different projects, it is possible to derive unit costs and resource inputs associated with reinforcing bars characterized inputs associated with reinforcing bars characterized by any given diameter. Analysis of variations in these values will help both to improve control and to provide feedback from site of a quality, which allows the estimator to predict costs with more certainty.

Conclusions:

1. Items of the same trade whose quantity is greater than the mean for that trade represent about 80% of the total quantity of the trade, and 30% of the number of items.
2. For many trades, the relationship between value and quantity is surprisingly linear.
3. Quantity-significant work packages may be formed by aggregating those items within a trade for which a linear regression of value yields a correlation coefficient of greater than 0.99, and an intercept insignificantly different from zero.

4. Each work package may be characterized by the item representing the largest quantity within it.
5. The value of quantity-significant work packages can generally be determined by pricing all the items within the package at the unit rate of the characteristic item.
6. Application of the concept of quantity-significance should lead to simpler estimating and more effective control procedures. In particular, there is no need to allocate cost and resources to the various items constituting a work package. The total quantity of the work package divided by the total cost or resource input represents the unit cost or productivity for the package.
7. The following further work is necessary before the technique can be applied with confidence.
   a. A rigorous set of rules must be developed to define the boundaries of the project categories and quantity-significant work packages within them.
   b. The ability of estimators to define the characteristic items and their associated unit rates need to be tested in practice.
   c. It is necessary to investigate whether the quantity-significant work packages are project category dependent, or whether the packages for a given trade can be applied across all categories of project.
   d. A formal control system based on quantity system and quantity significant work packages needs to be designed and tested in practice.

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