Resource Significant Cost and Time Models for Building Projects

نماذج لحساب الكلفة والفترة الزمنية لمشاريع البناء

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Abstract

Cost and time models have been developed for road and bridge projects using resource significance analysis, which is in turn based on the 80/20 rule. The work packages in these models are designed to relate to site operations. They serve as the basis for measurement, estimating, planning, valuation and control in civil engineering projects. For defined categories of work, a standard set of work packages have been developed which consistently contribute about 90% of a project's resource costs and hours. The resource significant cost and time models for bridges and roads predict cost to an accuracy of 4% Cv and 3% Cv respectively. The resource hours for a project can be predicted to an accuracy of 6% Cv for bridges and 3% Cv for roads. The bridge model contains 26 work packages and the road model contains 22 work packages. Coarser models have also been developed for situations where the road or bridge is only part of an overall project, with only a small loss of accuracy.

Keywords: *Time models, Cost models, Significant Philosophy and Cost estimate.*

ملخص

لقد تم اشتقاق نماذج لحساب الكلفة والفترة الزمنية لمشاريع الطرق والجسور باستخدام نظرية العناصر الاكثر أهمية والتي تعتمد على قانون ٨٠/ ٢٠%. إن الرزم في هذه النماذج تصف العمليات الإنشائية وقد استحدثت كأساس للقياس، وللحسابات، وللتخطيط ولمراقبة المشاريع الهندسية، لقدتم اشتقاق نماذج أساسية لهذه الرزم والتي تمثل ٩٠% من عناصر الكلفة والوقت. إن نماذج حساب الكلفة والفترة الزمنية للجسور والطرق بإمكانها حساب الكلفة والفترة الزمنية بمقدار خطأ ٤% للجسور،٣% للطرق. إن الفترة الزمنية للمشروع يمكن حسابها بمقدار خطأ ٦% للجسور و٣% للطرق. أن نموذج الجسور يحتوي على ٢٦ رزمة ونموذج الطرق يحتوي على ٢٢ رزمة، كذلك تم اشتقاق نموذج عندما تكون الجسور والطرق جزء من المشروع العام مع فقدان الدقة بنسبة ضئيلة.

Introduction

To prepare accurate cost estimates and programmes, an accurate model is needed. It should also be simple. The "operation" is the fundamental basis around which cost and time are realistically estimated and controlled, and results subsequently fed back to produce an effective database. Accordingly, the work packages in the model should relate to site operations, and the model should be standardised.

Theory of Resource Significance

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 (Dmaidi, 2000a, Dmaidi, 2000c) These items are called the "Cost Significant Items". Significance theory introduces simplification to the prediction and control processes in construction (Asif, 1989, Mair, 1991, PSA, 1987, Zakieh, 1991). Prediction and control is a term used to denote estimating and planning through to valuation, monitoring, analysis, control and feedback. This simplification is achieved by bundling insignificant items together and treating them as a factor which is adjusted in proportion to the value of the significant items. The insignificant items are generally either so small in value or so abstract that they do not contribute greatly to successful prediction and control. Further simplification is achieved by grouping related work items into work packages on an operational basis. These work packages are then more suited for use in the various prediction and control processes.

In order to develop an acceptably accurate, standard model, the significant items or work packages need to represent a consistent proportion of total value. Value is a general term to denote the amount of a variable in a particular case. The list of variables includes cost and duration.

Cost and time are interdependent in the prediction and control processes. Also, the material content of a project can be relatively easy to estimate and control. It is only one of a number of major factors linking prediction and control. Resource significance analysis and modelling is thus designed to identify work packages which are significant in terms of cost and/or time on a construction project by considering all three major resources of labour, plant and materials.

In this paper the development of resource significant cost and time models (RSCTM) for reinforced concrete bridges and road projects (flexible construction) is outlined. The aim is to identify categories of work which fulfil similar functions using similar design solutions and then investigate whether resource significant work packages will represent an acceptably consistent proportion of project value within these categories.

Derivation of Resource Significant Cost and Time Models

Splitting the rates

Cost significant items were defined by Saket (1986) and others (Mair, 1991, Dmaidi, 2000a, Dmaidi, 2000b) in their researches as those items in a bill of quantities whose value is greater than or equal to the mean item value. The mean measured item value being the total bill value divided by the total number of measured items (Dmaidi, 2000a, Dmaidi, 2000b). They represent 80% of the value of a project in 20% of the items. This is known as the 80/20 rule. Resource significance was, however, developed to identify those parts of a project which contain significant resource costs and/or resource durations (*ie* hours). Ideally, fully resourced estimates are required in order to ascertain the labour, plant and material breakdown for each item in a bill of quantities. This type of data is only available in a limited number of cases and never in sufficient quantity to satisfy the requirements of full model development. Additionally, a certain proportion of work will always be subcontracted for which no breakdown will be available.

Generally, the only data available for developing resource significant models is the priced bill of quantities. In order to carry out resource significance analysis it was therefore necessary to split the BQ prices down into their constituent resource costs and hours by some acceptable means. In this respect, it was decided to use a commercial civil engineering estimating database which was in common use. The Wessex Civil Engineering Database (Wessex, 1990) was chosen. Research work by Talhouni (1990) into productivity has indicated that Wessex databases represent a good approximation of the average productivities from a sample of six commercial databases and observed site productivities for masonry (Figure 1).

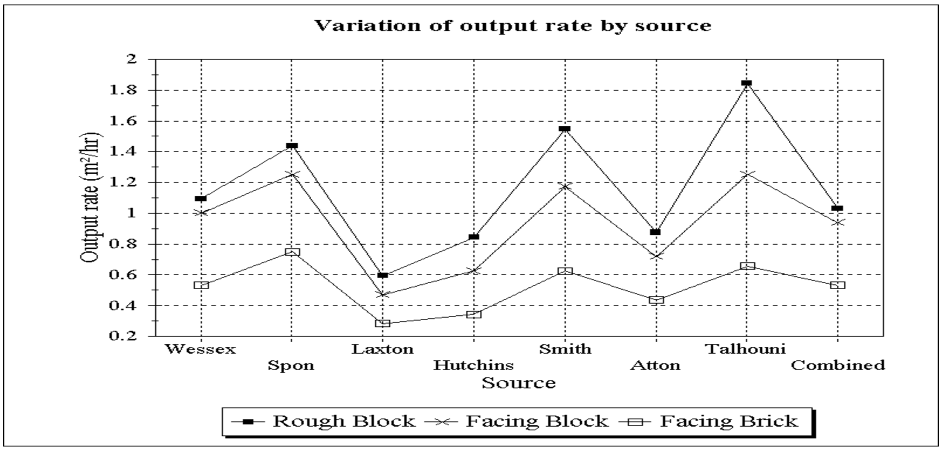

Figure (1): Comparison of outputs (Source Talhouni (1990)

Using the Wessex Database, labour, plant and material costs (LC, PC, MC) are obtained by adjusting the unit rate for each bill of quantities item pro-rata on the basis of the apportionment of these resource costs within the equivalent database item.

Defining Resource Significant Items

It was necessary to develop a set of criteria for different types of resource significance (Figure 2).

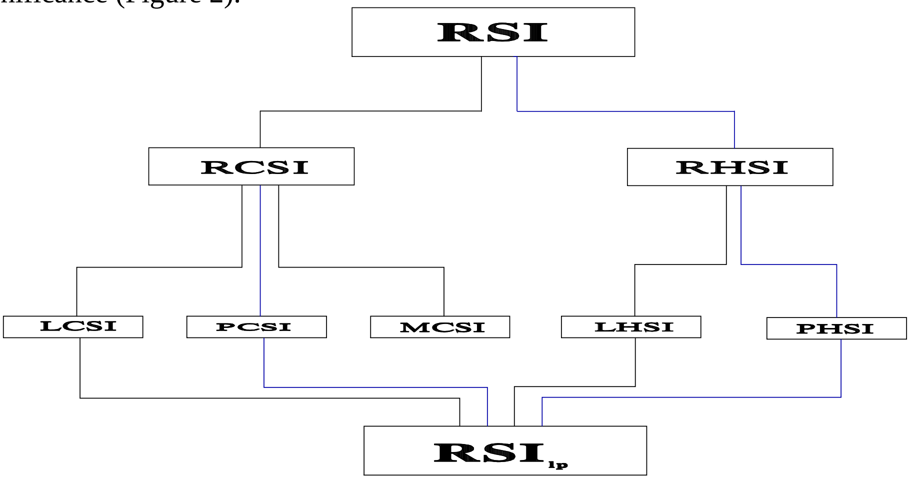

Figure (2): Relationship between different types of Resource Significant Items

The most obvious choice was to separate items which are resource cost significant rather than resource hours significant. Resource cost significant items (RCSI) fall into three classes:

labour cost significant items (LCSI);

plant cost significant items (PCSI); and

material cost significant items (MCSI).

Resource hours significant items fall into two categories:

labour hours significant items (LHSI); and

plant hours significant items (PHSI).

Any item which is LCSI or PCSI or MCSI is a resource cost significant item (RCSI). Any item which is LHSI or PHSI is a resource hours significant item (RHSI). Any item which is RHSI or LCSI or PCSI is a labour/plant resource significant item (RSI_{lp}). Any item which is either RCSI or RHSI (or RSI_{lp}) is a resource significant item (RSI).

A labour cost significant item (LCSI) is any item whose labour cost value is greater than or equal to the mean labour cost value for the total bill. A similar definition is used for PCSI and MCSI. A labour hours significant item (LHSI) is any item whose labour hours value is greater than or equal to the mean labour hours value for the total bill. A similar definition is used for PHSI.

Using the classification in Figure 2 and the above definition, the relationship between item number and resource costs or hours was investigated to see whether they conformed with the 80/20 rule. The results in Table 1 and Figure 3 broadly confirm this to be the case.

Table (1): 80/20 Relationship in 21 Bridge Bills

Bridge Bill	Cost						Hours			
	V_{LC}	N_{LC}	V_{PC}	N_{PC}	V_{MC}	N_{MC}	V_{LH}	N_{LH}	V_{PH}	N_{PH}
BDG1	0.83	0.25	0.80	0.21	0.88	0.21	0.84	0.26	0.80	0.21
BDG2	0.84	0.31	0.77	0.29	0.85	0.24	0.82	0.28	0.74	0.24
BDG3	0.79	0.26	0.80	0.21	0.86	0.23	0.79	0.25	0.79	0.26
BDG4	0.74	0.21	0.88	0.32	0.84	0.15	0.72	0.18	0.87	0.32
BDG5	0.82	0.25	0.77	0.28	0.86	0.18	0.80	0.20	0.74	0.26
BDG6	0.83	0.27	0.78	0.29	0.88	0.29	0.82	0.27	0.79	0.29
BDG7	0.86	0.29	0.83	0.37	0.87	0.24	0.86	0.29	0.86	0.33
BDG8	0.83	0.27	0.70	0.27	0.84	0.24	0.83	0.27	0.79	0.33
BDG9	0.84	0.20	0.84	0.18	0.80	0.15	0.83	0.20	0.86	0.20
BDG10	0.85	0.29	0.81	0.29	0.86	0.23	0.85	0.29	0.79	0.28

… continue table (1)

Bridge Bill	Cost						Hours			
	V_{LC}	N_{LC}	V_{PC}	N_{PC}	V_{MC}	N_{MC}	V_{LH}	N_{LH}	V_{PH}	N_{PH}
BDG11	0.82	0.27	0.79	0.33	0.83	0.21	0.82	0.26	0.76	0.29
BDG12	0.76	0.16	0.78	0.32	0.84	0.21	0.79	0.18	0.78	0.26
BDG13	0.83	0.30	0.80	0.26	0.82	0.30	0.82	0.30	0.82	0.26
BDG14	0.83	0.23	0.79	0.25	0.87	0.20	0.83	0.23	0.76	0.20
BDG15	0.79	0.30	0.83	0.18	0.85	0.26	0.81	0.31	0.86	0.25
BDG16	0.81	0.25	0.83	0.24	0.84	0.17	0.81	0.25	0.83	0.24
BDG17	0.81	0.32	0.74	0.26	0.80	0.16	0.82	0.34	0.76	0.28
BDG18	0.82	0.26	0.84	0.23	0.84	0.17	0.81	0.25	0.86	0.25
BDG19	0.79	0.25	0.78	0.22	0.80	0.19	0.79	0.25	0.76	0.17
BDG20	0.77	0.27	0.80	0.34	0.82	0.24	0.80	0.29	0.77	0.29
BDG21	0.80	0.23	0.86	0.29	0.85	0.21	0.82	0.25	0.86	0.29
X	81.26	25.95	80.18	26.79	84.36	21.19	81.33	25.74	80.37	26.21
s	3.03	3.84	3.99	5.24	2.41	4.28	2.92	4.15	4.54	4.26
Cv	3.73	14.81	4.98	19.56	2.86	20.18	3.60	16.11	5.65	16.25

V_{LC} (Labour cost significant value factor) = Value of LCSI as a proportion of total labour cost for project

N_{LC} (Labour cost significant number factor) = Number of LCSI as a proportion of total number of items

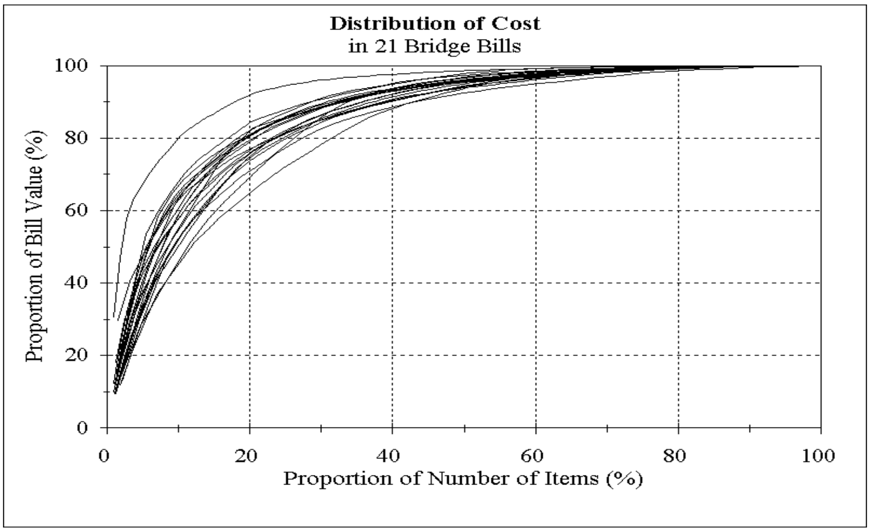

Figure (3): Observed distribution of Cost in 21 Bridge Bills

As stated, a resource significant item is any item which is either LHSI, PHSI, LCSI, PCSI or MCSI. By combining these five distributions, which overlap, the resulting RSI's exhibit a 90/35 relationship; 35% (with a Cv of 15.10%) of the items are resource significant and contain almost 90% of the value, whether expressed in resource costs (89% with a Cv of 2.48%) or hours (86% with a Cv of 3.51%). This would tend to suggest that the work packages in the eventual model would contain 90% of project value, rather than the 80% contained in cost and quantity significant models.

Choosing the level of significance

A cost significant item was identified as any item with a value greater than or equal to the mean item value (Saket, 1986). Similarly, a quantity significant item was defined as any item with a quantity greater than or equal to the mean (Zakieh, 1991). Saket (1986) defined the mean item value as a significance level of 1.00. It is this level of significance which generally produces the 80/20 relationship, and Saket concluded that it was the most effective relationship. From Figure 3 we can see that the slope of the curves approximates to 45" at the point where the 80/20 relationship occurs. As the level of significance falls below 1.00, the proportion of the number of items which must be modelled begins to rise at a greater rate than the proportion of bill value they represent. Clearly, there is a need to strike a balance between the accuracy (consistency) we require from any model, and the level of detail of the model.

Resource significance deals with resource costs for labour, plant and materials rather than the unit rate, which compounds all three. It also deals with resource durations. Project costs have to be analysed in considerable detail in the first instance and this dictated that a single level of significance should be adopted.

Work Packages

The identification of RSI's and RSI_{lp}'s (labour/plant resource significant items) gives an indication of work items which should be formed into work packages for subsequent analysis. A work package must satisfy the various requirements of estimating, planning, control and valuation and subsequent feedback to an effective database for future use. Accordingly, as each work package is defined based on the occurrence of RSI's and RSI_{lp}'s it must:

1. Be capable of site measurement;
2. Contain only one class of material;
3. Have one productivity;
4. Relate to a realistic site operation;

5. Relate to a single trade; and
6. The productivity or unit rates for labour and plant teams and materials should be easily identifiable without having to further split the work package into work items (Mair, 1991, Zakieh, 1991, Horner, 1992).

The work packages are based on a basic work breakdown structure (WBS) for the project category chosen. The WBS is derived by identifying distinct parts of a project which fulfil a similar design function irrespective of location or specification. The work package forms the lowest level of detail within the standard WBS for a defined project category. It does not necessarily form the lowest level of detail for pricing or planning, so each WP must contain sufficient detail to allow these functions to be carried out effectively. The facility must be available to supplement the standard WBS for each work category with additional levels because the circumstances of each individual project will vary. Work packages must satisfy the need for this flexibility, and must therefore be capable of further splitting to form suitable control elements for site measurement and control.

Identifying the Productivity and Rates

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 which encompass a number of traditional work items while retaining enough detail to allow sufficiently accurate estimates to be prepared. As each work package is defined, based on the characteristics listed before, it is important to bear in mind that we should be able to describe a work package so that its cost and duration can be estimated to an adequate level of accuracy.

Zakieh (1991) demonstrated the strong relationship between quantity and value (Figure 4) for related work items in a bill of quantities. This led him to conclude that the value of a work package could be estimated by applying the unit rate for the work item with the largest quantity to the total quantity for the work package, with only a small loss in accuracy. He therefore termed the largest quantity the characteristic quantity.

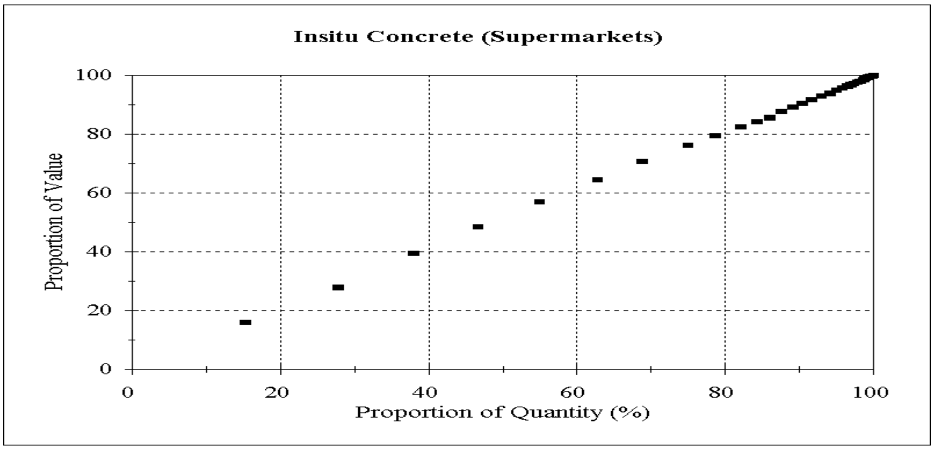

Figure (4): Relationship between cost and quantity [Source: Zakieh, 1991]

The data for a rebar work package in Table 2 is drawn from a typical bridge bill. A regression analysis of the data (Table 3) shows that the *x* coefficient / gradient (319.65) is very close to the unit rate of the largest quantity (316.00) and the constant is very low in relation to the work package value. The correlation between value and quantity is very high (r = 0.99992).

Table (2) 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%**

Table (3): Regression analysis on rebar work items

Regression Output:	
Constant	-64.03
Std Err of Y Est	37.51
R	0.99992
No. of Observations	4.00
Degrees of Freedom	2.00
X Coefficient(s)	319.65
Std Err of Coef.	2.90

With resource significance, we are not only dealing with cost but hours as well. The model is designed to express the link between cost and time. We therefore wish to determine whether the characteristic quantity can be used to determine the cost and hours (or productivity) of the work package. Figure 5 illustrates how the relationship between hours and quantity is the same as that exhibited between cost and quantity. In Table 4 regression analysis confirms that the productivity of the largest quantity (89.28hrs/Tonne) is very close to the *x* coefficient/gradient. Figure 5 also shows that hours and quantity are highly correlated.

Table (4): Regression Analysis on Productivity of Rebar Items

Regression Output:	
Constant	57.94
Std Err of Y Est	45.47
R	0.9993
No. of Observations	6.00
Degrees of Freedom	4.00
X Coefficient(s)	87.675
Std Err of Coef.	1.69

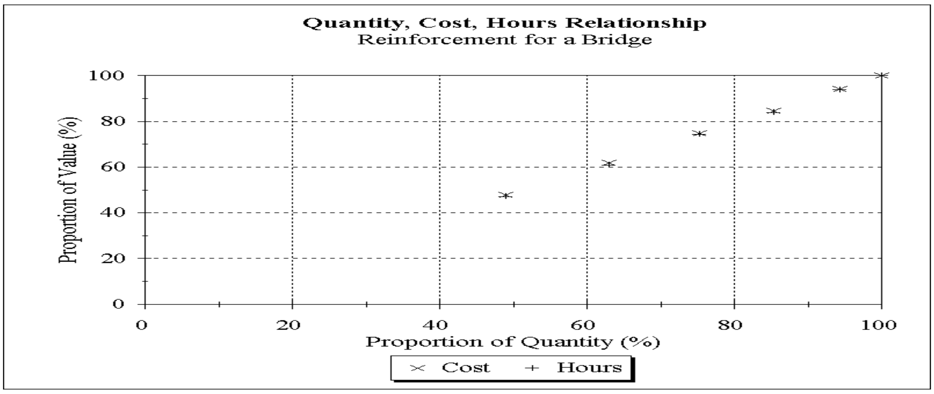

Figure (5): Using the characteristic quantity to predict cost and hours (productivity) of a work package

By considering labour, plant and materials in isolation rather than collectively as a single rate, the characteristic quantity can be used to package items which would not normally be packagable due to the wide variation in unit rates relating to the same operation. The operation of filling involving one team may have a new and existing material element (imported fill and fill arising from excavations). The characteristic quantity or quantities will allow us to package these items of work together and apply one productivity for labour and plant. In order to estimate the material cost accurately the new material element will need to be identified (*ie* scheduled) separately in the work package.

In practice, each work package will have a general description (*eg* reinforcement to bridge deck) which will be supplemented by the definition of the work which characterises the work package (*eg* reinforcement to bridge deck, characterised by 20mm diameter mild steel reinforcement). The contractor will then use this information to estimate and plan the work.

Consistency

Once the work packages are identified based on the resource significant items, preliminary models can be developed. As stated the aim is to identify those items or work packages which contain a consistent proportion of a resource value, expressed in hours or cost.

Consistency Ratio

The consistency ratio (C_R) is a measure of the frequency with which a particular work package is significant relative to the number of times it occurs As an example, "soiling <10E to the horizontal" has a consistency ratio (C_R) of 60% for LC and 80% for PC, whereas "soiling >10E" has a C_R of 40% for both. The final work package is "soiling to any inclination" and its C_R is 80%.

The Initial Model

The resource significant cost and time model (RSCTM) is primarily aimed at linking cost with time. The models are initially developed by concentrating on work packages which are labour or plant resource significant ($RSWP_{lp}$). The model is subsequently checked to ensure it includes work packages which are material significant only.

The $RSWP_{lp}$'s are ranked in descending order of consistency ratio and as each $RSWP_{lp}$ is added to the list the proportion of cost (C), resource hours (H), labour cost (LC), plant cost (PC), etc. contained in that list of WP's is expressed as a proportion of total project value (C_t, H_t, LC_t, PC_t, etc.). For example, in Figure 6 all work packages with a consistency ratio of 70% or higher contain an average of 62% of the total labour costs and hours with a Cv of approximately 4%.

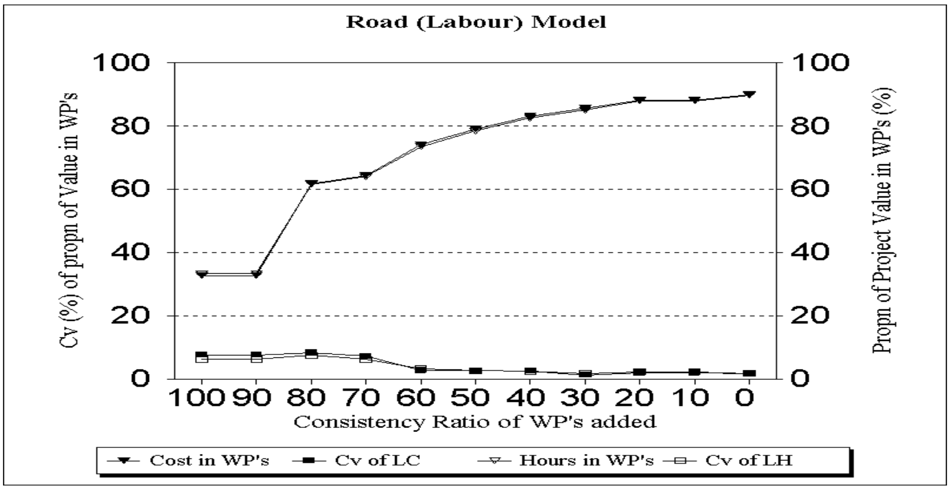

Figure (6): Tracking Cv of labour model as work packages (WP's) are added in descending order of Consistency Ratio (C_R)

Each proportion represents the model factor (MF) for that set of work packages for that sample project. Ideally we are looking for a list of $RSWP_{lp}$ for which the MF for each sample project is the same. In the real world this will not be the case. The values of MF will vary from sample project to sample project. The 80/20 rule and the use of the project category serve to produce a list work packages for which the variation in the MF is low. This variation is measured using the coefficient of variation (Cv) (Figure 6 and Figure 7).

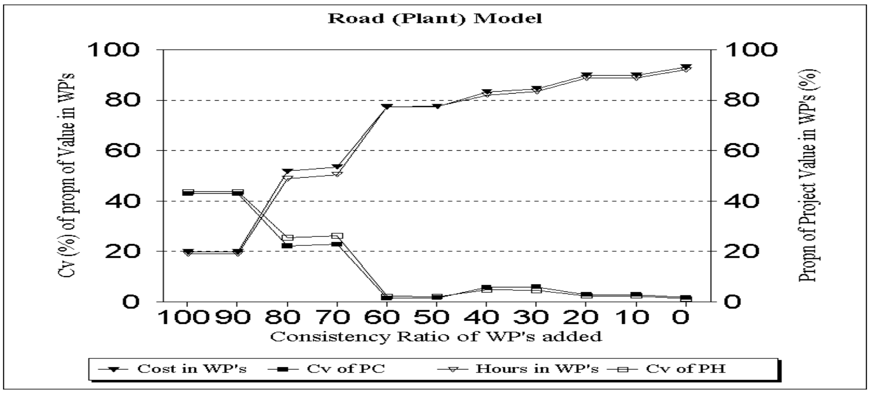

Figure (7): Tracking Cv of plant model as work packages (WP's) are added in descending order of Consistency Ratio (C_R)

The Cv represents the accuracy of the model in predicting a known fraction of total value. The mean is the model factor (MF). As each $RSWP_{lp}$ is added to the list the central limit theorem and the relative proportion of MF to total value will cause a reduction in the Cv of MF. The initial model is identified by choosing a level of consistency ratio at which the Cv of resource cost and hours and totals is acceptably low (Figure 8). As stated earlier, a Cv of 4% was felt to be an acceptably low model error which could be offset by increasing the accuracy at which the smaller number of work packages could be estimated.

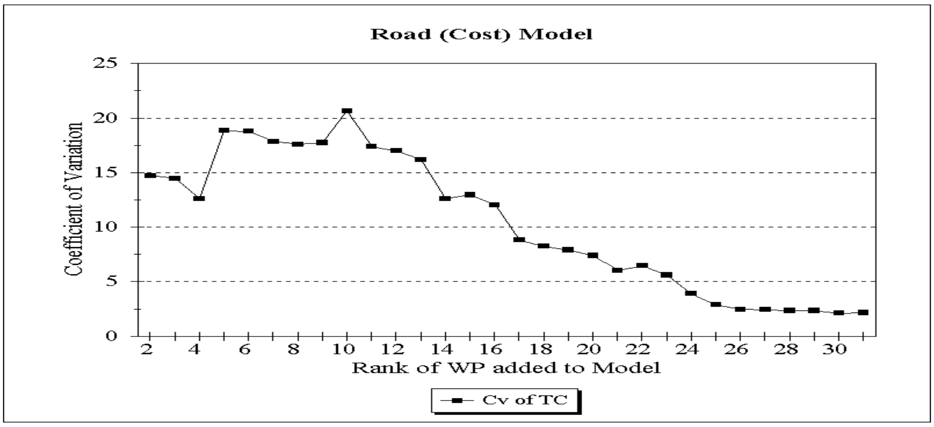

Figure (8): Tracking Cv of combined Labour, Plant and Material model as work packages are added

Material Cost Significance Check

The model was then checked for material cost consistency. Any WP's which are material cost significant ($RSWP_m$) but not labour and plant resource significant ($RSWP_{lp}$) are included in the model. In all cases it was found that the work packages in the initial model included all WP's which were also material cost significant ($RSWP_m$). The initial model now contains resource significant work packages (RSWP).

Sequence Significance Check

Sequence significant work packages are not resource significant. They are included in the standard set of RSWP's to produce a model which is applicable to planning, estimating and control. Certain low value WP's may be crucial to the sequencing of a project type and are added to the model.

Definition of the project category and model factor boundaries

In practice, it is essential to define the correct model and model factors for a project is paramount. There is no reason why the scope of a project category cannot be extended or widened to include different design characteristics or material classes, provided that the different model factors are identified. A resource significant cost and time model (RSCTM) may be developed for beam bridges with reinforced concrete and/or precast concrete decks whose work Packages will also suit beam bridges with steel and/or composite decks. Each project type would have a different set of model factors (MF).

The process of definition of the boundaries to which a MF applies is therefore critical to the successful use of the model, and in particular the use of the model for estimating and planning up to tender stage.

Proposed definition method

The method of defining a project category depends on defining the design characteristics, as well as clearly stating the type of work excluded from the project category. This can be done descriptively under these two headings, using the data available from the sample of projects used to develop and test the model, by listing the type of work covered and any specific exclusions. If the boundaries of the projects used to develop and test the model match, and the accuracy of the results is acceptable, there is no reason why similar accuracy will not be achieved on future projects which also fall within the boundaries.

RSCTM Generally

Resource significant cost and time models have been developed for concrete bridges and roads of flexible carriageway construction. In this section the models are described and the results of testing for accuracy are given.

Estimating Accuracy

It is apt at this stage to consider accuracy in the context in which it will be applied. Beeston (1973) states that "the measure of variability of most value statistically is the coefficient of variation". The coefficient of variation (Cv) is calculated by expressing the standard deviation as a percentage of the mean. His studies of accuracy in building concluded that variability of tenders between contractors bidding for the same work averages 5.2% Cv. He also studied variability in bill items and concluded that the average Cv ranges from 13% for glazier work to 45% for earthworks. This figure for civils work fits well with Barnes and Thompson's (1971) assessment of the variability in civil engineering ates of 40%. Beeston concludes that the variability for civils work is "clearly much greater than a typical building item". However, Barnes and Thompson concluded that a civil engineering contractor can predict costs to an accuracy of 5.8% Cv, only slightly worse than the figure quoted by Beeston.

These are not the only views on estimating accuracy. Moyles (1973) concluded that contractors could estimate to an accuracy of "5%, though this figure is based on an opinion survey. Both Mair (1991) and Ashworth and Skitmore (1983) report Gates' findings in the USA of a Cv of 7.5% based on the variability of contractor's estimates on 110 highway projects. Ashworth and Skitmore conclude that contractors estimate with a Cv of 6% and Ogunlana and Thorpe (1987) quote a Cv of up to 6.5%.

Mair (1991), in his review of estimating performance found the average of published estimating performance to be a Cv of 6.5%. Overall, it is anticipated that the reduction in the number of items will allow estimators to dedicate more time to the resource significant work packages and thereby improve their accuracy (Saket, 1986). As Ashworth and Skitmore (1983) note, "accuracy in estimating is likely to be improved by the familiarity of the chosen method" and "the removal of minor items might go some way towards improving the accuracy of the remaining items".

Planning Accuracy

Very little has been published on this aspect of accuracy. Zakieh (1991) quotes King and Wilson (1967) who found that early estimates of activity duration were still the best estimate, despite an increase in the level of information. Roderick (1977) however noted that in most cases the duration of activities was "very much greater" than the contractor's estimate.

The preparation of programmes relies on the ability to estimate durations which in turn relies on the ability to predict output rates and resource hour requirements for each activity (CIOB, 1980, Peer, 1974). The importance of interaction between estimating and planning cannot be overemphasised. As Brockfield (1988) notes, "the programme is perhaps the most helpful of the aids to the estimator".

Development of Bridge RSCTM

Ten bridge bills were used to develop the RSCTM and calculate its model factor and expected accuracy; a further 5 bills were used to test the model. The standard WBS for the bridge model is shown in Figure 9. The WBS splits the work category into major elements which fulfil separate functions.

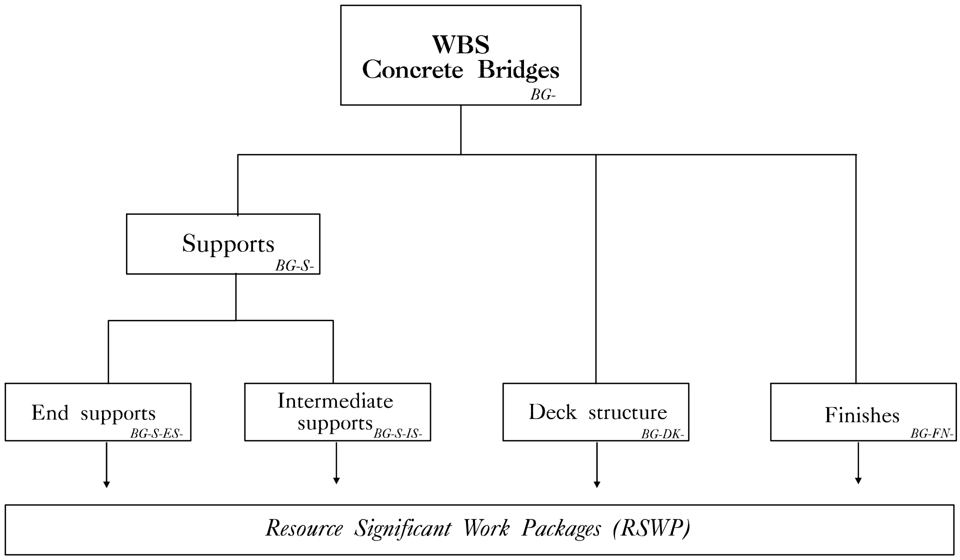

Figure (9): Standard WBS for Concrete Bridges

The lowest level of the WBS dictates the minimum level of detail at which work packages must be defined. Beyond this minimum level of detail, programming and control can be carried out to the client's and contractor's preference. Some work packages may be common to two or more branches in the WBS (*eg* the concrete work package appears in end supports, intermediate supports and deck structure (Table 5). However, the WBS has been designed so that programmes are sufficiently detailed for use in valuation, and so that effective control and feedback can be exercised. The WBS will dictate the format of the tender documents issued to the contractor by the client. The accuracies quoted below are based on estimates being produced at this level of detail. The contractor can, for example, combine all concrete or reinforcement work packages when preparing an estimate, though this may reduce the expected accuracy for the model.

Table (5): Example Extract from Consistency Ratio Calculation File

Significant Items/Packages	Occurrence of LCSI					Consistency Ratio					
	LC27	**LC23**	**LC16**	**LC13**	**LC3**	**C**	**LC**	**LH**	**PC**	**PH**	**MC**
Excav Topsoil	1	1	1	1	0	80%	80%	80%	80%	80%	0%
Suitbl/Cuttgs/Open	1	1	1	0	1	80%	80%	80%	80%	80%	0%
Unsuitbl/Cuttgs/Open	1	1	1	1	1	95%	100%	80%	100%	100%	0%
Rock/Cuttgs/Open	1	1	0	0	0	40%	40%	40%	40%	40%	0%
Pavement Etc	1	1	1	0		75%	75%	75%	75%	75%	0%
Dep in Embank	1	1	1	1	0	80%	80%	80%	80%	80%	0%
Dep in Cappg	1					100%	100%	100%	100%	100%	0%
Dep Sub/Verg/Side	1			0	0	33%	33%	33%	33%	33%	0%
Dispose Offst/Suitbl	1					100%	100%	100%	100%	100%	0%
Dispose Offst/Unsuitbl	1	1	0	1	1	70%	80%	60%	60%	80%	0%
Imp Suitbl Fill Embank		1	1	0	0	50%	50%	50%	25%	25%	100%
Imp Gran to Sub /Verg/ Side			1			100%	100%	100%	100%	100%	100%
Imp Gran to Embank					0	20%	0%	0%	0%	0%	100%
Imp Freedrn Embank		1				100%	100%	100%	100%	100%	100%
Soil 100/150/<10d	0	1	1	1	0	70%	**60%**	60%	**80%**	80%	0%
Soil 100/125/>10d	0	1	1	0	0	45%	40%	40%	40%	60%	0%
Grass/<10d	0	0	0	1	0	20%	20%	40%	0%	0%	0%
Grass/>10d	1	1	0	0	1	40%	60%	60%	0%	0%	0%
Weed<10d			1			100%	100%	100%	0%	0%	0%
Form Suitbl	1	0	1	1	0	60%	60%	60%	60%	60%	0%
Capping Reinf	0				1	67%	50%	50%	0%	0%	100%
Subbase	1	1	1	1	1	92%	100%	100%	80%	80%	100%
150 Roadbase	1		1	1	1	100%	100%	100%	100%	100%	100%
Roadbase		1				100%	100%	100%	100%	100%	100%
Roadbase		0				20%	0%	0%	0%	0%	100%
Reg Crse to Sub	0	0	0	0		5%	0%	0%	0%	0%	25%
100 Flex Surf Alt	1	0	1	1	1	84%	80%	80%	80%	80%	100%
Flex Dens Bit Mac		1				100%	100%	100%	100%	100%	100%
Wear Crse/Chips	0		0	0	1	10%	25%	25%	0%	0%	0%
Reg Crse to Surf	0		0	0	0	5%	0%	0%	0%	0%	25%
Plane Extg Pavemnt	1					75%	100%	100%	100%	0%	0%
Pck Strght K1	1	1	1	1	1	93%	100%	100%	0%	0%	80%
Pck Strght K2	1	0	0	1	1	47%	60%	60%	0%	0%	20%
Pce Strght E1	1		0		1	56%	67%	67%	0%	0%	33%
Safeticurb Dbk2			1			100%	100%	100%	0%	0%	100%
Flex Footway	1	0	0	0	1	36%	40%	40%	40%	20%	40%

0 work item exists in bill

1 work item exists in bill and is resource significant

The results are given in table 6 and the model, containing 26 work packages, is described in Table 7.

Table (6): Results for Bridge Model 1

Bridge Model 1							
	C_t	**H_t**	**LC_t**	**LH_t**	**PC_t**	**PH_t**	**MC_t**
Model Factors and expected results							
MF	0.90	0.91	0.90	0.91	0.89	0.90	0.91
s	2.45	4.37	3.88	4.69	3.67	5.34	2.91
Cv	2.67	4.79	4.28	5.14	4.04	5.90	3.15
Results of testing							
Mean Ac	0.05	-2.87	-1.76	-3.22	-1.57	0.09	1.10
Cv	3.70	6.25	6.36	6.55	4.21	4.37	3.08

C_t is total project cost
LC_t is total project labour cost
LH_t is total project hours

Table (7): Details of Bridge Model 1

Bridge Model 1			
	Code	**UoM**	**Work Package Description**
SUPPORTS	BG-S-ES-1	m^3	Excavate natural material other than rock
	BG-S-IS-1		
	BG-S-ES-2	m^3	Excavate rock
	BG-S-IS-2		
	BG-S-ES-3	Item	Drainage
	BG-S-ES-4	m^3	Fill
	BG-S-IS-4		
	BG-S-ES-5	m^2	Vertical formwork >300mm wide (generally)
	BG-S-IS-5		
	BG-S-ES-6	m^2	Vertical formwork >300mm wide (patterned)
	BG-S-IS-6		
	BG-S-IS-7	m^2	Formwork (curved)
	BG-S-ES-8	T	Reinforcement (mild or high yield steel)
	BG-S-IS-8		
	BG-S-ES-9	m^3	Concrete (excl. blinding)
	BG-S-IS-9		
DECK	BG-DK-1	m^2	Formwork >300mm wide (generally)
	BG-DK-2	T	Reinforcement (mild or high yield steel)
	BG-DK-3	m^3	Concrete
	BG-DK-4	No.	Bearings
	BG-DK-5*	No./m^3	Precast/Prestressed/Post-tensioned concrete beams

…continue table (7)

Bridge Model 1	Code	UoM	Work Package Description
FINIShES	BG-FN-1	m^2	Waterproofing (proprietary)
	BG-FN-2	m^2	Waterproofing (asphalt or similar)
	BG-FN-3	m^2	Concrete protection
	BG-FN-4	m^2	Paving
	BG-FN-5	m	Parapet/Walling
	BG-DK-1	m^2	Formwork >300mm wide (generally)

* not subject to adjustment with Model

Initially, the model was developed to encompass all the work packages shown, including precast, prestressed or post-tensioned concrete members (PPP members), and the model factor calculated on this basis. However, the model described here treats PPP members in a different manner. Analysis of some bridge bills outside the sample used to develop the model revealed that the PPP members can account for an extremely high proportion of total bridge value. To counter this, PPP members are not included in the model. Their cost is estimated separately and added to the value predicted by the model.

Discussion of the results

With a Cv of 2.67% and 4.79%, the expected accuracy for the prediction of cost and hours is good. The test results of 3.70% and 6.25% are close to the expected accuracies for the model. The fact that they are outside the expected accuracy boundaries is not surprising because the projects used to derive and test the model represent two small samples from the population. In addition, the test results are themselves based on the model factors calculated from the sample used to derive the model. A difference in accuracy is thus expected. Overall, however, the test result for cost prediction is still less than 4%, which was identified before as being acceptable. The average accuracies for the tests of 0.05% for cost and -2.87% for hours are not significantly different from zero at the 10% level of significance.

The model factors for total cost (C_t), total hours (H_t), right through to total material cost (MC_t), are very close to 0.9 (The average is in fact 0.9 with a standard deviation of 1%). For research purposes full analysis and testing was performed on the individual resources to confirm the accuracy of the RSCTM. The results do indicate, however, that a single model factor could be quoted with only a slight fall in accuracy. This would ensure the model was simple to use in practice.

Detailed Model Accuracy versus Coarser Model Accuracy

As discussed earlier, resource significance analysis tends to encompass a greater proportion of value of a project than cost or quantity significance. The initial bridge RSCTM models around 90% of a project's value.

Further work was carried out to develop an even simpler model for bridges. The results for this model are shown in Table 8 and the model, containing 21 work packages, is described in Table 9. Because some work packages (fill, bearings, concrete protection) have been removed, the model factor falls. Understandably the accuracy of the model also falls.

Table (8): Results for Bridge Model 2

Bridge Model 2							
	C_t	H_t	LC_t	LH_t	PC_t	PH_t	MC_t
Model Factors and expected results							
MF	0.79	0.83	0.82	0.83	0.83	0.81	0.78
S	5.09	6.05	4.32	6.62	6.05	8.06	7.82
Cv	6.41	7.32	5.24	7.98	7.33	9.93	10.03
Results of testing							
Mean Ac	0.03	-1.85	-1.46	-1.90	0.06	-2.89	0.36
Cv	1.03	6.78	8.22	8.75	9.59	13.29	2.37

Table (9): Details of Bridge Model 2

Bridge Model 2			
	Code	**UoM**	**Work Package Description**
SUPPORTS	BG-S-ES-1	m^3	Excavate natural material other than rock
	BG-S-IS-1		
	BG-S-ES-2	m^3	Excavate rock
	BG-S-IS-2		
	BG-S-ES-3	Item	Drainage
	BG-S-ES-5	m^2	Vertical formwork >300mm wide (generally)
	BG-S-IS-5		
	BG-S-ES-6	m^2	Vertical formwork >300mm wide (patterned)
	BG-S-IS-6		
	BG-S-IS-7	m^2	Formwork (curved)
	BG-S-ES-8	T	Reinforcement (mild or high yield steel)
	BG-S-IS-8		
	BG-S-ES-9	m^3	Concrete (excl. blinding)
	BG-S-IS-9		

…continue table (9)

Bridge Model 2			
	Code	**UoM**	**Work Package Description**
DECK	BG-DK-1	m^2	Formwork >300mm wide (generally)
	BG-DK-2	T	Reinforcement (mild or high yield steel)
	BG-DK-3	m^3	Concrete
	BG-DK-5*	No./m^3	Precast/Prestressed/Post-tensioned concrete beams
FIN	BG-FN-1	m^2	Waterproofing (proprietary)
	BG-FN-2	m^2	Waterproofing (asphalt or similar)
	BG-FN-4	m	Parapet/Walling

* not subject to adjustment with Model Factor

Discussion on Results

With a Cv of 6.41% and 7.32%, the expected accuracy for the prediction of cost and hours is good. When tested the results for Cv of 1.03% and 6.78% are within the expected accuracy boundaries. The average accuracies for the tests of 0.03% for cost and -1.85% for hours are not significantly different from zero at the 10% level of significance. The average model factor is 0.81 with a low standard deviation (2%). Once again, a single model factor would probably suffice in practice, and with only a slight fall in accuracy.

A once-off bridge project would be ideally suited to the more detailed model 1. If, however, the bridge is constructed as part of a road project then the coarser model 2 may be more appropriate. The combination of this latter model with other similar models for the roadworks and other structures would remove the loss in accuracy, due to the central limit theorem.

Development of Road RSCTM

A total of 11 bills were used to develop the road model. They consist of flexible dual carriageway projects. Five bills were used to develop the initial model and 6 were subsequently used to test it. The WBS for the road model is shown in Figure 10.

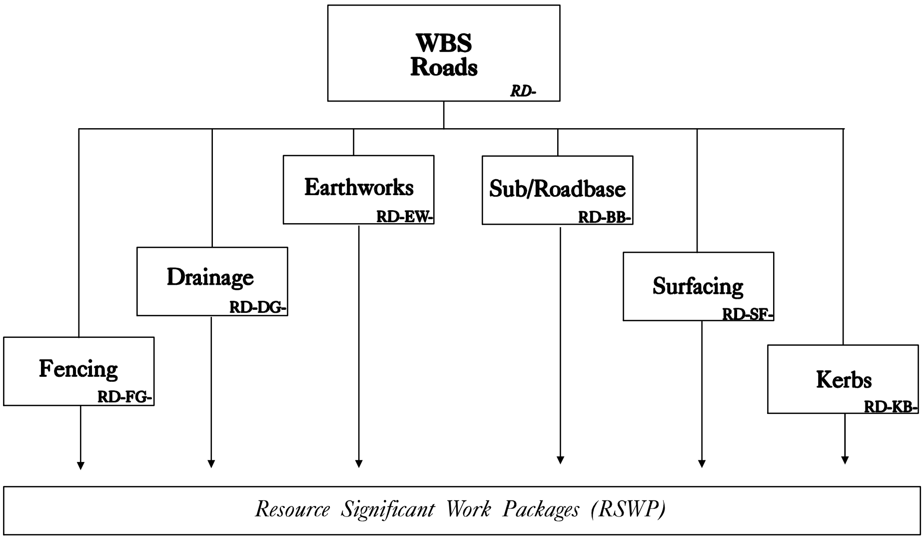

Figure (10): Standard WBS for Road Model

The results are given in Table 10 and the model, containing 22 work packages, is described in Table 11.

Table (10): Results for Road Model 1

Road Model 1							
	C_t	**H_t**	**LC_t**	**LH_t**	**PC_t**	**PH_t**	**MC_t**
Model Factors and expected results							
MF	0.95	0.96	0.95	0.96	0.95	0.97	0.95
s	0.66	2.76	1.77	3.69	3.28	1.45	1.79
Cv	0.69	2.87	1.87	3.83	3.44	1.50	1.88
Results of testing							
Mean Ac	-0.84	-1.40	-0.29	-1.29	0.36	-1.82	-0.97
Cv	3.42	3.11	3.05	2.99	3.40	3.66	3.93

Table (11): Details of Road Model 1

Road Model 1		
Code	**UoM**	**Work Package Description**
Fencing		
RD-FG-1	m	Fencing, excluding temporary fencing
RD-FG-2	m	Safety fencing
Drainage		
RD-DG-1	m	Sewers 100-375mm diameter
RD-DG-2	m	French drains 100-375mm diameter
RD-DG-3	No.	Catchpits and manholes
RD-DG-4	No.	Gullies and kerb manholes
Earthworks		
RD-EW-1	m^3	Excavate topsoil
RD-EW-2	m^3	Excavate natural material in bulk
RD-EW-3	m^3	Excavate rock or artificial hard material in bulk
RD-EW-4	m^3	Disposal
RD-EW-5	m^3	Filling except to subbase
RD-EW-6	m^3	Filling to subbase
RD-EW-7	m^2	Capping reinforcement
RD-EW-8	m^2	Completion of formation
RD-EW-9	m^3	Soiling
RD-EW-10	m^2	Grassing
Sub/Roadbase		
RD-BB-1	m^3	Subbase
RD-BB-2	m^3	Roadbase
Surfacing		
RD-SF-1	m^3	Surfacing
Kerbing		
RD-KB-1	m	Kerbing
RD-KB-2	m	Edging
RD-KB-3	m^2	Footway

Discussion of results

With a Cv of 0.69% and 2.87%, the expected accuracy for the prediction of cost and hours is very good. When tested the results for Cv of 3.42% and 3.11% are higher than the expected accuracies, but nevertheless good. The fact that they are outside the expected accuracy boundaries is not surprising because the projects used to derive and test the model represent two small samples from the population. In addition, the test results are themselves based on the model factors calculated from the sample used to derive the model. A difference in accuracy is thus expected. Overall, however, the test result for cost prediction is once again less than 4%, which was identified before as being acceptable. The average accuracies for the tests of -0.84% for cost and -1.40% for hours are not significantly different from zero at the 10% level of significance. The average of the individual model factors is 0.96 with a standard deviation of 1%. The fact that they correspond so closely indicates that a single model factor would suffice in practice.

Detailed Model Accuracy versus Coarser Model Accuracy

As with the bridge model, the initial road model contains a high proportion of project value. A coarser model was developed which would be of use when the road forms only part of an overall project. The results for this coarser model are shown in Table 12 and the model, containing 13 work packages, is described in Table 13.

Table (12): Results for Road Model 2

Road Model 2							
	C_t	**H_t**	**LC_t**	**LH_t**	**PC_t**	**PH_t**	**MC_t**
Model Factors and expected results							
MF	0.83	0.82	0.79	0.81	0.82	0.85	0.83
s	5.65	5.71	3.53	7.22	4.96	2.71	9.19
Cv	6.82	7.00	4.48	8.97	6.04	3.21	11.02
Results of testing							
Mean Ac	-0.13	-3.14	-2.27	-2.76	0.36	-3.65	1.12
Cv	7.95	7.71	8.68	7.71	7.72	7.75	9.01

Table (13): Details of Road Model 2

Road Model 2		
Code	**UoM**	**Work Package Description**
Fencing		
RD-FG-2	m	Safety fencing
Drainage		
RD-DG-1	m	Sewers 100-375mm diameter
RD-DG-2	m	French drains 100-375mm diameter
Earthworks		
RD-EW-1	m^3	Excavate topsoil
RD-EW-2	m^3	Excavate natural material in bulk
RD-EW-3	m^3	Excavate rock or artificial hard material in bulk
RD-EW-4	m^3	Disposal
RD-EW-5	m^3	Filling except to subbase
RD-EW-6	m^3	Filling to subbase
Sub/Roadbase		
RD-BB-1	m^3	Subbase
RD-BB-2	m^3	Roadbase
Surfacing		
RD-SF-1	m^3	Surfacing
Kerbing		
RD-KB-1	m	Kerbing

Discussion of results

With a Cv of 6.82% and 7.00%, the expected accuracy for the prediction of cost and hours is worse than for the detailed model. When tested the results for Cv of 7.95% and 7.71% are close to the expected accuracies. The average accuracies for the tests of -0.13% for cost and -3.14% for hours are not significantly different from zero at the 10% level of significance. If a single model factor were to be used in practice, the average of the individual model factors (0.82 with a standard deviation of 2%) would only produce a slight fall in accuracy.

General discussion on results

The expected accuracy and test accuracy of the detailed models, expressed as the Cv, are favourable. They generally fall within the 4% target set by Saket (1986), Dmiadi (2000c) and Mair (1991) for project model accuracy. As expected, there is a loss of accuracy when the coarser models are used for both the roads and the bridges. However, as part of a larger project, the loss in accuracy will be offset by the inclusion of other models for structures, etc. As an example, if we assume a roadway project includes two bridge structures, the combined Cv for the total project model, excluding preliminaries, would be 4% for cost (taking 7% as expected accuracy for road and bridges) and 4.3% for hours (taking 7.5% as expected accuracy). This would be acceptable.

Conclusions

1. Resource significance allows individual resources of labour, plant and materials to be analysed by cost and hours, thus ensuring that work which is critical to both the cost and time performance of a project are encompassed.
2. The distribution of cost and hours for each of the three major resources broadly confirms the existence of a 80/20 relationship between value and the number of items containing that value.
3. Resource significant items generally account for 89% of the cost of a project (2.48% Cv) and 86% of resource hours (3.51% Cv) in 35% of the items (15.10% Cv).
4. A significance level of 1.00 was chosen for resource significance analysis of labour, plant and materials because:
   a. A significance level of 1.00 is easily understood and applied.
   b. A significance level of 1.00 introduces a model error of Cv 4.0%.
   c. The significance level of 1.00 would be used to analyse the individual distributions of labour cost (LC), plant cost (PC), material cost (MC), labour hours (LH) and plant hours (PH). When these distributions are combined the overlap was expected to result in a relationship closer to 90/30. A lower level would result in too detailed a model.
   d. Industrialists are familiar with the 80/20 concept.
5. There is a strong linear relationship between the quantity and the resource cost and hours for related work items in a bill of quantities. These items can

be packaged together and the productivity and unit rate predicted on the basis of the productivity and unit rate of the largest quantity.

6. The project and model factor boundaries for a RSCTM should be defined by the design characteristics of the projects as well as a statement of specific exclusions.
7. Contractors can estimate the cost of a project to an accuracy of 6.5% Cv.
8. The RSCTM is expected to introduce a model error of 4.0% Cv, which, when combined with an estimating accuracy of 6.5%, produces an overall accuracy of 7.6% Cv.
9. This loss in accuracy can be offset because the increased time available for the smaller number of items in the RSCTM should promote greater estimating accuracy.
10. A RSCTM containing 26 work packages has been developed for bridges with a cost model factor of 0.90 and an hours model factor of 0.91. The model can predict cost and hours with respective accuracies of 4% and 6% Cv. A coarser model containing 21 work packages can predict the cost and hours to an accuracy of 6% and 7% Cv respectively.
11. A RSCTM containing 22 work packages has been developed for roads with a cost model factor of 0.95 and an hours model factor of 0.96. The model can predict both cost and hours with an accuracy of 3% Cv. A coarser model containing 13 work packages can predict the both cost and hours to an accuracy of 8% Cv.

The individual model factors for resource hours and costs are very close to each other. The averages of the model factors for the detailed bridge and road models have a standard deviation of only 1%, and the averages for the coarser models have a standard deviation of 2%. For the sake of simplicity, a single model factor could be used in practice with only a slight fall in accuracy.

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