USING RISK ANALYSIS TO DETERMINE CONSTRUCTION PROJECT CONTINGENCIES

By Stephen Mak[1] and David Picken[2]

ABSTRACT: A contingency allowance is an amount of money used to provide for uncertainties associated with a construction project. Traditionally, it is a percentage addition on top of the base estimate. Estimating using risk analysis (ERA) is a methodology that can be used to substantiate the contingency by identifying uncertainties and estimating their financial implications. A study of the effect of ERA was carried out to compare the variability and consistency of the contingency estimates between non-ERA and ERA projects. This paper presents results of a survey that compares a total of 287 non-ERA and 45 ERA projects. The results show a highly significant difference in variation and consistency between these groups. It indicates successful use of the ERA method for public works projects to reduce unnecessary and exaggerated allowance for risk. However, the contingency allowance for ERA projects was still considered high. Improvement and refinement of the ERA method as well as recommendations on capital budgeting policy are suggested.

INTRODUCTION

Risk has long been recognized in the construction industry. Contractors are required to accept a certain level of risk due to unforeseen costs that they incur during construction. Risk is also an issue for clients. The term ''clients'' refers to those persons or organizations investing in the construction of built facilities. This risk manifests itself in unforeseen expenditure that was not envisaged at the planning stage. It is the risk to clients that this paper deals with. When cost consultants are preparing feasibility and subsequent planning stage estimates, risk can be reflected by the inclusion of a contingency sum.

The contingency sum, usually expressed as a percentage markup on the base estimate, is used in an attmept to allow for the unexpected. Construction and development is fraught with difficulty, and the basic notion of risk analysis is that it is useful to at least make an attempt to identify these risky items and attach some financial value to them. These amounts can then be added to a project budget as items of possible expenditure. The intention is that the project budget becomes a more realistic representation of the client's likely outlay.

At different stages of project development, there are different types of risk. At the feasibility and inception stages, for example, the client might not have decided exactly on the floor area that is required, or an amount of additional floor area over that in a basic scheme may be in abeyance. Such matters will represent an uncertainty from the estimator's point of view. The depth of piling for foundations is another typical example of uncertainty. Some of the uncertainties will be eliminated or clarified as the planning of the project develops toward detailed design stage when, for example, the client has decided the floor area required. Some uncertainties will be carried forward to tender stage. The use of risk premium money is regarded as standard practice in construction (Raftery 1994). The practice of presenting project cost estimates as a deterministic figure comprising a base estimate and the addition of a single contingency amount (usually as a percentage addition) has been adopted in the construction industry for a long time for budgeting purposes. Usual practice is for this amount to be a single lump sum with no attempt made to identify, describe, and value various categories and possible areas of uncertainty and risk. Often the contingency amount allowed is merely a percentage of the overall project cost. In many cases it amounts to an educated guess at best. If there is some form of tender documentation provided to bidders, the contingency will usually be transferred to the provisional sums section in these documents. In an attempt to deal with the determination of contingencies in a more analytical way the Hong Kong Government implemented a technique called Estimating using Risk Analysis (ERA) in 1993. ERA produces similar base plus contingency cost estimates at pretender stage. For building projects that usually use the government's fixed quantities contract, the magnitude of the final account variations (comprising additions and omissions) can be compared with the contingencies included in estimates. This comparison can be used to assess the accuracy of the allowance made for the contingencies at the planning stages. This paper compares the contingency estimates and final account variations of public works projects by analyzing data sets of pre-1993 (non-ERA) and post-1993 (ERA) projects.

With the traditional approach of guessing at contingencies in mind, it can then be perceived that project proposals (what it is intended to build; for example, the size and the level of quality) will be affected by the contingency amount. If one takes a wider view than just one project, for example, in the case of public expenditure, the task becomes one of distributing the available funds among various competing projects. The situation will arise that some proposed facilities are not included in a construction program due to the limited funds. Having chosen those projects that will be included, the budgeted capital expenditure becomes committed and ''locked up'' for the duration of the program. Sometimes project teams can inflate the contingency allowances in an attempt to avoid the need to seek additional funds if budgets become overspent. However, this inflation can become exaggerated. In such a case if, ultimately, there are no heavy calls on the contingency fund beyond what might reasonably have been expected for the project, budgets can be seriously underspent. The magnitude of the underspending can be so large that it is possible to identify facilities that were previously foregone but could have been included in a construction program in the first place. Explaining situations such as this can be just as embarrassing for project teams as seeking additional funds because of budgets being inadequate to meet unforeseen costs.

It is these matters that prompted the Hong Kong Government to seek alternative methods of dealing with risk and uncertainty in its capital cost estimating. The following sections describe the background to this search for a new methodology.

[1]Asst. Prof., Dept. of Build. and Real Estate, Hong Kong Polytechnic Univ., Kowloon, Hong Kong.

[2]Sr. Lect., School of Arch. and Build., Deakin Univ., Geelong 3217, Australia.

Note. Discussion open until September 1, 2000. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 17, 1998. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 126, No. 2, March/April, 2000. ©ASCE, ISSN 0733-9634/00/0002-0130–0136/$8.00 + $.50 per page. Paper No. 19034.

The issues as perceived by the related government departments are outlined, and the methodology eventually adopted is described. In addition, this paper describes an investigation of the Hong Kong Government's experience in using its new approach.

CAPITAL COST BUDGETING

The Hong Kong Government's Works Branch gives the background to the issue of risk, and how it should be dealt with, in a circular to the various departments responsible for the development and construction of buildings and infrastructure (Works Branch 1992). The view of financial risk is that it emanates from uncertainty about the implications on cost of the design team not having complete information. There can be uncertainty both about the scope of the feature in question and, flowing from that, its value.

Risks can arise from planning decisions, where the outcome cannot be adequately costed. The majority of risks, however, arise from matters yet to be decided (e.g., incomplete brief or no site investigation). Risk assessment of the cost of uncertain features will be present at all stages of a project. The number of risks will normally decrease as a project progresses through the various planning stages of the Public Works Program. Obviously, other risks can arise until planning is complete and during the construction phase.

Estimates are prepared at various stages of the planning process. The specific stages are identified as Feasibility, Category C, Category B, and Category A. As a project becomes more definite (likely to go forward) its category designation is changed—Category A being more certain than Category C. As part of the confirmation process, estimates are prepared at each stage.

The Works Branch identified that there is a need to employ more scientific approaches for dealing with this category of risk in construction projects. These approaches would seek to identify the areas of uncertainty and risk on a project. That is, there would still be a contingency allowance, but the nature of the contingencies would be described, and the amounts allowed against them would be calculated. Briefly, the description would indicate what the risk is and the likelihood of its occurrence. The amount allowed would be an estimate, with backup calculations, of the likely expenditure associated with the risk should it occur.

As the project is developed through the various stages, the process of risk analysis and identification seeks to reduce the level of uncertainty. The Hong Kong Government approach concentrates on the major risks.

As risks are resolved the dollar value is added to the base estimate, which is, in effect, the value of the risk free elements of a project.

CONTINGENCIES

Traditionally, cost estimates are point estimates. That is, single value estimates based on the most likely values of the cost elements. These point estimates may or may not accurately indicate the possible value of the estimate, and they certainly do not indicate the possible range of values an estimate may assume (Toakley 1995). When estimating, the most common method of allowing for uncertainty is to add a percentage figure to the most likely estimate of the final cost of the known works. The amount added is usually called a contingency (Thompson and Perry 1992).

Contingencies are often allowed in cost estimates. The objective of contingency allocation is to ensure that the estimated project cost is realistic and sufficient to contain any cost incurred by risks and uncertainties. However, Thompson and Perry (1992) pointed out several weaknesses of using a contingency amount:

- The percentage figure is, most likely, arbitrarily arrived at and not appropriate for the specific project.
- There is a tendency to double count risk because some estimators are inclined to include contingencies in their best estimate.
- A percentage addition still results in a single-figure prediction of estimated cost, implying a degree of certainty that is simply not justified.
- The percentage added indicates the potential for detrimental or downside risk; it does not indicate any potential for cost reduction and may therefore hide poor management of the execution of the project.
- Because the percentage allows for all risk in terms of a cost contingency, it tends to direct attention away from time, performance, and quality risks.
- It does not encourage creativity in estimating practice, allowing it to become routine and mundane, which can propagate oversights.

There are a number of methods in risk analysis practice that are used to deal with uncertainty. For budgeting purposes, however, rather than indicate a range of figures, there is a need to present an estimate as a fixed amount so that the client can arrange for the financing of the project. The estimate is also important in reaching a decision on whether to proceed with a project, given that the client has only a fixed budget.

There is a tendency for estimators to include an inflated buffer in the contingency estimate. Raftery (1994) has identified personal bias and differences in personal risk attitude. Kahnaman and Tversky (1972) referred to this as ''conservatism.'' The term conservatism originated from studies of human information processing in that individuals tended to revise their opinions in the light of new evidence to a lesser degree than would be expected of an optimal information processing system. This tendency for humans to be less extreme than optimal in their judgments has been termed conservatism in probabilistic information processing.

Moreover, due to the effect of negative sanctions (i.e., imposing a penalty for an underestimate, where tender bids are above the pretender estimate but no reward/penalty for an overestimate), an over-exaggerated contingency is not uncommon in many project estimates. For public works projects, this leads to misallocation of resources as more than sufficient funds are locked up in projects. Misallocation of resources will severely disturb the important fiscal functions of public sector spending in (1) provision of social goods; (2) distribution of income and wealth; and (3) maintenance of a stable economy in the aspects of employment and price levels (Musgrave and Musgrave 1984).

ERA

To alleviate these usually overexaggerated contingency estimates, the Hong Kong Government has introduced the technique of ERA in all public works projects. The Property Services Agency (a government agency that manages government real estate and property) in the United Kingdom was among the first to adopt an ERA style approach that was known as Multiple Estimating using Risk Analysis (HM Treasury 1993).

ERA is used to estimate the contingency of a project by identifying and costing risk events associated with a project. The starting point for the ERA process is a base estimate, which is an estimate of the known scope and is risk free. The contingencies as determined by the ERA process are added to the base estimate. The first step in the ERA process is to identify risks by the project team. These risk items are then categorized as either (1) fixed; or (2) variable. For each risk event, an average risk allowance and a maximum risk allowance are

TABLE 1. Relationship between Risk Allowance and Risk Category in ERA

Type of risk (1)	Average risk allowance (2)	Maximum risk allowance (3)
Fixed risk	Probability × maximum cost	Maximum cost
Variable risk	Estimated separately	Estimated separately
Assumption	50% chance of being exceeded	10% chance of being exceeded

calculated. The relationship between risk category and risk allowance is shown in Table 1.

Fixed risk events are those that either happen in total or not at all. If the event happens, the maximum cost will be incurred; if not, then no cost will be incurred. An example is the need for an additional access road. At the early stages of a project, the client might be uncertain as to whether an additional access road will be required, rendering this as a fixed risk item. The scope of the road, should it be required, can be known and used to determine the maximum risk allowance. The uncertainty is whether the road will be needed or not. The maximum risk allowance is the cost of constructing this access. The average risk allowance is the probability of the client requiring it multiplied by the maximum risk allowance.

Variable risk events are those events that will occur, but the extent to which they will occur is uncertain. The cost incurred will therefore by uncertain and variable. An example is the depth of piles required to be driven. The maximum risk allowance is estimated by the project team members based on past experience or records. This means the most expensive type of piling being required at the maximum length. The Hong Kong Government's ERA method requires an assumption to be made that there is only a 10% chance that the actual cost incurred will exceed this allowance. The average risk allowance is estimated with an assumption of a 50% chance of being exceeded. There can be a mathematical relationship between the average and maximum risk allowance, but it is also legitimate for these two allowances to be estimated separately.

The rationale for using a 50% chance of being exceeded in the average risk allowance is that it is unusual for all identified risks (i.e., the worst case) to occur. The swings and roundabouts effect of the totality of the risk events identified should be able to cover the most likely costs incurred.

Having identified all risk events and calculated their average and maximum risk allowances, the summation of the average risk allowance of all events will become the contingency of the project concerned. Fig. 1 shows a typical ERA worksheet.

ERA Calculation

Project: Construction of the Central Library — Date: 2 March 1995
Client: Urban Council — ERA Run: 1

(1) Risk	(2) Type	(3) Probability (Fixed Risks Only)	(4) Average Risk Allowance $	(5) Max. Risk Allowance $	(6) Spread (5) - (4) $ M	(7) Spread square d $ M
Design Development	V		8,400,000	12,600,000	4.2	17.64
Additional Space	F	.70	11,760,000	16,800,000	5.04	25.4016
Site Conditions	V		525,000	1,000,000	.475	0.2256
Market Conditions	V		4,000,000	8,500,000	4.5	20.25
A/C Cooling Source	V		250,000	1,250,000	1	1
Access Road	F	.50	250,000	500,000	.25	0.0625
Additional Client Requirements	V		1,680,000	4,200,000	2.52	6.3504
Contract Variations	V		8,400,000	12,600,000	4.2	17.64
Project Co-ordination	V		500,000	1,500,000	1	1
Contract Period	F	.60	1,000,000	1,750,000	.75	0.5625
			36,765,000			90.1326
					Sq Root	9.494

Maximum Likely Addition = $9,494,000

Base Estimate = $168,000,000
Average Risk Estimate = Base Estimate + *Total* Average Risk Allowance
= $204,765,000 (21.88% on base)

Maximum Likely Estimate = Base Estimate + Average Risk Allowance + Maximum Likely Addition
= $214,259,000 (27.54% on base)

Note: *The Maximum Likely Addition is the figure (the additional amount) which would flow from a situation where every identified risk identified by the project group occurs in total with maximum financial consequences. This is seen as a catastrophic set of circumstances. The mathematical expression of the combined effect of the maximum risk allowances is that they do not add together by simple addition. This situation is dealt with by the Central Limit Theorem - that is the various maximum risk allowances for each risk add together by the sum of their squares.*

FIG. 1. Example of ERA Worksheet at Sketch Design Stage

ERA Calculation

Project: Construction of the Central Library — Date: 11 September 1995
Client: Urban Council — ERA Run: 2

(1) Risk	(2) Type	(3) Probability (Fixed Risks Only)	(4) Average Risk Allowance $	(5) Max. Risk Allowance $	(6) Spread (5) - (4) $ M	(7) Spread squared $ M
Design Development	V		5,400,000	9,000,000	3.6	12.96
Additional Space	F	No longer a risk			-	-
Site Conditions	V		250,000	750,000	.5	.25
Market Conditions	V		0	4,250,000	4.25	18.0625
A/C Cooling Source	V	No longer a risk			-	-
Access Road	F	No longer a risk			-	-
External Cladding	V		3,150,000	4,500,000	1.35	1.8225
Redesign	F	.75	2,275,000	3,030,000	.755	.5700
Additional Client Requirements	V		1,800,000	3,600,000	1.8	3.24
Contract Variations	V		9,000,000	13,500,000	4.5	17.64
Project Co-ordination	V		0	500,000	.5	.25
Contract Period	F	.90	1,800,000	2,000,000	.2	.04
			23,675,000			54.835
					Sq Root	7.405

Maximum Likely Addition = $7,405,00

Base Estimate = $180,000,000
Average Risk Estimate = Base Estimate + *Total* Average Risk Allowance
= $203,675,000 (13.15% on base)

Maximum Likely Estimate = Base Estimate + Average Risk Allowance + Maximum Likely Addition
= $211,080,000 (17.27% on base)

FIG. 2. Example of ERA Worksheet at Pretender Stage

ADVANTAGES OF ERA

The ERA process is usually carried out several times during the pretender period for any one project. Fig. 2 shows the ERA calculations for another stage of the same project. As the project develops, some events that were originally identified as uncertain will be clarified and will be either deleted from the list of risk events or included in the base estimate as a certainty. For example, the requirement for the secondary access road may have been confirmed. The remaining uncertainties will form the final contingency allowance. Fig. 3 shows how the total average risk allowance evolves at successive ERA exercises as more becomes known about the uncertain items identified. Fig. 4 shows the relative proportion of risk allowance (contingency) and base estimate at different stages of the project. It should be noted that the use of ERA does not necessarily reduce the total cost of a project. It makes it less uncertain. A distinct advantage of ERA lies in its ability to retain the traditional method of presenting a project cost estimate in the form of a base estimate plus a contingency. It imposes a discipline from the outset to systematically identify, estimate cost, and consider the likely significance of any risks associated with a project. It also aids financial control in having risk and uncertainty costs identified before action is taken to determine precise requirements. Furthermore, the itemized and substantiated contingency forms the basis on which to evaluate the impact of risk and uncertainties upon completion of the project, thereby providing useful data for use in investment appraisal. In short, it is a mechanism for accountability for public money. Rigorously done, it will reduce the usually conservative and excessive percentage add-on contingency and lead to a better allocation of resources.

EMPIRICAL DATA

A summary of completed projects was received from the government in December 1997 that detailed the contract sum, original contingency, amount of additions, amount of omissions, final account amount, and start date of 332 building projects, as shown in Table 2. Forty-five of these building projects used the ERA process for determining contingencies and 287 were done by the traditional method. Because all of the building projects used the government's standard forms of contract, it is possible to compare the contingency allowance against variations. The original contract sums ranged from HK$0.31M to HK$1,331.0M. Only 15 projects had a contract sum larger than HK$100M.

A new variable, *DEVI*, defined as the ratio between the amount of contingency and the amount of variation at final account, was used to reflect the accuracy of the original contingency estimate, having included all the additions and omissions in the final account. In most building contracts, a fixed contract sum is used whereby a contractor is paid according to a sum shown in the contract documents. Only if there are variation orders will the contractor be paid accordingly. Therefore, the summary of variations should, by and large, reflect how accurately the estimator has calculated the uncertainties at the pretender stage. If the value of *DEVI* is 1, then there is a perfect match between contingency and variation, and the contingency is capable of covering uncertainties.

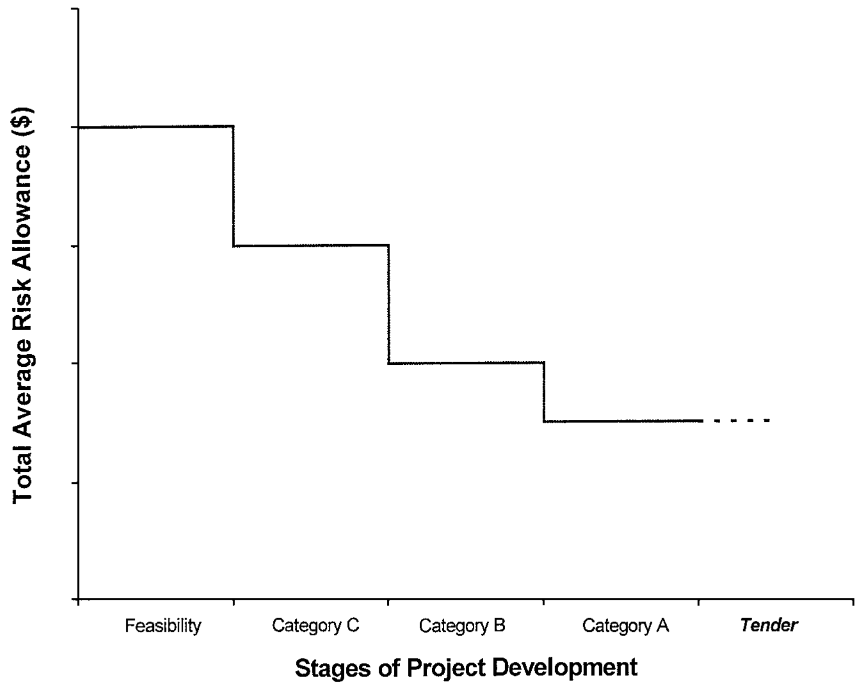

FIG. 3. Total Risk Allowance versus Stages of Project Development

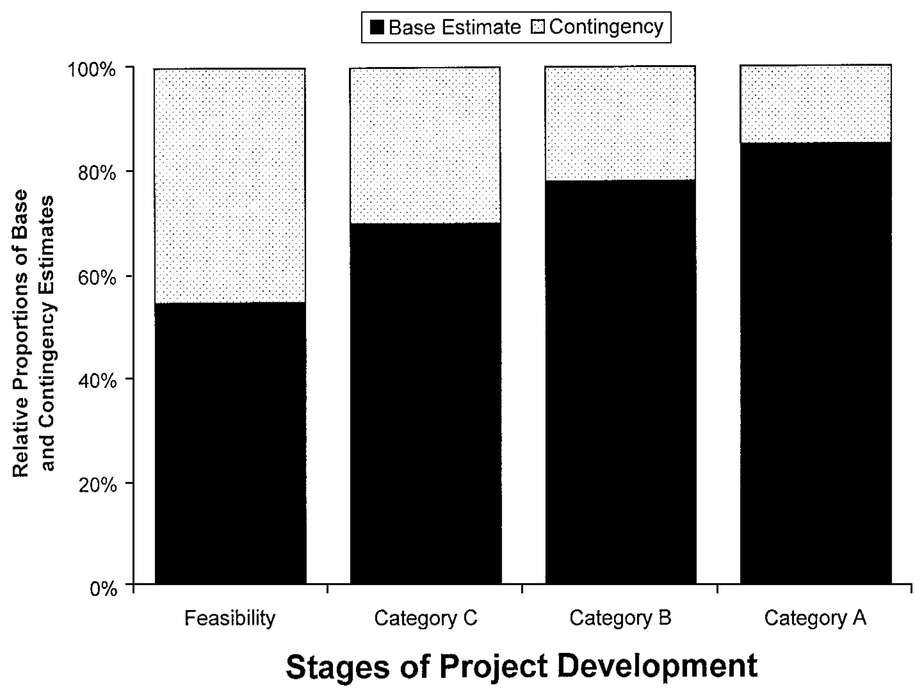

FIG. 4. Proportion of Total Risk Allowance versus Stages of Project Development

TABLE 2. Summary of Raw Data

Statistic (1)	Non-ERA (2)	ERA (3)
Number of projects	287	45
Contract sum (minimum)	0.31M	0.99M
Contract sum (maximum)	1,331.01M	208.48M
Contingency (minimum)	0.15M	0.08M
Contingency (maximum)	110.00M	38.00M
Contingency/contract sum (minimum)	0.67%	4.02%
Contingency/contract sum (maximum)	137.40%	18.23%
Final account variation (minimum)	6.00K	41K
Final account variation (maximum)	85.98M	27.39M
DEVI (minimum)	0.10	0.30
DEVI (maximum)	45.00	6.64

If the value is higher than 1, then there is surplus in the contingency fund and vice versa. A negative *DEVI* value means that the amount of omissions is larger than additions, that is, a net reduction in final contract sum.

ANALYSIS

It was hypothesized that the ERA process should produce better project estimates by making more realistic allowances for contingencies. Better project estimates means the mean and standard deviation of *DEVI* should be consistently smaller for projects with ERA than those without ERA.

Table 3 shows that the variance for ERA and non-ERA projects are 2.9387 and 28.0390, respectively. The variance for non-ERA projects is surprisingly high. This is contrary to the law of large numbers due to its sample size compared with ERA projects. This can be attributable to the fact that a fixed or blind percentage was added to the base estimate to arrive at the contingency amount for non-ERA projects.

An analysis of the *F*-statistic, which is the ratio between the two variances, shows that the *F* value is 9.5412, which is much higher than the critical value of *F* (1.7998) at the 1% significance level ($p < 0.00001$). Thus, the hypothesis that the variances of the two populations are equal is rejected. It can therefore be concluded that there is a significant difference between the variances of the two populations, which indicates that the variability of contingency allowance for non-ERA projects was much higher and that the contingency allowance for ERA projects was more consistent.

Table 3 also shows the mean values of *DEVI* of the two groups of projects. It can be seen that the mean for ERA projects is 2.1490 whereas that of non-ERA projects is 3.1498, indicating that an average of 115% more funds has been set aside for uncertainties in ERA projects and an average of 215% more for non-ERA projects. It is not surprising that both methods resulted in excess funding reserved for uncertainties as estimators are usually conservative, as discussed above (Kahnaman and Tversky 1972; Raftery 1994). However, the discrepancy of nearly two times (115% versus 215%) the contingency allowance in non-ERA projects has resulted in severe misallocation of resources. When contingencies are exaggerated in this way, some projects under consideration in a given phase of a public works program have to be foregone or deferred due to insufficient funds.

It was hypothesised that the ERA process should lead to a smaller *DEVI* value than the non-ERA process. A one-tail *t*-test was used to determine whether the means of the two groups are different, with the assumption of a different variance (supported by the *F*-statistic). The resultant *t*-value is 2.4788 with 204 degrees of freedom (Table 4). This is larger than the critical value for *t* (2.3488) at the 1% significance level ($p = 0.0070$). The hypothesis that the means of *DEVI* for the two groups are equal is rejected. It can therefore be concluded that the ERA group had a much smaller *DEVI* value than the non-ERA group of projects. The low significance level of <1% reveals that the contingency allowance for non-ERA projects was highly exaggerated.

TABLE 3. *F*-Test Result for Variable *DEVI*

Statistic (1)	Non-ERA (2)	ERA (3)
Mean	3.1498	2.1490
Variance	28.0390	2.9387
Observations	287	45
df	286	44
F	9.5412	—
$P (F \le f)$ one-tail	0.0000	—
F critical one-tail (1%)	1.7998	—

TABLE 4. *t*-Test Result for Variable *DEVI*

Statistic (1)	Non-ERA (2)	ERA (3)
Mean	3.1498	2.1490
Variance	28.0390	2.9387
Observations	287	45
Hypothesized mean difference	0	—
df	204	—
t	2.4788	—
$P (T \le t)$ one-tail	0.0070	—
t critical one-tail (1%)	2.3448	—
$P (T \le t)$ two-tail	0.0140	—
t critical two-tail (1%)	2.6001	—

The *F*-statistic supports the hypothesis that the contingency allowance was more variable for non-ERA projects and more consistent for ERA projects. The *t*-statistic supports the hypothesis that the contingency allowance was much smaller for ERA projects.

Having said that, it was considered that, on average, the contingency allowance for ERA projects was still very high. This can be revealed from the mean value of 2.1490 of the variable *DEVI*. That is, the contingency allowance was overestimated by 115%. This certainly will also lead to misallocation of resources. There is an urgent need to further refine the techniques of ERA. Possible solutions may include (1) the provision of historical project records for making knowledgeable estimates; (2) a review of the policy of capital budgeting; and (3) a study of the effects of positive and negative sanctions on estimators. These will be discussed in greater detail in the Recommendations and Conclusions sections.

USERS' FEEDBACK

Beyond the statistical analysis of contingency funds, variations, and contract sums described above, it was also considered useful to examine the views of the estimators who were required to implement ERA. A questionnaire was developed for this. In the questionnaire survey, estimators who have used ERA were asked to rank on a scale of 1 to 5 the importance of three factors for their using ERA (they ranked the factors independently instead of ranking the relative importance of the factors). It was revealed that ERA was applied to all types of government building projects such as government offices, fire stations, and airport projects. ERA was used an average of four times throughout the pretender stage of a project. A severity index was used to measure the perceived importance of various factors in motivating the respondents to use ERA. In particular, three areas were identified, namely, ERA being a policy requirement, ERA helping to identify accountability, and ERA's potential for accuracy in determining contingency allowances. Table 5 shows the summary of the findings.

It can be seen that the respondents, who were government officials, saw policy as the most important factor for using ERA. Achieving accuracy in estimating was ranked least important among the three attributes. These results were no surprise as one reason for introducing ERA was accountability at management level due to severe underspending of budgets in the early 1990s.

The respondents also expressed difficulties in implementing ERA due to a lack of data and records for them to determine the probability of occurrence of risk items and the cost associated with these items. These would make estimating less realistic. They expected more feedback to be made available from past projects.

RECOMMENDATIONS

Although there has been a great deal of improvement in the estimate of contingency allowance having implemented the

TABLE 5. Summary of Feedback

Rank (1)	Policy requirement (2)	Accountability (3)	Accuracy (4)
1 (most important)	15	2	1
2	2	9	7
3	3	5	6
4	1	3	4
5 (least important)	0	2	3
Number of respondents	21	21	21
Severity index	86.90	57.14	48.81

ERA technique, the contingency allowance was still considered to be overly exaggerated (115% more on average). This reinforces previous findings that estimators are conservative, as reported by Edwards (1968) and Raftery (1994). From the feedback of estimators who were using ERA, it was found that they used ERA because they were required to do so and they they viewed ERA as a mechanism of accountability more than a way of improving the accuracy of estimating. Nonetheless, they also expressed the insufficiency of historical data for them to make better estimates of uncertainties.

Therefore, several measures can be considered to improve the effectiveness of the ERA technique. First, historical data of finished projects have to be made accessible. In view of the nature of construction projects with data being stored in different formats such as site diaries, calculation sheets, payment forms, and even annotated drawings, the use of information technology is very desirable. To this end, there needs to be further studies.

Second, a sanction or rewarding system has to be implemented, particularly in view of the relatively passive reception of the ERA technique. Accurate estimates, for instance, within ±50% of contingency, should be rewarded whereas the penalty for an overestimate should be similar to that of an underestimate.

Third, for even better accountability to be achieved in the expenditure of public money, the totality of public works spending should be scrutinized instead of on a project-by-project basis. When it is extremely difficult to ask for budget top-up in case of an underestimate, there is a tendency to overestimate. If the swings and roundabouts principle is applied to the whole of public works spending, then projects that are underestimated can be compensated by savings from projects that are overestimated. Taking a more macroview, this should lead to the ultimate goal of good allocation of resources.

Finally, a long-term record of estimating accuracy should be kept so that the Treasury Department can make appropriate adjustments to applications for public works budgets, based on performance of previous years. This will, in one way or another, correct the effect of reporting bias as described in Raftery (1994).

CONCLUSIONS

ERA is a simple to use method for implementing the use of risk analysis in estimating for construction projects. The way it handles risk analysis is consistent with the traditional practice of estimators at pretender stage to produce a deterministic figure in advising clients of likely bid levels. Empirical findings from a government department showed that the use of the ERA approach has improved the overall estimating accuracy in determining contingency amounts. The samples in this study revealed significant improvement in project estimates as the mean and variance of ERA projects are consistently smaller than those of non-ERA projects. Further research should be carried out to increase the sample size, particularly that of ERA projects. Clustering of projects into different sizes may also be useful to explore the effects of project size (complexity) and type (building, civil engineering, HVAC) on the uncertainty of estimates. To further improve the accuracy of contingency estimates, a number of measures are suggested that include the use of information technology to make historical data more readily accessible, the implementation of equal sanction/reward for both under- and overestimates, and adjustment of the amount of budget requests by the Treasury.

APPENDIX. REFERENCES

Edwards, W. (1968). ‘‘Conservatism in human information processing.’’ *Formal representation of human judgment*, B. Kleinmuntz, ed., New York. Wiley,

HM Treasury. (1993). ‘‘Managing risk and contingency for works projects.’’ *Guidance Note No. 41*, Central Unit on Procurement, Her Majesty’s Treasury, U.K.

Kahneman, D., and Tversky, A. (1972). ‘‘Subjective probability: A judgment of representativeness.’’ *Cognitive Psychology*, 3, 430–454.

Mak, S., and Raftery, J. (1992). ‘‘Risk attitude and systematic bias in estimating and forecasting.’’ *J. Constr. Mgmt. and Economics*, 10(4), 303–320.

Musgrave, R. A., and Musgrave, P. B. (1984). *Public finance in theory and practice*. McGraw-Hill, New York.

Raftery, J. (1994). *Risk analysis in project management*. E&FN Spon, London.

Thompson, A., and Perry, J. G. (1992). *Engineering construction risks: A guide to project risk analysis and risk management*. Thomas Telford, London.

Toakley. (1995). ‘‘Risk management applications—a review.’’ *Australian Inst. of Build. Papers*, 6, 77–85.

Works Branch Government Secretariat. (1992). ‘‘Works Branch Technical Circular No. 21/92: Estimating using risk analysis.’’ *Works Branch Internal Document*, Hong Kong Government, Hong Kong.