# DATA-DRIVEN ANALYSIS OF "CORPORATE RISK" USING HISTORICAL COST-CONTROL DATA

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**ABSTRACT:** The process of risk management includes three phases of risk identification, risk quantification, and risk control. Of the three phases, many managers agree that the major benefits of risk management are derived from the insights through the way project risk is identified. The approach for managing project risks may be broken down into two ways. One way is to analyze risks by those unique characteristics associated with individual projects, and implement project strategies by a single project. Another approach may be to classify risks into similar groups, those that exist simultaneously and routinely in a portfolio of company's projects, and adopt corporate strategies across projects. This paper is concerned with the second approach. This research postulates that there exist some covariable risks, or corporate risk, among a company's project portfolio, and maintains the hypothesis that such risks could be diminished efficiently using strategies made at the higher levels of corporate management rather than strategies at the project level. While most managers may acknowledge this assertion, they often lack a useful tool by which to analyze risk at issue. As a result, the major goal of this paper is to provide managers with a theoretical framework of risk analysis methodology that will support analyzing a project's risks from their company's point of view.

## INTRODUCTION

One of the premises underlying this research depends on the fact that the large number of references discussing risk strategies have been limited to those concerning bid/no-bid decision-making (Vergara 1977; Carr 1982). Other strategic issues in construction include considerations such as organization, financing, and technology. The strategies regarding these other issues are also important to maximizing company's profit after projects are bid, and it is mainly for this purpose that many construction managers are expected to play an important role within a company.

In construction management, what often occurs is that the task of managing risks falls to personnel at the project level. In other words, project risks are quantified and controlled with one project at a time. At the project level, management has begun to develop and integrate various contractual and organizational strategies. The use of joint venture, for example, has fulfilled the need to diversify project risks and increases their cost effectiveness. The application of recently developed management strategies such as incentive plans (CII 1988) and contractual risk allocation (CII 1989; Levitt et al. 1980) may also be good examples of project strategies.

It must be realized, however, that most construction companies operate multiple projects at the same time. That is, they operate a portfolio of projects in which the uncertainty of different tasks is dependent on inherent, common risk factors among projects simultaneously. The importance of recognizing common risks is that it may motivate managers to control them in a group of projects. Developing management strategies at the corporate level has only just begun. The recent emergence of alliances (or partnering) and strategic benchmarking (Watson 1993) are examples of an innovation in corporate management strategies.

The risk management process is a continuous cycle that consists of risk analysis, strategy implementation, and monitoring. Decisions made by management when selecting possible management options depend on the value of control, which is the benefit obtained by controlling risks rather than taking no actions on them. In other words, the calculation of value of control requires the evaluation of the trade-off between risk reduction and the needed costs of control from different levels of management functions. In an attempt to develop management strategies, it is, therefore, necessary to quantify uncertainty involved in projects.

The appraisal of corporate risk as proposed in this paper requires that the likely extent of variable factors and their interactions be assessed. While the difficulties of accommodating the interaction of various risk factors into risk analysis are acknowledged, a simple yet comprehensive scientific method of risk quantification of covariable risks should considerably enhance the opportunity for managers to plan effective corporate strategies for implementing a company's projects.

In the field of construction, a major factor preventing the widespread use of analysis tools based on science is the tremendous effort needed to gather information. There are many types of research devoted to project risk analysis. Acquiring the knowledge of experienced people, empirical studies, and complicated statistical analyses, that generally need complex and time-consuming procedures of data acquisition is common to all methodologies. Despite this difficulty, however, many construction companies have already developed a sophisticated cost-control system and collected data from previous projects. These data, although very expensive, are nonetheless valuable for applying risk analysis to future projects. Generally, the major use of such data is still limited to making estimates of construction costs during bidding. However, if a company's cost-control information extracted from completed projects were used more efficiently, it would greatly enhance the data acquisition process and reduce the corporation's costs.

The research in this paper focuses on the issue of project risk arising from multiple projects undertaken by a single company. The result is the development of a risk analysis methodology in which interactions of various risk factors among projects are considered. The methodology quantifies covariable risks using a company's cost-control data.

The following section shows the basic concept of corporate-risk identification. At the center of this discussion lie concepts and insights drawn from modern portfolio theory (MRT) that are used to develop the concept of corporate risk. Second, a single-index model is then shown to obtain beta, the performance regression coefficient relating the performance of a cost element to the overall project performance of completed projects, which will serve as a measure of corporate risk. Third,

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J. Constr. Eng. Manage., 1998, 124(1): 42-47

an example analysis using actual cost-control data of a Japanese contractor is shown to illustrate some of the key features of the developed model.

## IDENTIFICATION OF CORPORATE RISK

A project includes different cost elements associated with inherent risk factors that arise from combinations of political, economic, industrial, and company conditions common to multiple projects, as well as from conditions specific to individual projects. For example, some risks associated with safety may be common to steel work, concrete work, and others in the project. Similarly, economic risks, such as inflation, may affect the price of steel, concrete, and other materials simultaneously. On the other hand, individual cost elements are also exposed to risks that are unique to each of them. For example, the productivity of steel work may be affected by bad weather or the absence of some key person at the time a job is carried out (Fig. 1).

The uncertainty of a project can be quantified as an aggregation of the uncertainty of its cost elements by dividing the uncertainty of a given cost element into two parts: one that arises due to the interactions of common, or covariable risk factors that affect multiple cost elements simultaneously, and the other that results from unique risk factors within the cost element independently. In this paper, the former type of risk is termed as "dependent risk," and the latter as "independent risk." Thus, the total risk run by a project consists of its dependent and independent risks.

$$\text{Total Risk of a Project} = \text{Dependent Risk} + \text{Independent Risk} \quad (1)$$

The classification of a project's risk described in the preceding text may have a significant impact on management's decision-making when they are developing management strategies. While both dependent and independent risks are important for managers, the phenomenon caused by independent risks within a single project is basically a matter confined to individual projects since it arises due to unique conditions of risks within individual projects, or project risk. On the other hand, most construction companies operate multiple projects at the same time, and dependent risks are likely to be observed

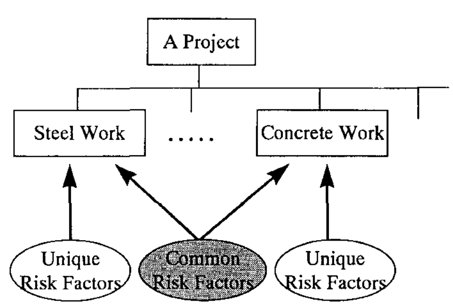



**FIG. 1. Identification of Risk Affecting Uncertainty of Project**

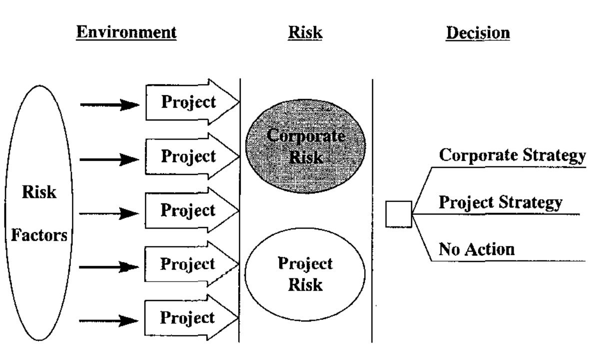



**FIG. 2. Risk Classification and Management Decision-Making**

across several projects as well as within a single project. While the decision to manage dependent risk at either the corporate or project level is a matter of anticipated result effectiveness, when some dependent risks are recognized as a matter of a company's projects as a whole, they may become a company-wide problem, or corporate risk (Fig. 2). Then, it is hypothesized that effective risk reduction may be possible if uncertainty due to dependent risk factors could be managed simultaneously in a company's project portfolio (Minato 1994), since the uncertainty increases rapidly as more and more "related" projects are added to a company's project portfolio.

Not only does corporate risk have a synergistic relationship with corporate strategies like partnering, but it also has a tremendous role to play in the development of other innovative management approaches from a company's point of view. While many managers may acknowledge the potential in this line of management philosophy, they often lack a useful tool by which to analyze the risks at issue. As a result, a rigorous, systematic methodology for quantifying dependent risk should be developed as tool, with the added benefit of aiding managers assessing risks from their company's point of view.

At this point, the problem may be reduced to quantifying the uncertainty due to dependent risk. One of the best sources of information to estimate the uncertainty for any future project may be company's cost-control data from past projects. Each construction company may have its own cost-account system that is hierarchically and logically formulated with a common numbering system generic to its own construction types. If a company keeps a well-defined, cost-account system, the standardized cost codes will provide a structural uniformity and a basis for comparing every project run by a company.

At completion, the performance of a single project can be defined using two numbers: actual cost and the expected cost. With these numbers, performance is measured by the following equation:

$$\text{Performance}(\%) = \frac{\text{Actual Cost} - \text{Expected Cost}}{\text{Expected Cost}} \quad (2)$$

Expected cost is the budgeted or estimated cost of the work before construction starts, actual cost is the aggregated, end-of-construction cost at completion. In (2), positive performance denotes cost overrun, and negative performance cost underrun.

Within a project control system, since a project can be represented as a combination of its component work packages (CII 1987), the performance can be calculated for not only the overall project, but any work packages of completed projects. In addition, standardized numbering of a cost-account system allows work packages to be formed by sorting cost accounts into any combination for the purpose of performance calculation. The aggregation of such numbers from completed projects is a random variable that forms a certain probability distribution of historical project performance of the company (Fig. 3).

The specific question to be answered in this paper is: "what will the probability distribution of a project's uncertainty due to dependent risks look like?" In quantifying risk, an "anchoring" characteristic of project risks that might first come into a contractor's mind may be the scale of uncertainty on the final project performance. That is, risks are simply thought to be important whenever the dispersion of performance is large. The parameter used to describe the dispersion is variance, showing the potential for the degree of deviation from its expected value. However, variance reveals nothing about the way in which the covariable portion of risk is calculated in a project's or firm's bundle of work packages. In statistics, the factor that does provide this information with regard to



J. Constr. Eng. Manage., 1998, 124(1): 42-47

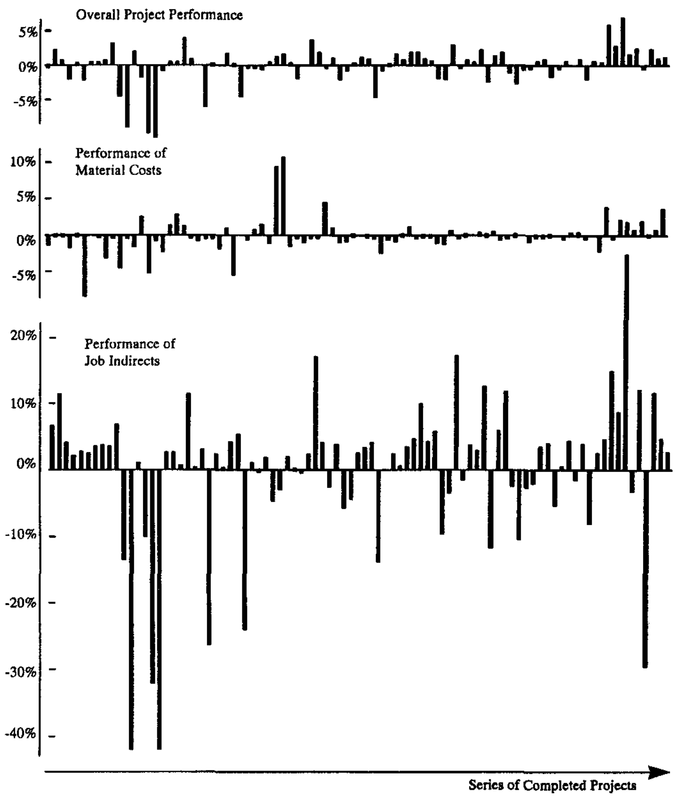



**FIG. 3. Historical Performance of Projects**

interaction of risk variables is the covariance, which represents the joint-probability distribution among various random numbers.

The exact procedure for calculating the covariance among the performances of component cost elements of a project is to use a variance/covariance matrix and assume a one-to-one correspondence of the elements. However, the practical problem with this approach becomes apparent when a project is divided into a large number of cost elements that are relevant to the analysis. As the number of elements becomes larger, the number of covariances to be handled also becomes larger, but in a squared manner. Moreover, the critical problem is that each entry in the variance/covariance matrix does not reflect the classification of risk into either dependent or independent.

To estimate the covariable portion of the uncertainty of a particular cost element, "beta," the ratio of the covariance between the performance of the cost element and overall project performance is calculated by the following equation:

$$\text{Beta} = \frac{\text{covariance with overall project performance}}{\text{variance of overall project performance}} \qquad (3)$$

In statistical terms, (3) is nothing more than the regression coefficient in which the performance of a cost element responds to the pull of an indexed variable which, in this case, is taken to the overall project performance (Fig. 4). Beta measures the contribution of a cost element to the deviation of an overall project performance, and the degree of the contribution depends on how the cost element is related to the variability of the overall project performance.

What is most important in the preceding mathematical formulation is the notion of beta. The principles of that beta, developed in the *Capital Asset Pricing Model*, and accordingly used in the single-indexed market model (Haugen 1990) in modern portfolio theory, are applied here. The way a financial portfolio is analyzed depends on the condition that the risk of the portfolio is quantified by the interrelationship between securities. The insight of beta in the market model postulates that it measures the covariance risk of a security with regard to the variance of a market portfolio, which represents the systematic risk. The presumption underlying systematic risk is that it relates to the risk in the market as a whole. In other words, systematic risk may be viewed as being subject to changes, particularly changes that occur in a macroeconomic environment in which all securities in the market are affected to some degree.

Using the previous notion of modern portfolio theory, the synthesis used in developing the idea of beta in (3) is that it relates the market return to overall project performance and the return of individual securities to the performance of the cost elements of projects, respectively. When this logic is applied to construction projects, it is not unreasonable to think that the effect of multiple risk factors on various cost elements of a project can be measured through the beta value tied to the overall project performance. In other words, a portion, or all of the covariability that is caused by the interaction of multiple, common risk factors of a cost element could be measured by beta, since it represents the correlated portion of the performance of a cost element against the variation of the project's overall performance. As a result, the task of quantifying dependent risk is to obtain the beta value of individual cost elements that constitute either a unit of construction, a project, or, accordingly, a group of projects (Fig. 5).

It should be noted here that the proposed approach enables the uncertainty of a project to be estimated within the cost-control system of a company. In other words, the proposed methodology consists of a "component analysis" within the cost-account system, and differs from an approach using external variables that serve as explanatory indices. As a result, the strength of this approach is that it represents a significant increase in efficiency in the data acquisition process.

## MATHEMATICAL MODEL

By assuming that the performance of a particular cost element responds to the level of a project's overall performance, the pair of time-history data between the output and the input

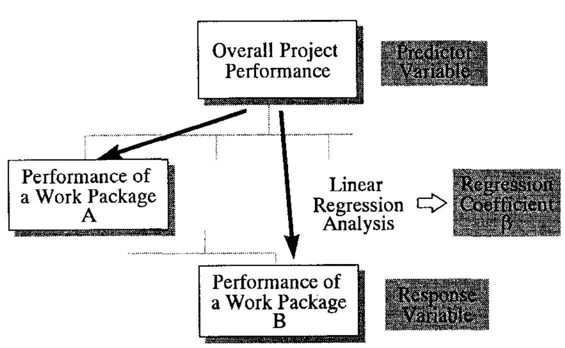



**FIG. 4. Regression Analysis**

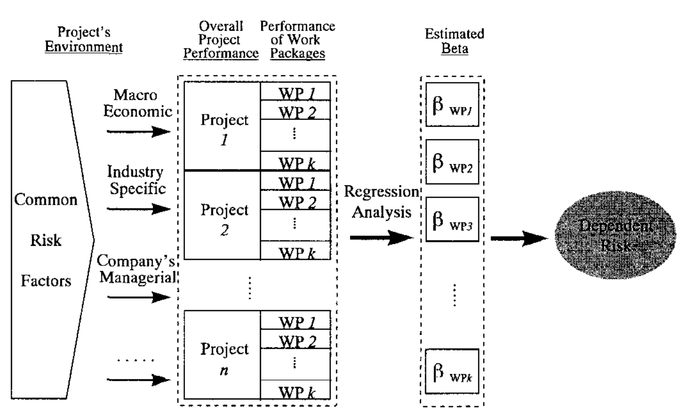
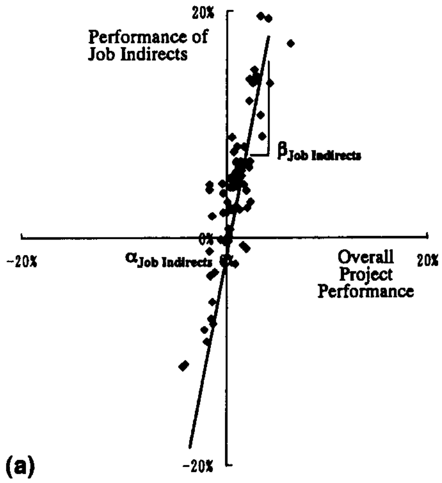



**FIG. 5. Analysis of Dependent Risk**



J. Constr. Eng. Manage., 1998, 124(1): 42-47



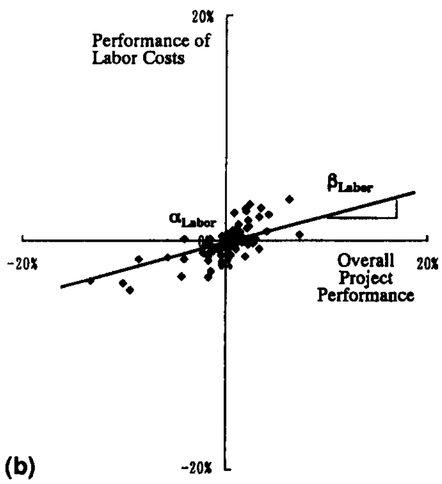




**FIG. 6. Calculation of Beta: (a) Job Indirects; (b) Labor Costs**

from completed projects can be plotted to obtain a regression line. For example, using the data of the example analysis later used in this paper, the pair of numbers between job indirect costs and overall project performance is plotted in Fig. 6(a), and the pair of numbers between material costs and overall project performance is plotted in Fig. 6(b). In either Fig. 6(a) or 6(b), the plot represents the underlying joint probability distribution between the cost element and overall project performance, and, in those areas of the figures where the pairs of data are most highly concentrated, it is shown that there is a higher probability of occurrence for the pairs of performances.

The straight lines going through the pair of data in Fig. 6, which are single-index regression models, are expressed as

$$\tilde{x}_j = \alpha_j + \beta_j \tilde{x}_P + \tilde{\varepsilon}_j \tag{4}$$

where $\tilde{x}_p$ and $\tilde{x}_j$ (random variables) = performance of the overall project and a particular cost element $j$, individually; and $\varepsilon_j$ = residual term. The line is the "best fit," which means that there is no other line that could be drawn in such a way that the deviation of the residual term is smaller than the one of the best fit.

The alpha factor in (4) is represented by the intercept of the regression line on the vertical axis. It is equal to the average value of the performance of a cost element, which cannot be explained by the overall project performance. In other words, the alpha represents the average of variation about the line resulting from the risk factors unique to individual projects, such as lower productivity due to unexpected weather, etc.

The beta factor, on the other hand, is the slope of regression line and it is calculated as follows:

$$\beta_j = \frac{\sigma_{j,p}^2}{\sigma_p^2} = \rho_{j,P} \frac{\sigma_j}{\sigma_P} \tag{5}$$

where $\sigma_{j,p}^2$ = covariance between the performance of a particular cost element $j$ and overall project performance; $\sigma_j$ and $\sigma_p$ = standard deviations of the particular cost element $j$ and overall project performance; and $p_{j,p}$ = correlation between the performance of the particular cost element $j$ and overall project performance. Since these quantities are derived from past reference projects, the calculated $\beta_j$ is a "historical" parameter.

Using (4), the estimated performance of a cost element can be subdivided into two portions: (1) One that depends on the overall project performance, or dependent risk; and (2) the other is represented by what is left over after dependent risk is accounted for, or independent risk. This, in turn, means that the performance of a cost element is "risk-adjusted" by these two parameters. It should be remembered here that the need for risk evaluation is governed by a manager's objectives when developing specific strategies. If the manager is in the role of controlling many projects simultaneously, then the variation due to dependent risks may be the relevant measure on the overall level of risk in the company's project portfolio. If, however, a manager focuses on project-specific risks, then direct attention may be given to the variation due to independent risks. While the calculation of the risk-adjusted performance of a cost element can basically be based on one of these two viewpoints, the variation due to independent risks is ignored here because the objective of this paper is to look at the dependent risk that is caused by the interaction of risk factors common to a company's projects.

Similarly, the variance in performance of a cost element consists of two portions: one that is correlated with dependent risk, and the other with independent risk. Without independent risk, the valuation of dependent risk is straightforward, and it is quantified as beta times the standard deviation of overall project performance:

$$SD(\tilde{x}_j) = \beta_j \sigma_P \tag{6}$$

The tacit assumption of this proposed mathematical model is that the calculation of the regression coefficient, beta, consists of a linear regression analysis. This formulation is then accompanied by a key feature of beta, namely, that the estimated historical betas for various cost elements are "additive." In other words, when various cost elements are combined to form a new work package, its beta is calculated from its component cost elements. In fact, the beta of each segmented work package is calculated as a weighted average of the estimated betas of its component cost elements. This characteristic, beta's additivity, enables the estimated betas to be used to predict either part or all of new projects' uncertainties.

It should be also noted that cost elements with large positive values of beta contribute more to the dependent risk of a project. On the other hand, if there is a cost element with a negative value for beta, it means that the cost element contributes to diversifying the uncertainty of the project. With (5), the beta of the indexed variable, which in this case is the overall project performance, is calculated as 1.0. If beta of a cost element is greater than 1.0, then the cost element is more volatile than the index. As a result, corporate managers should direct attention to those cost elements with a beta greater than 1.0.

## EXAMPLE ANALYSIS

The preceding methodology has been used by a Japanese road construction contractor working primarily for regional governments. The company operates approximately 30 projects a year, or about $15,000,000 in contracts.

Within the company's cost-account system, project costs are first categorized into material costs, labor costs, and job indi-



J. Constr. Eng. Manage., 1998, 124(1): 42-47

rects, each of which accounts for approximately 20, 60, and 20% in the company's total accounts. Although these are further divided into lower levels of cost accounts, only the subaccounts of job indirects, salaries of supervision, temporary construction, general expenses, and insurance, are presented in this paper. As a result, the cost breakdown to be used in this example is defined in Fig. 7.

The historical cost-account database contains 88 completed projects. Both expected and actual costs of individual cost elements are compiled to calculate the performance, followed by the regression analysis to estimate the betas of the cost elements. Table 1 represents the results of the statistical analysis. While all of the relevant numbers (such as the average performance of individual accounts), and the covariances cannot be shown for confidentiality reasons, the results include the following information: column (1) gives the name of cost elements; columns (2) and (3) are the estimated beta and its standard error, respectively; column (4) is the coefficient determination $R^2$ in percentage term for the regression; and column (5) is the number of observations. Also, the deviation of overall project performance for completed projects was $\sigma_P$ = 3.98%.

The results indicate that job indirects include above-average dependent risk, which at 3.77, show approximately six times as much dependent risk as material costs having a beta of 0.64. In this way, beta can be used both as an absolute and relative measure of dependent risk among different cost elements. Using (6) also shows that the estimated performance deviation of job indirects, for example, is approximately 15% (=3.77 × 3.98%). Assuming the expected annual cost of job indirects is \$3,000,000 per year, the company may assume approximately ±\$0.45 million of uncertainty due to corporate risk in this account alone.

It should be understood that the true beta of a cost element cannot be observed. Instead, all that can be done is to estimate its value. In interpreting the condition of an estimated beta value, the degree of standard error is, therefore, particularly important. According to Table 1, it is understood that the probability is approximately 66% that the true beta of, for example, job indirects will lie between 3.77 ± 0.19.

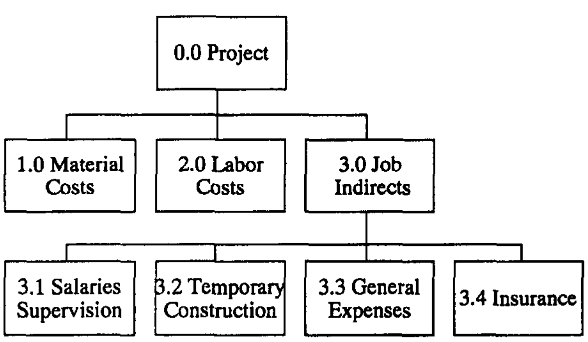



**FIG. 7. Cost Breakdown Structure in Example**

**TABLE 1. Regression Statistics**

| Cost elements (1) | Beta (2) | Standard error for beta (3) | $R^2$ (4) | Number of observations (5) |
|---|---|---|---|---|
| 1.0 Material costs | 0.64 | 0.06 | 0.05 | 85 |
| 2.0 Labor costs | 0.14 | 0.04 | 0.11 | 85 |
| 3.0 Job indirects | 3.77 | 0.19 | 0.82 | 88 |
| 3.1 Salaries | 5.23 | 0.56 | 0.51 | 88 |
| 3.2 Temporary construction | 1.16 | 0.34 | 0.12 | 88 |
| 3.3 General expenses | 0.98 | 0.53 | 0.04 | 88 |
| 3.4 Insurance | 0.00 | 0.00 | 1.00 | 88 |

Another important statistic is the coefficient of determination $R^2$, which provides an indication of how the variation in performance of a cost element is related to the variation in the overall project performance, and it is calculated as the square of correlation coefficient between the two variables. In essence, coefficient of determination represents the explained proportion of the total variation in the performance of a cost element by the movement of the overall project performance. For example, for job indirects, it can be said that 82% ($R^2$ = 0.82) of the deviation in performance can be attributed to movement of the overall project performance. On the other hand, for the labor costs, since its coefficient of determination is 0.11, the unexplained proportion, or the residual variance that cannot be explained by the overall project performance of labor costs is significantly high. As far as the cost-control data in this example goes, job indirects are closely related to the overall project performance, and it can be said that variation in the overall project costs is actually driven by the factors associated with job indirects.

In general, cost elements can be grouped into several different segments according to attributes that measure some distinguishing features of the risks underlying the segmented work packages. The segmentation limits the attributes, taking mutually binary sets for simplifying the description. To take a specific example, imagine that the four elements of job indirects are divided into two segments, one that contains a mixture of cost elements that are sensitive to management's payment due to inefficient management processes, or "Inefficient," and the other that is irrelevant to this condition, or "Normal." Also, suppose that the first segment Inefficient includes salaries and general expenses, and the segment Normal consists of temporary construction and insurance. Then, the dependent risk associated with both Inefficient and Normal could be evaluated as an averaged beta of the cost elements included in each segment. The company's historical data show that the sum of budgeted costs of salaries and general expenses is approximately \$6,000,000 (for simplicity, the amount is rounded to the nearest million), in which salaries account for 80%. Then, the beta of segment Inefficient is

$$\beta_{\text{Inefficient}} = (0.8)(5.23) + (0.2)(0.98) = 4.38 \quad (7)$$

Similarly, the beta of segment Normal is calculated as $\beta_{\text{Normal}}$ = 0.93. Moreover, suppose that the contractor forecasts the costs of salaries and general expenses of future projects to be \$6.500,000. Then, the beta of segment Inefficient is predicted to become larger, or 4.43. In this way, once the uncertainty of an individual cost element is known, and some cost elements are grouped together by some underlying risk attribute, the estimated beta can be used as a "predictive" parameter for quantifying either a part or the whole of project uncertainty in the future. The result of the predictive analysis can be differentiated by comparing the betas of each segment. In particular, if the beta of a risky segment is recognized to be "distinctively" larger than that of normal segment, the differentiated beta represents the potential variation in uncertainty due to the dependent risk involved in the risky segment.

The profile of projects' uncertainty changes over time. Fig. 8 shows the moving average of the beta of the Inefficient segment to identify recurring patterns in beta movements. The calculation is done by selecting the first 50 projects, followed by the replacement of the older five projects by newer ones. This process is repeated until all 88 reference projects are included in the calculation. This analysis is done with the belief that these patterns repeat themselves, and the predictive capacity of beta can be used to measure the change in a portion or the whole of project uncertainty. The results show the fluctuations in the beta values from the standard level (4.38) over the reference periods, and the more recent trend shows the moving average of beta, or dependent risk, is rising.



J. Constr. Eng. Manage., 1998, 124(1): 42-47

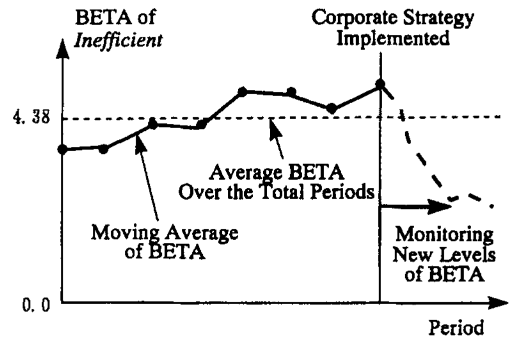



**FIG. 8. Risk Control Diagram**

Within the process herein, managers may assert that the study of past performance of projects allows them to identify times when an appropriate management strategy is implemented. Dependent risks are of particular interest from the point of a company's management view because the uncertainty of corporate risks increases rapidly as more and more "related" projects are added to a company's project pool. That, in turn, may motivate managers to seek more effective management strategies when they try to govern the risk as a whole at a corporate level. Since it takes time to implement a management option and makes its impact effective, the consequence should be evaluated on the consideration of the "term-structure" of project risk resolution, given a particular option. The usefulness of historical beta is not limited to the fact that it simply measures the magnitude of uncertainty. In addition, the beta may facilitate the way managers look at risk over time. The reference company is actually planning to implement new information technologies into management processes as a company-wide strategy, and its effect may be seen in the reduction in beta in the future.

## CONCLUSIONS

This research has paid direct attention to the aspects of project risk management under the precept of management functions at the corporate level. Within this concept, this research focused on dependent risk, which arises due to interactions of common risk factors among multiple projects, and, therefore, may be regarded as corporate risk to be managed by corporate management options.

A construction project was defined as a portfolio of work packages on the supposition that the uncertainty associated with a given project, either in part or in whole, can be calculated as the aggregate uncertainty of its component cost elements. Using this idea, project risks were then classified into two types: (1) Dependent risk that arises from the interaction of risk factors on multiple cost elements; and (2) independent risk that affects the total risk of a project independently.

Then, a mathematical model was developed to estimate the uncertainty of a cost element. The model developed the mechanism by which the expected performance of a cost element was analyzed in accordance with the overall project performance. The most important parameter of the proposed model is beta, the measure of uncertainty due to dependent risks. It was shown that beta was a regression coefficient of a single-index model, in which the performance of a cost element of completed projects is related to its overall project performance. Also shown was the characteristic of beta's additivity, which enabled the model to predict the uncertainty due to the dependent risks of a project. This characteristic of additivity is the key feature of the proposed methodology.

This methodology, formulated within the framework of work breakdown structure, and using the historical cost-control data of a company, not only provides a systematic, logical way to quantify risks at issue, but also considerably facilitates the efforts required to gather information for the analysis. To see this, an empirical study was then shown, using actual cost-control data of a contractor, to describe some key features of the proposed methodology.

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