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A RISK ANALYSIS METHODOLOGY FOR CORPORATE MANAGEMENT OPTIONS

Takayuki MINATO[1] and David B. ASHLEY[2]

[1]Member of JSCE, Ph.D., Assistant Professor, Dept. of Marine Civil Eng., Tokai University (3-20-1 Orido, Shimizu, Shizuoka 424, Japan)

[2] Ph.D., Professor and Chair, Dept. of Civil Eng., University of California at Berkeley (Berkeley, CA 94720, U.S.A)

This research focuses on the issue of project risk arising from multiple projects undertaken by a single company. It has developed a risk analysis methodology to serve as a support for developing management options from company's view. The methodology is built on the work breakdown structure of a project, in which a project is defined as a portfolio of its component work packages. The concept of *beta*, which is a performance regression coefficient relating the performance of a work package to the overall project performance, and its use in the *segment portfolio analysis*, with which the risk of a construction project is measured within a homogeneous group of work packages, are the major focuses in this research.

Key Words : *project, risk analysis, work package, work breakdown structure, option, portfolio*

1. INTRODUCTION

The word, risk, can be defined as an event that has aspects of uncertainty. Project risks arise from a combination of political, economical, industrial, and company conditions, as well as from conditions specific to individual construction projects.

The need of risk identification for effective risk management should be governed by a manager's objectives when developing specific strategies. In construction management, what occurs often is that the task of managing risks falls to personnel at the project level. It must be realized, however, that certain risks are inherent to a company's projects as a whole, and such risks could be mitigated more effectively in a group of projects. The concept of a corporate strategy, which takes account of the existence of the inherent risks in a company's projects, is the principal precept in the development of a risk analysis methodology in this research.

The concept of viewing construction projects from a company's point of view has been developed by some researchers for "project selection problems[1),2)]," whose scope is concerned with bid/no-bid decision making. The principal motivation behind such research was to diversify risk by "selecting" new projects that would give optimal efficiency to existing projects, and the theoretical framework was provided to help assess current risk exposure from a company's point of view. This research, on the other hand, focuses on managing a company's overall project after projects are bid, and develops a methodology to analyze risk as a means to improving the final performance of projects[3)].

The task undertaken by this research, to identify risks, depends on the following crucial considerations.

- When a firm's projects are viewed as a portion of a "portfolio of projects," then it can be seen more readily that there exist some risks common among all projects. In other words, the uncertainty of a project could be caused by two reasons: a portion that it shares in common with other projects of the company, or one that is unique to an individual project.
- Part of the uncertainty of individual projects is derived from risk that is co-variable across multiple projects. Effective risk reduction is possible if the co-variability of a company's projects were managed simultaneously.
- Of the three types of risk, *known-known, unknown-known,* and *unknown-unknown*[4)], the known-known risk comes from familiar sources and typically occurs at high frequencies in a company's entire portfolio of projects. Since it is so common, the identification and quantification of known risks may be vital in risk management from a company's point of view because reducing

risk effectively and efficiently may occur by managing them on a multiple project basis.

The major conclusion to be drawn from the preceding considerations is that this research focuses on analyzing uncertainty due to co-variable risks that commonly arise from known sources in a company's entire portfolio of projects. Such risks include, for example, a company's "inefficient" safety program that may cause a company-wide problems across multiple projects. Co-variable risks are of particular interest from the point of a company's management view because the uncertainty of co-variable 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 strategies when they try to govern the risk as a whole at a corporate level.

This paper consists of two topics. The first is the development of a mathematical model for quantifying the co-variable risk. At the center of the model lie concepts and insights drawn from financial portfolio theory[5),6),7)] that are used to estimate the uncertainty of work packages of projects. A single-index model, which relies on historical information, is then developed by which the uncertainty of a work package is *estimated* in relation to the co-variance of the overall performances of past projects. The model is also formulated so that the analysis is done within the work breakdown structure of projects, without relying on external explanatory variables.

Second, a risk analysis process, called *segment portfolio analysis*, is proposed. In this scheme, a project is first divided into a portfolio of work packages, and the overall uncertainty is seen as the aggregate of the uncertainty in each package. It also presents the procedure by which the joint probability of the uncertainty of work packages is used for the segment portfolio analysis. The key feature of the estimation model is that it is also used to *predict* the uncertainty of projects when risk control is evaluated.

2. DEPENDENT RISK AND RESIDUAL RISK

A project typically consists of work packages that include various types and kinds of resources - people, material, equipment, and so on. To fully comprehend the scope of a construction project, it is useful to define it as a portfolio of various work packages. Moreover, most managers will agree that some of a project's risks are common to multiple work packages. For example, some risks associated with safety may be common to steel workers, concrete workers, carpenters, and others engaged in a

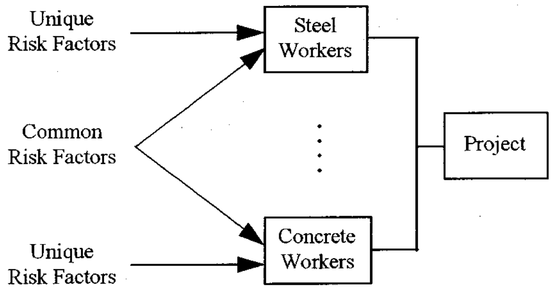


Fig.1 Elements of Risk Affecting Uncertainty of Project

project. Similarly, economic risks, such as inflation, may affect the price of steel, concrete, and other materials simultaneously. Although individual work packages are affected by common risk factors, they are also exposed to others that are unique to each of them. For example, the performance of steel workers may be affected by bad weather or the absence of some key person at the time a job is carried out **(Fig.1)**.

In this paper, the type of risk common to several work packages is called *dependent risk,* whereas a risk unique to a particular package is called *residual risk.* When taken together, these types of risk form either a portion or the whole of the uncertainty associated with a given project. In other words, the total risk run by a project consists of its dependent and residual risks.

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

The dependent risk accounts for a portion of co-variance due to the interaction of common risk factors. The presumption underlying dependent risk is that it relates directly to the risks of a project as a whole. In other words, dependent risk may be viewed as subject to changes that occur due to project environment in which all projects of a company are affected to some degree. On the other hand, the residual risk is assumed to affect the total variance of a project's performance independently.

The classification of a project's risks described above may have a significant impact on management's decision-making when they develop their strategies. While both risks are important for project managers, residual risk is basically a matter confined to individual projects. On the other hand, the phenomenon caused by common risk factors, or dependent risks, is likely to be observed across

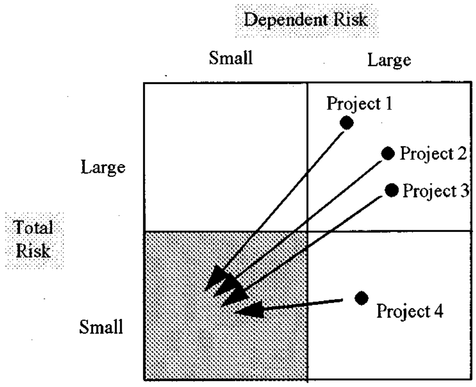


Fig.2 Group Identification of Dependent Risk

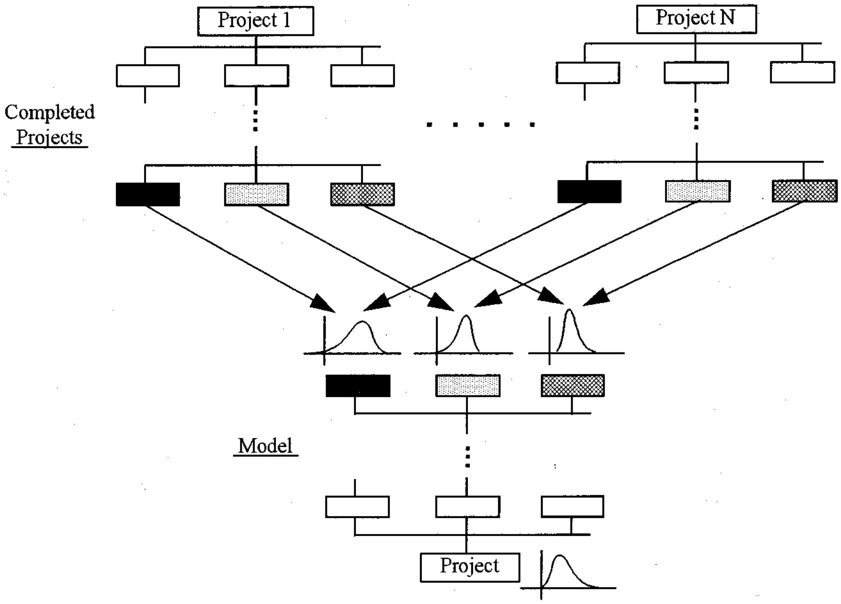


Fig.3 The Uncertainty of a Project's Performance

several projects carried out by a company. Using the safety example, inefficient safety control of a particular project may cause dependent risk within the project. However, on the other hand, when the risk of safety is recognized as a company-wide problem, then the dependent risk due to inefficient safety control becomes a matter of a company's projects as a whole. In general, while residual risk may be confined to individual projects, dependent risk may arise at a single project level, at a company's portfolio of projects, or at both.

Moreover, some important considerations emerge from the group identification of dependent risk on a multiple project basis, the most interesting of which is the question of whether to manage dependent risk independently at the project level or as a group at the corporate level. Suppose that dependent risk is dominant for a majority of projects (**Fig.2**). In general, when such a phenomenon is observed, it could be hypothesized that projects may be managed more efficiently as a group at the corporate level although the decision of how to manage projects still depends on the efficiency of options available to management.

3. A MATHEMATICAL MODEL

The uncertainty associated with a given project, either in part or in whole, can be calculated for one package and for the aggregate of its component packages. Then, the specific question to be answered is: "What will the probability distribution of the performance of work packages look like (**Fig.3**)? "

Each construction company may have its own cost-account system with a common numbering system that can be applied to their generic types of construction. A building contractor, for example, may break down their projects into works of earth, steel, concrete, and so on. If a company keeps a well-defined, cost-account system, the standardized cost codes provide a structural uniformity and a basis for comparing every project run by the company. In addition, such standardized, cost-account system allow work package to be formed by sorting cost accounts into any level of several combinations for the purposes of risk analysis.

The aggregation of cost information from completed projects is a random variable that forms a certain probability distribution of performance, which can be calculated at any level of work breakdown structure (WBS)[8], and represents the deviation of performances of the reference projects in a company's historical data base. At the highest level of WBS, the performance can be calculated for the entire project because the project itself is a work package. In this research, the probability distribution of performance calculated from completed projects is called *project performance* for completed projects.

In the same way, the probability distribution of performance can be calculated for any component work packages at any level in the work breakdown structure. For example, such a distribution can be calculated for labor, material, and equipment in terms of resources. At other levels of the hierarchy of WBS, the labor component may be further divided into steel workers, iron workers, carpenters, pipefitters, and so on. In this research, the performance of a project's subaccounts is called *performance of work packages* for completed projects.

The development of a mathematical model starts with defining performance of a work package. At completion, the performance of a single project can be calculated with the actual cost and the expected cost by the following equation.

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

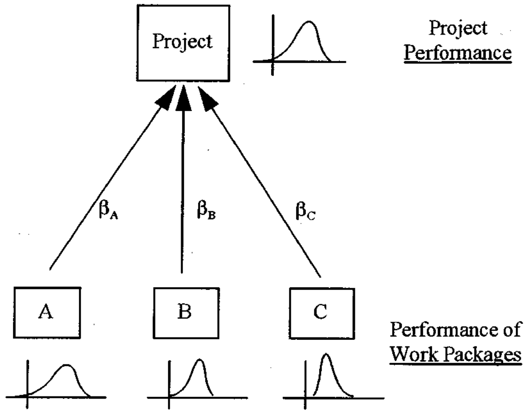


Fig.4 Principle of Analysis for a Work Package

The expected cost is really the budgeted cost or estimated cost of work, and it becomes the denominator of the equation. When the aggregation of the historical performance of completed projects is formed into a series of data, the equivalence due to different volume of individual projects should be taken into account. In other words, the performance of individual projects should be adjusted according to their relative costs. Suppose, for example, that the cost of a work package of project A is twice as large as that of project B. Then, the historical performance of project A should be weighted twice as much as that of project B. One reason for this weighting is that a work package with "more" cost is simply more important than other work packages with "less" cost. Another reason arises from analytical consideration, in which the performance of individual work is regarded as a random *process* rather than a random *variable*. Since a work package with more cost generally contains more of the process than others with less cost, the data represented by such a work package may result in a "better" or more "reliable" measure of performance.

The mathematical model for project risk analysis depends on the financial portfolio theory, using the *market model* (refer to Appendix A for detail) by which the probability distribution of security return is measured in accordance with the *market portfolio*, which consists of all securities included in the investment. The key parameter of the market model is the *beta* that measures the co-variance between securities in accordance with the market portfolio(**Fig.4**). The beta is calculated based on the historical relationship between a market portfolio and a security. This condition of beta entails an investment decision based on the consideration that the market conditions during the investment horizon will not be much different from those of past periods for which the historical beta is calculated.

The comparison between the analysis of a financial portfolio and a project risk analysis can be made by relating market return with project performance and return of individual securities with performance of work packages, respectively. Doing so is tied to the idea that a construction firm undertakes risky tasks in its projects and this risk can be quantified as a portfolio of risky work packages. The application of this idea to construction results in the development of a mechanism by which the relationship of a work package to the overall project performance of completed projects is used to estimate the probability distribution of performance of the individual work packages.

When the performance of a work package is related to the overall performance of a project, the pair of time-history data between the output and the input can be plotted to obtain a regression line. The form of the regression line is a single index model, assuming that the performance of a work package responds at the level of a project's performance. The line going through the pair of data is the line of *best fit* that minimizes the sum of the squared error and can be expressed by the following equation.

$$\tilde{z}_j = \beta_j \tilde{z}_p + \varepsilon_j \qquad (3)$$

where: $\tilde{z}_j$ = the actual performance of a work package j (%). This value is normalized so that its average $\bar{z}_j$ is set to zero. $\tilde{z}_p$ = the actual project performance (%). This value is also normalized, and therefore its average $\bar{z}_p$ is also set to zero. β_j = regression coefficient, and ε_j = residual term (%).

The definition of beta arises from the fact that it measures the correlated portion of the performance of a work package against the variation of the overall project performance of completed projects. In other words, the beta measures the contribution of a work package to the deviation of the project performance, and the degree of the contribution depends on how the work package is liable to the variability of the overall project performance, and it is calculated as follows.

$$\beta_j = \frac{\sigma_{j,p}^2}{\sigma_p^2} \qquad (4)$$

or, equivalently,

$$\beta_j = \rho_{j,p} \frac{\sigma_j}{\sigma_p} \qquad (5)$$

where: $\sigma_{j,p}^2$ = the covariance between performance of a work package j and project performance of completed projects(%), σ_p = the standard deviation of the project performance of completed projects (%), σ_j = the standard deviation of performance of work package j of completed projects (%), $\rho_{j,p}$ = the correlation between work package j and project performance of completed projects. Since the above model, or equation (3), depends on historical information derived from completed projects, the beta coefficient β_j is a "historical" parameter.

The beta is the most important aspect in estimating the risk associated with a work package because it measures the co-variance of project risk that stems from the common risk factors of the entire project. In other words, it measures the dependent risk of a project that is caused by the interaction of multiple risk factors such as safety, productivity, quality assurance and quality control (QA/QC), and so on. This means that the effect of multiple risk factors on work packages can be measured through the beta tied to the project.

It should be noted that interpretation of estimated beta values must be conditioned by the degree of possible measurement error which is estimated by *standard error* coefficients associated with beta. Suppose, for example, that the estimated beta is 1.50 and its standard error is 0.15. Thus, the probability is approximately 66 percent that the true beta will lie between 1.50 ± 0.15.

From equation (3), the variance of a work package's performance can be calculated by the following equation.

$$Var(\tilde{z}_j) = \beta_j^2 \sigma_p^2 + \sigma_{\varepsilon_j}^2 \qquad (6)$$

where: $\sigma_{\varepsilon_j}^2$ = the residual variance of work performance j $(\%)^2$.

In the preceding model, the estimation of variance in the performance of a work package can be subdivided into two portions: one that depends on the co-variance to project performance of completed projects $\beta_j^2 \sigma_p^2$, and the residual portion σ_ε^2. Thus, the first portion measures *dependent risk,* and the second portion measures *residual risk.* The dependent risk of a work package is known, and it is fully accounted for by the historical quantities of beta, β_j, and the variance of project performance, σ_p^2, of completed projects. On the other hand, the residual risk is not only difficult to ascertain but it is unknown for future projects.

The tacit assumption of the model is that it consists of a *linear* regression analysis whose formulation is accompanied by some key features as described below. The historical betas of various work packages are "additive", that is, when various work packages are combined to form a "portfolio" of work packages, its beta can be calculated as a sum of the betas of the component work packages. In fact, the beta of the portfolio is calculated as a weighted average of the estimated betas of its component work packages. This characteristic of the model enables the historical betas to be used to *predict* the beta of a new project. Furthermore, the predictive capacity of the model can be used to measure the change in a portion or a whole of the uncertainty of a project when various management options are evaluated. Remember that the underlying precept of the risk analysis in this research is to examine the value of risk control; such calculation may be easily done by changing the betas of a work package on which a particular management option is taken.

It should also be emphasized that the proposed model enables the uncertainty of a work package to be estimated within the work breakdown structure of a project associated with its cost data. In other words, the proposed model consists of a "component analysis" within the work breakdown structure, which differs from an approach using external variables that serve as explanatory indices. The strength of this approach lies with the systematic formulation of the model because the information can be integrated easily within the work breakdown structure. In addition to the structural configuration, the model needs no additional efforts to collect data because it depends on a cost control database that already exists within a company. In conclusion, the proposed model represents a significant improvement in the knowledge acquisition process for project risk analysis.

4. SEGMENT PORTFOLIO ANALYSIS

Since the uncertainty of a construction project arises from the interaction of various risk factors such as safety, productivity, and technical difficulties,

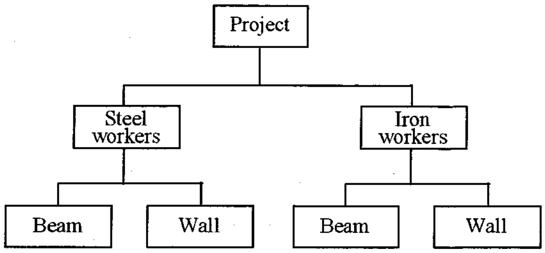


Fig.5 Cost Breakdown Structure

it is a hard task to isolate these into individual and autonomous elements. As a result, this research tries to propose a new way to develop project risk analysis.

The method by which to quantify project risk proposed here is the *segment portfolio analysis*, which consists of two major steps. The first is portfolio segmentation, the act of dividing a project's work packages into groups, for example, one that contains a mixture of risky work packages and the other that consists of work packages that contain normal conditions. The second is to quantify the uncertainty of individual segments.

Portfolio segmentation is a way to derive risk analysis for construction projects, whose principal hypothesis is that some work packages can be grouped together according to attributes that represent some distinguishing features of the work packages themselves. Then, a project's work packages can be classified into groups with some attribute that represents one or more of the characteristics underlying the risk factors for the entire project. In general, work packages can be grouped into several different segments depending on the risk highlighted.

Assume a hypothetical cost breakdown of a project as shown in **Fig.5**. It is further assumed that the project consists of only two types of workers, steel and iron workers for beam and wall construction.

Consider two segments of labor portfolio, for example, one that consists of steel workers with the work packages of SB and SW, and the other consisting of iron workers with work packages of IB and IW. The abbreviations, SB, SW, IB, and IW, show the name of work packages. For example, SB represents Steel workers working for Beam.

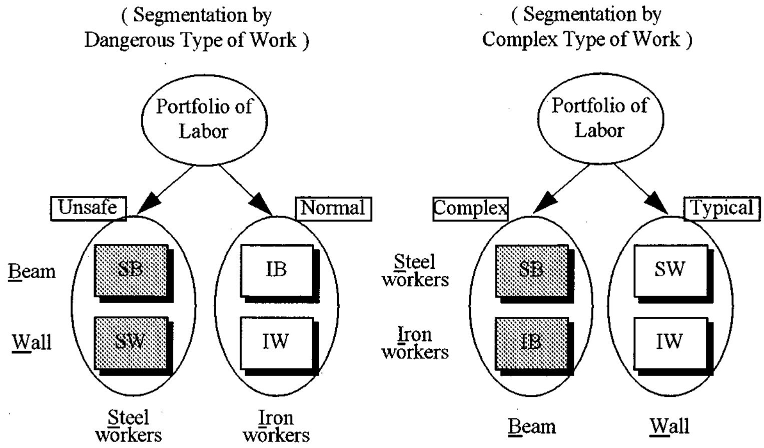


Fig.6 Segmented Portfolio

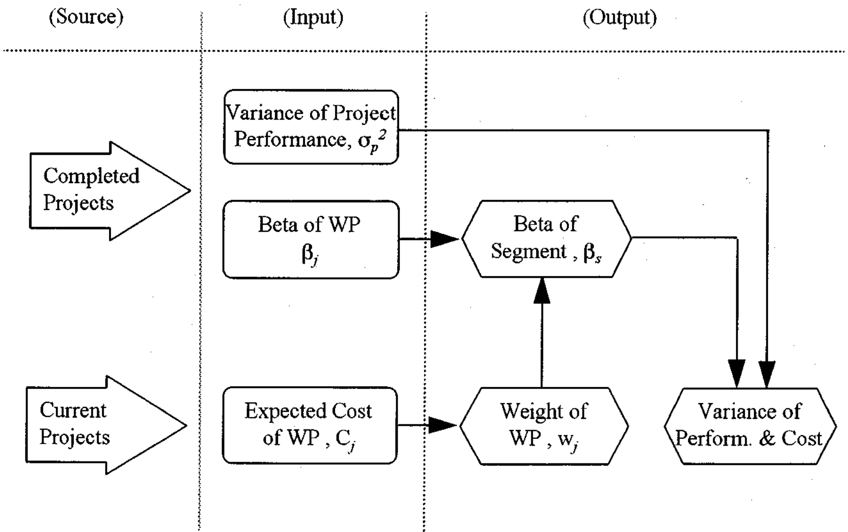


Fig.7 The Process of Risk Analysis of Current Projects

Using this categorization, the first segment is called *Unsafe*, and the second one *Normal*. In this example, it is assumed that the segment Unsafe represents a group of labors that is a class of dangerous workers and the segment Normal represents a normal class of workers. Consider another type of segmentation that divides labor accounts into one consisting of the work of beams, and the other, walls. The former segment includes the work packages of SB and IB, and the latter includes the work packages of SW and IW. Again, using this categorization, the first segment is called *Complex* and the second one *Typical*. In this example, the segment Complex is assumed to represent work that is a class of complex tasks, and the segment Typical represents a normal class of tasks. In these two classification schemes, the four work packages can be grouped into the segments as shown in **Fig.6**.

The immediate question then becomes whether or not the attributes provide sufficient information to make distinctions between the two segments in terms of the magnitude of their uncertainty. In particular, if the two classified groups have identical values of uncertainty, it is clearly impossible to differentiate between the two groups with reference to the given attributes. In such a case the given attribute is inadequate for the purposed portfolio segmentation and hence for the task of identifying risk. On the other hand, if the attribute is adequate, the classification can be useful to differentiate work packages because such an attribute will help identify underlying risk of a project.

The second step quantifies the expected cost variance of individual segments. The calculation consists of three steps: 1) calculation of proportion of expected cost, or the weight, of individual work packages in the segment portfolio, 2) calculation of segment beta, and 3) calculation of variance in performance and cost of the segment portfolio. The entire process is shown in **Fig.7**.

There are three inputs used for the calculation of a segment portfolio. They are the variance of the project performance of completed projects, the beta, and the expected cost of work packages included in the segment portfolio. Of the three, variance of project performance and the beta are given parameters that are drawn from the analysis of completed projects. In other words, they represent prior knowledge. The expected cost, on the other hand, is the budgeted or estimated cost of work packages for a project to be executed in the future. It is, thus, assumed that the expected cost is also known with considerable accuracy when a project starts.

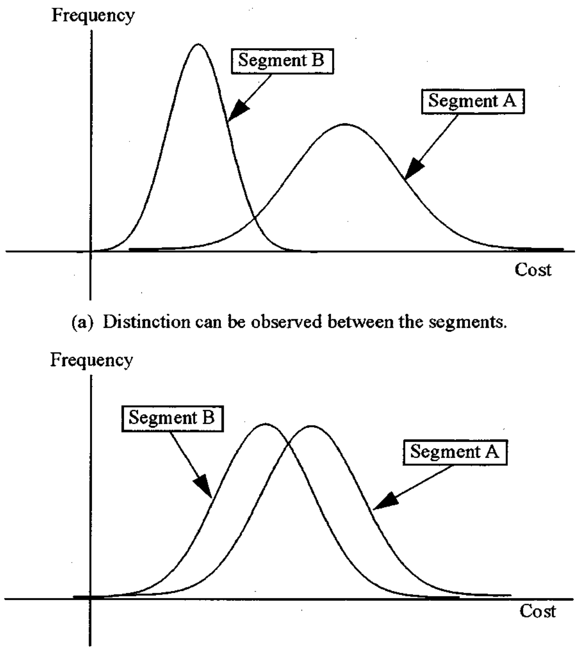
With a single index model as shown in equation (3), the variance of a segment portfolio could be calculated as follows.

$$Var(\tilde{z}_s) = \beta_s^2\sigma_p^2 + \sum_{j=1}^{N} w_j^2\sigma_{\varepsilon_j}^2 \qquad (7)$$

$$\beta_s = \sum_{j=1}^{N} w_j\beta_j \qquad (8)$$

where β_S denotes the segment's beta, w_j denotes the fraction of cost for work packages in the segment, and β_j denotes the beta factor of the component work packages. Again, the first term of equation (7) represents dependent risk, and the second residual risk.

The variance in performance of a segment is quantified by ignoring the right-hand side of equation (7) because the objective of this research is to look at the dependent risk, or the co-variance that is caused by the interaction of factors common to a company's projects. Although the residual risk may be of great importance to individual projects, it is not important from a company's point of view because the residual



(a) Distinction can be observed between the segments.

(b) Distinction cannot be observed between the segments.

Fig.8 Result of Segmentation Analysis

risk is a matter pertinent to individual project. The portion of risk that is important from the point of multiple projects is the dependent risk explained by beta. As a result, the variance in performance of a segment portfolio is calculated by the following equation.

$$Var(\tilde{z}_s) = \beta_s^2\sigma_p^2 \qquad (9)$$

The output of segmentation analysis can be seen in two ways as shown in **Fig.8**. One case (a) illustrates that there is distinction in uncertainty between the two segments, and the other case (b) shows that there is no such distinction between the two. The segmentation is of interest only when the result is obtained as shown in (a), in which a distinction can be observed in uncertainty between the two segments.

In general, the distinction can be observed by comparing the beta of segments. When a distinction is observed between segments by a particular attribute, managers may recognize and, thus be motivated to control the relevant risk. On the other hand, when an attribute does not give sufficient information to distinguish segments, the solution to the result is to identify the other attributes continually until the distinction is recognized.

The final stage of the risk valuation is to calculate the value of management's range of options. Among these, the most important decision to be made consists of three choices. 1) manage risk using a corporate strategy, 2) manage risk using a project strategy, and 3) take no action at all (**Fig.9**).

It is expected that the results of the segment portfolio analysis aid management's decision-making when they evaluate their options in an attempt to differentiate between corporate- and project-based strategies. Suppose there is a management option that reduces the beta of a risky segment to the beta of normal segment. Then, the risk reduction by the control can be easily calculated using equation (9).

5. EXAMPLE ANALYSIS

A hypothetical example that assumes the cost breakdown of a project as shown in **Fig.5** is used to illustrate the risk-analysis process developed in the previous chapters. It is also assumed that four work packages of SB, SW, IB, and IW are categorized as shown in **Fig.6**.

Calculating the historical beta of a work package is a straightforward matter. Assume the standard deviations of the performance of work package SB and the overall project performance are 6% and 3%, respectively, and the correlation between them is 0.90. With equation (5), the beta coefficient of SB is calculated as follows.

$$\beta_{SB} = 0.90 \times (0.06/0.03) = 1.8$$

Suppose that a construction company holds a new project, and that the contractor estimates the estimated costs of the four packages to be $40M, $10M, $25M, and $25M, which sum to $100 million.

Assume the beta of SW is 1.4. Using the segmentation by dangerous type of work as shown in **Fig.6**, the beta of segment Unsafe is calculated as follows.

$$\beta_{Unsafe} = (40/50)(1.8) + (10/50)(1.4) = 1.7$$

Similarly, assume the betas of IB and IW are 0.9 and 0.7, respectively. The beta of segment Unsafe is calculated to be 0.8.

It should be remembered that a segment's beta is simply a weighted average of the betas of its component work packages. This means that the differences in segment's betas come from the different cost proportion of work packages in each segment. Furthermore, work packages with larger

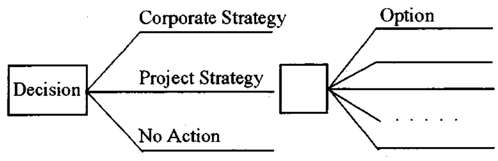


Fig.9 Management's Decision

positive values of beta contribute more to the dependent risk of the segment. On the other hand, work packages with negative values of beta generally contribute to diversifying the risk of the segment.

6. SUMMARY

This research has developed a risk analysis methodology based on work packages for project management using a company's historical cost control information derived from completed projects. The methodology assesses a project's uncertainty by considering the interactions among work packages to quantify the co-variance that arises in a project because of common risk factors. The following lists summarizes some of the significant aspects of the contributions made by this research.

First, the underlying precepts of this research pay direct attention to the functions of a company's management approach at the corporate or project levels to gain greater efficiency. As a result of this, conception, a project's risks are classified into dependent risk, which arises due to the interactions of common risk factors, and residual risk, which results from unique risk factors within individual projects. Such risk identification enables managers to focus their attention on choosing more effective corporate or project strategies.

Second, this research also develops a risk analysis approach formulated within the work breakdown structure of a project, instead of using external, explanatory variables. Such an approach provides a systematic, logical, and comprehensive way to quantify risk within the framework of WBS, which is the most common tool used to define construction projects. Some of the features of this methodology are as follows.

- The efforts required to gather information are facilitated considerably by the use of a company's cost control data; thus, the analysis enhances the knowledge acquisition process and reduces its costs.
- The co-variable risk of a work package is quantified by a single parameter, its beta. This

method is not only simple but also comprehensive, providing a strong quantitative measure for managers. In addition, the use of beta, the concept of which depends on financial portfolio theory, enables the results of fertile research in the field to be applied to construction projects.
The methodology, with the use of beta, is designed so that changes in uncertainty can be estimated easily when a particular management option is considered. In other words, the model is used to predict the change in profile of a project's risk when risk control is evaluated.

Third, the results of this research include a tremendous potential for further contributions to the novel development of project risk management. Some of them include the analysis of project risk resolution and allocation as well as the development of various management options.

Future research includes the extension of the mathematical model to consider the individual characteristics of a new project. It also includes the empirical study of the application of the developed model, using actual cost control data of a company.

APPENDIX A Market Model

The market model interprets a security's return-generating process as the return on *market*. The market model is sometimes confused with CAPM(Capital Asset Pricing Model). While the meaning of beta is the same for both models, they are different with regard to the underlying assumptions and formulation. The general form of a market model of security returns $\tilde{r}_i$ is written as follows (omitting the time subscript).

$$\tilde{r}_i = a_i + b_i \tilde{r}_m + e_i$$

where, $\tilde{r}_m$ is the value of the market return (random variable), a_i is the constant that may differ across securities, b_i is the factor loading that is the sensitivity of security i to $\tilde{r}_m$, and e_i is the random error term.

By means of a simple statistical formula, the beta coefficient is calculated as follows.

$$\beta_i = \frac{Cov(\tilde{r}_i, \tilde{r}_m)}{\sigma_m^2}$$

where, $Cov(\tilde{r}_i, \tilde{r}_m)$ denotes the covariance of return between security i and market, and σ_m^2 the variance of return in a market portfolio.

REFERENCES

1) Vergara, A.J. and Boyer, L.T. : Portfolio Theory: Applications in Construction, *Journal of Construction Engineering and Management,* ASCE, Vol. 103, pp. 23-38, 1977.
2) Kangari, R. and Boyer, L.T. : Project Selection under Risk, *Journal of Construction Division,* ASCE, Vol. 107, pp. 597-608, 1981.
3) Minato, T. : A Methodology for Project Risk Control: A Work Package-Based Approach Using Historical Cost Control Data, *Ph.D. Dissertation*, Department of Civil Engineering, University of California at Berkeley, 1994.
4) CII89a : Management of Project Risks and Uncertainties, *Construction Industry Institute*, Publication 6-8, 1989.
5) Markowitz, H.M. : Portfolio Selection, *Journal of Finance,* Vol. 12, pp. 77-91, 1952.
6) Sharp, W.F. : Capital Asset Prices, *Journal of Finance,* Vol. 19, pp. 425-442, 1964.
7) Modigliani, F. and Pogue, G.A. : An Introduction to Risk and Return, *Financial Analyst Journal,* Vol. 30, pp. 69-80, 1974.
8) CII89b : Work Packaging for Project Control, *Construction Industry Institute*, Publication 6-6, 1989.

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会社管理リスクの解析手法

湊 隆幸, David B. ASHLEY

本研究は、建設会社の工事管理において，複数の工事を“全社的な”立場から管理する場合のリスクマネジメントに焦点をあてながら，各々の工事に共通するリスク(工事の結果に不確実性をもたらす，潜在的および偶発的なでき事)による工事費用のばらつきを推測するための手法を開発した．本論文では、工事をワークパッケージで定義し，過去の工事の原価管理データを用いた線形回帰モデルにより計算されるパラメーターである"ベータ"の概念により，工事費用の共分散を求める手法を示した．本研究の結果は，会社全体の工事を管理する立場にある技術者が，全社的な建設マネジメント戦略を計画，実行する場合の有効な手段となるものと考えられる．

CIVAS

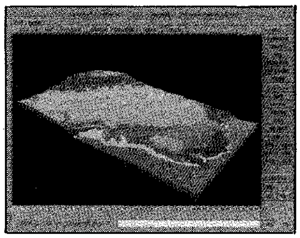
Civil Engineering
Analysis
Service

CRC地盤・地下水トータルサービス

地質解析

GEORAMA

3次元地質解析プログラム



3次元地質ブロック図

物性値のコンター表示

⇩

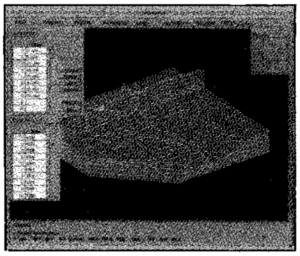
地盤・地下水解析

■プリ処理（データ作成）

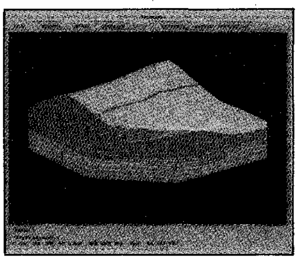
CIVAS/Pre

対話型プリプロセッサ

⇩



CIVAS/Preによる掘削データの入力画面



CIVAS/Preによる３次元メッシュ図

■解析処理

SoLver

各種解析コード

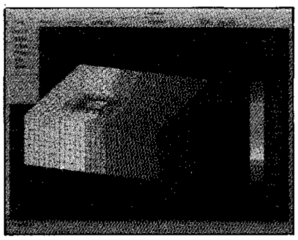
⇩

- **SEEPAGE-3D**（3次元地下水解析プログラム）
- **UNICOUP**（土と水の連成（逆）解析プログラム）
- **UNISSF（V-2）**（広域地下水変動解析プログラム）
- **Mr.SOIL**（地盤解析プログラム）

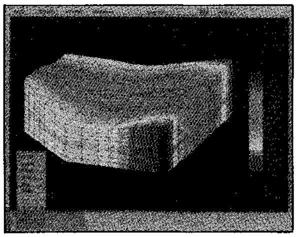
■ポスト処理（図化）

CIVAS/Post

対話型ポストプロセッサ



CIVAS/Postによる



CIVAS/Postによる
トンネル工事による全水頭コンター図

CRC 株式会社CRC総合研

事業部　建設エンジニアリング部
工東区南砂2-7-5 ☎(03)5634-5789
業部　科学システム営業部
央区久太郎町4-1-3 ☎(06) 241-4121

パソコン用、準3次元広域地下水変動解析プログラム

未来設計企業 CRC

PC/UNISSF Ver.3.0 for Windows

"PC/UNISSF Ver.3.0"は、すでに汎用機やEWSで実績のある準3次元広域地下水変動解析プログラム、UNISSF(V-2)に強力なプリ・ポスト処理プログラムを付加し、Windows版として新登場しました。このプリ・ポストプログラムは、マウスを使ったメニュー形式の導入、画面上での入出力等の機能により、すぐれた操作性をもたらします。

新登場！

プログラムの特徴（☆印は新機能）

■プリ処理

☆モデル作成のためのメッシュジェネレート機能
★地層データ、初期水位データ等の自動発生機能
☆モデル図を参照しながら、境界条件等各種データの入力、修正が可能
☆マウス入力とメニュー形式による操作性の向上

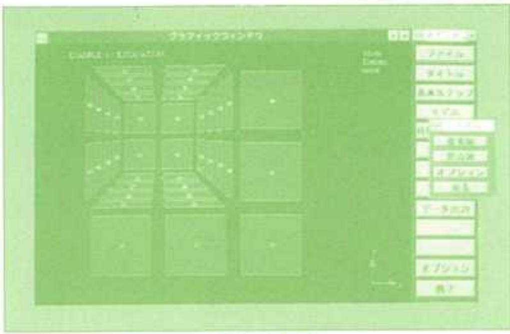
■解析機能

☆汎用機、EWS版と同一機能（順解析）、同一データフォーマット
☆約3000～10000節点までのモデルが解析可能
★降雨・揚水井・浸出面の取り扱いが可能
★水位・流量の経時変化
★境界条件の変更、材質の変更
★掘削機能・簡易漏水機能
★初期定常計算・非定常計算・最終定常計算

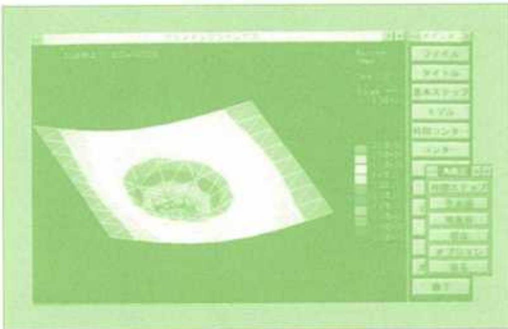
■ポスト処理

☆線画に加えて画面塗りつぶし処理が可能
☆水位の時間変化が簡単にグラフ化可能
☆マウス入力とメニュー形式による操作性の大幅な向上

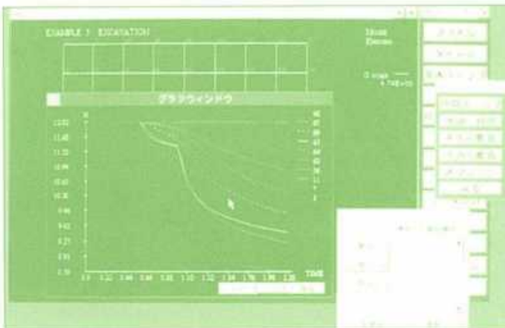
動作環境
Windows Ver.3.1
CPU：80386 以上（推奨 80486DX 33MHz以上）
RAM：8MB 以上
ハードディスク空容量：10MB以上



【モデル図】



【全水頭コンター】



【水位変化グラフ】

・UNISSFは情報処理振興事業会の委託を受けて当社で開発したプログラムです。
・Windowsは米国マイクロソフト社の商標です。

問い合わせ先
株式会社CRC総合研究所
西日本事業部 科学システム営業部
〒541 大阪市中央区久太郎町4-1-3
TEL.06-241-4730（担当／岩崎）

通商産業省 特別認可法人
情報処理振興事業協会（IPA）
〒105 東京都港区芝公園3丁目1番38
TEL.03-3437-2301

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