QUANTITATIVE ANALYSIS FOR THE RISK MANAGEMENT OF A SUPER-HIGHRISE RESIDENCE

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ABSTRACT : In a super-highrise residence project, a project manager needs to form the long-term risk management plan which covers the problems from the beginning of project to the time of demolition. The cause and responsibility for a risk are clarified and quantitatively evaluated through the life cycle of a project. Development of the system which supports a risk strategy effectively is needed as a project becomes complex. In this paper, through the life cycle of a specific super-highrise residence project, a risk phenomenon is specified from a viewpoint of each participant, and the mathematical model is formulated choosing the combination of the optimal strategy against a risk quantitatively within a fixed risk strategy budget.

Key words: super-highrise residence, management, life cycle of a project, risk strategy, project management

1. BACKGROUND

In super high-rise residence projects, a long-term risk management is necessary considering weather, labor force, financial conditions. In addition to construction itself, flaws that revel after release, environmental aspects and demolition problems shall have to be considered.

However, available knowledge is limited to manage risks over life cycle of a project that begins with planning, followed by construction, occupation and demolition, with a standpoint of corresponding parties in horizontal prospect. Previous studies deal with risks mainly in qualitative manner [1] rather than quantitatively [2-4]. After all, risk management framework has not theoretically been established yet.

Therefore, this study focuses on the following aspects.

1) As an example, a specific construction project is surveyed. Through its life cycle, characteristics and details of risks are identified.
2) A methodology is developed to manage specified risks quantitatively and a mathematical model is developed to support decision-making to select an optimal combination of strategies within a fixed risk strategy budget.

2. IDENTIFICATION OF RISKS IN A REAL PROJECT

Risks are identified through the survey of a real project.

2.1 Risk survey in a real project

A continuous questionnaire survey was carried out for each corresponding party. In parallel, a list of inhabitants' claims at a private view near a completion and a list of owner's instructions at the inspection of the completion were investigated. By this procedure, all the potential risks were identified. In addition, details were collected concerning the identified risks by interview with persons in charge. Schematics and range of the survey are shown in Table 1. Items of the survey are shown in Table 2.

2.2 Development of Database

By summarizing the survey results, a database was developed, which can be used to share risk information. By this way, risk data can be summarized which was separately gathered by individuals, project teams and enterprises. This will lead to better management of risks to unify know-how's, to distinguish standard risk strategies with optional strategies, to understand correlations between multiple sources of risks. Sharing risk information will be beneficial to establish risk management protocols in future similar projects [5, 6]. An example of database presentation is shown in Figure 1.

Table 1. Schematics and range of the survey

Subject of the survey		Super-highrise residence "A"
Parties *:Subject	Owner	"B* "
	Architect	"C"
	Superviser	"D"
	Contractor	Joint venture ("X*", "Y", "Z")
	Construction Manager	"E*"
Term of construction		From August 2001 to September 2003
Number of Stories	Building	36 stories above and 2 under the ground
	Penthouse	2 stories above
Height		116.05m
Structure		Reinforced concrete (Partly precast concrete)
Area of a building site		5,439.5m^2
Area of a building		3,213.52 m^2
Period of the survey	The 1$_{st}$ survey (questionnaire)	From September 2001 to September 2003
	The 2$_{nd}$ survey (hearing)	After the 1st survey
Method of the survey	・ Questionnaire, ・ Hearing, ・ A list of inhabitants' claims at a private view near a completion ・ A list of inhabitants' instructions at a completion inspection	

Table 2. Items of the survey

	The 1$_{st}$ survey	The 2$_{nd}$ survey
Risk event	O	
Risk strategy	O	
Possible timing of occurrence	O	
Who currently owns the risk	O	
Who undertakes the strategy	O	O
Possible timing of undertaking the strategy	O	O
Costs for the strategy		O
Occurrence probability (after the strategy and without the strategy)		O
Impact		O
Amount of damage		O
Alternative strategy		O

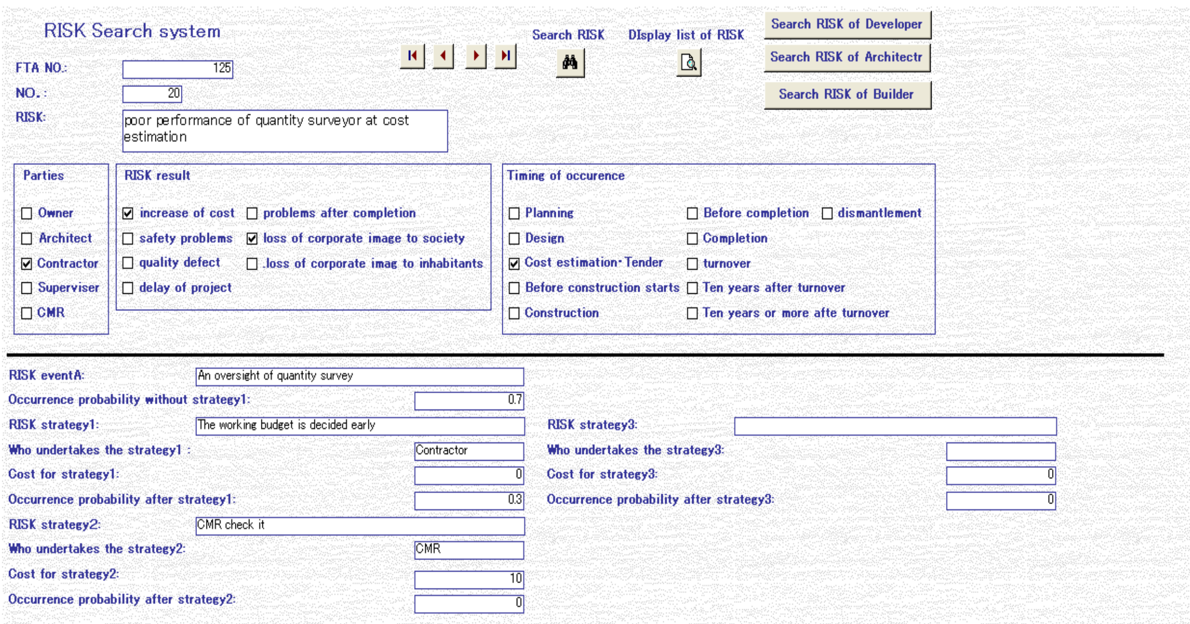

Fig. 1. An example of database presentation

3. DEVELOPMENT OF RISK BREAKDOWN STRUCTURE MODEL

Based on the risk survey in previous section, sources of the risks were put into risk breakdown structures by fault tree analysis (FTA).

Undesirable outcomes were classified into the following seven categories, which we call "risk results";

1. increase of costs
2. safety problems
3. quality defects
4. delay of project
5. problems after completion
6. loss of corporate image to society
7. loss of corporate image to inhabitants

Putting these seven risk results on top of the structure, the causes of each risk result was broken down by FTA format down to failure causes.

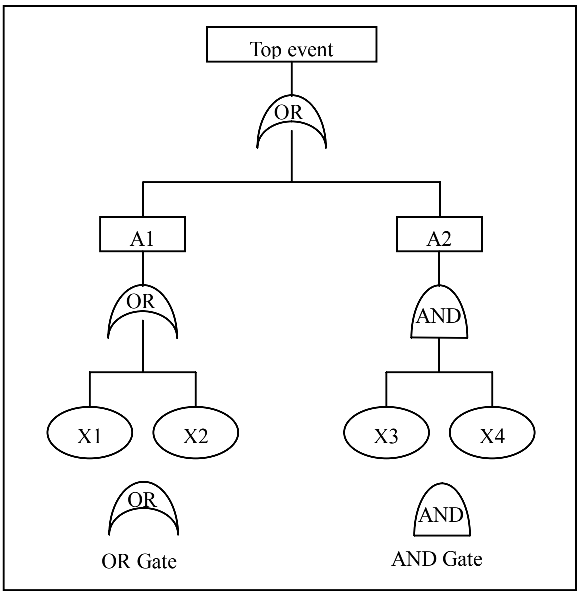

Fig. 2. A simple model of fault tree

4. RISK QUANTIFICATION AND FORMULATION

The structured risks were quantified so that we can find an optimal combination of risk strategies within a fixed risk strategy budget. In quantification process, probability measure was adopted.

4.1 Risk quantification

Probability of occurrence of each risk result P_T is calculated by formula (1)

$$P_T = \coprod_{j=1}^{k} \prod_{i \in K_j} P(X_i) \qquad (1)$$

where, $P(X_i)$ is the probability of occurrence of failure cause X_i, K_j corresponds with minimum cut-sets, k denotes the number of minimum cut-sets.

4.2 Quantification of risk strategies

In many cases, multiple strategies are feasible for one failure cause. Relationships between risk strategies shall be considered.

In this study, the following categories were determined. In the optimization process, all the risk strategies were converted into exclusive set of strategies. Then we select one set among sets of strategies. In this procedure, whole the problem was simplified to a combinational optimization problem of risk strategy sets.

1) Independent strategy

Each strategy can be adopted independently with no limitation to combine with other strategies. The effect of strategy is additive.

2) Exclusive strategy

Two strategies in this category cannot be adopted simultaneously. This category includes cases of physically impossible and cases of economically impracticable.

3) Interactive strategy

The effect of multiple strategies corresponds to each other. In this case, costs and effect are not additive. Depending on the combination, a set of new strategies is to be determined.

4) Priority strategy

The effect of one strategy is only to supplement another strategy. Namely, supplemental strategy cannot be adopted alone.

5) Timing strategy

Even though the details of strategy and costs are the same, the effect may be deferent depending on the timing of the adoption of strategy. In this study, we considered that the optimum strategy corresponds with the timing that yields maximum effect.

Considering the probability of occurrence of failure cause, reduction of risk results and corresponding costs of adoption of risk strategy sets are applied as a measure of quantification.

- reduction of probability of occurrence of failure causes is calculated by

$$\Delta P\left(S_i^r\right) = P_i^0 - P_i^r \qquad (2)$$

where P_i^0 is the probability of occurrence of failure causes without a risk strategy set, P_i^r is the probability of occurrence of failure causes after risk strategy set S_i^r is adopted.

- reduction of probability of occurrence of risk results is calculated by

$$\Delta P\left(S_i^r\right) = P_T\left(P_1^0, \cdots, P_i^0, \cdots, P_n^0\right) - P_T\left(P_1^0, \cdots, P_i^r, \cdots, P_n^0\right) \qquad (3)$$

where n is the number of failure causes, $P_T(P_1,\ldots P_n)$ is the probability of occurrence of risk results when the probability of occurrence of failure causes $\{P_1,\ldots P_n\}$ are given.

- Summary of costs of risk strategy sets adoption is calculated by

$$C=\sum_{i=1}^{n} b_i \tag{4}$$

where b_i is the costs of a risk strategy set corresponding with failure cause X_i .

5. QUANTITATIVE OPTIMIZATION METHOD OF RISK MANAGEMENT STRATEGY

A method is presented to search for the most effective combination of risk strategy sets among all the possible combinations of risk strategy sets under constraint on the fixed risk strategy budget.

5.1 Search for optimum combination by branch-and-bound method

The optimization problem is reduced to 0-1 integer programming problem. If there is risk strategy set S_i^r against failure cause X_i, decision valuable x_i^r was set. x_i^r is either 1 (adoption) or 0 (no adoption). The optimization problem is formulated as branch-and-bound method.

Minimize : P_T

Subject to : $P_T=\coprod_{j=1}^{k}\prod_{i\in K_j} P(X_i)$

$$P(X_i)=P_i^0-\sum_{r=1}^{l_i}\Delta P(S_i^r)x_i^r$$

$$\sum_{r=1}^{l_i} x_i^r \le 1\ ,\ \sum_{i=1}^{n} b_i \le C_{\max}\ ,\ b_i=\sum_{r=1}^{l_i} a_i^r x_i^r$$

$$x_i^r\in\{0,1\}\ ,\ (1\le i\le n) \tag{5}$$

where a_i^r is the costs of risk strategy set S_i^r, l_i is the number of risk strategy sets corresponding with failure cause X_i , C_{max} is the fixed risk strategy budget.

Table 3. Decision variable of x_i's and optimum combination

Risk events	Risk strategy	x_k	0 or 1
Excess over the cost because of failure of value engineering	CMR check it	x_1	0
	Operate value engineering from planning or design	x_2	0
Failure of estimation	Operate value engineering	x_3	0
Variation of floor plan after occupants saw drawings	Check lists of variation and progress of construction	x_4	1
Shortage of communication between architect and provider	CMR and builder adjust differences of opinion	x_5	1
Variation of design is not reflected in drawings	Adjust differences by working drawings	x_6	0
	CMR check it	x_7	1
	Both of them	x_8	0
Excess over the cost because of deffence between building and equipment	Adjust differences by working drawings	x_9	0
Hot spring is not available	Check geology of site	x_{10}	0
	Contingency for equipment	x_{11}	0
	Both of them	x_{12}	0
Exposure of ground pollution	Site survey	x_{13}	0
	Negotiate with ex-landowner	x_{14}	1
Exposure of obstacle underground	Survey history of site	x_{15}	0
	Negotiate with ex-landowner	x_{16}	1
Excess over cost due to restrictions of construction time on the east	Consultations with other developer	x_{17}	1
Imposed restrictions of construction time due to building agreement	Collect information relating to the construction work from general contractors constructing in the	x_{18}	1
Use the roads on the East and south of a building	Consultations with administration	x_{19}	1
Imposed restrictions of construction methods because of being railway on the south	Consultations with train company	x_{20}	1
Receive a claim from neighborhood	Meet a claim for damages	x_{21}	1
Influence of airstream on surrounding	Computer simulation	x_{22}	1
	Model test		
	Both of them	x_{23}	0
The electric wave trouble happens	Assume it and Measures are taken	x_{24}	0
It becomes a trouble with the occupants because of changing many menu or option of floor plan	Set a target for agreement	x_{25}	1
Ambiguous division of roles of supervisor and developer	Have a clear distinction between developer and superviser	x_{26}	1
The pending issue of administration at design	Inquiry of a pending issue	x_{27}	1
	Adjust at design	x_{28}	1

5.2 Search for optimum combination by enumeration method

Enumeration method is to list up all the combinations that satisfy constraints among exclusive sets. An optimum solution is found among the list of combinations.

All the combinations that yield the same costs are searched first. Among them, a combination that yields maximum reduction of risk results is searched. Varying the total costs of risk strategy sets, similar process is repeated. Finally, an optimum combination is found within a fixed risk strategy budget.

6. NUMERICAL EXAMPLE

As an example, risk events for owner, corresponding with the risk result, "delay of project" was searched through database established in Section 2.2. The searched strategies were converted into risk strategy sets by the method described in Section 4.2.

The risk breakdown structure was applied to a specific risk result, "delay of project". Probability of occurrence is calculated in accordance with formula (1) as

$$P_T = 1 - \{1 - P(X_1)\} \cdots \{1 - P(X_{102})P(X_{105})\} \qquad (6)$$

An optimal combination of risk strategy sets within a fixed risk strategy budget was searched by the method described in Section 5.1, 5.2, where the number of failure causes was 105, the number of risk strategy sets was 28, and the fixed risk strategy budget was ¥1.00M.

6.1 An example of search by branch-and-bound method

Decision variable x_i's were attributed to each risk strategy set. Optimization was carried out by branch-and-bound method. The results are shown in Table3.

From the results, the optimal risk strategy budget is ¥0.98M. We can see that a contractor needs to undertake many risk strategies to mitigate risk events corresponding with "delay of project".

6.2 An example of search by enumeration method

Database search results were incorporated into a FORTAN program to calculate by enumeration method. The results are shown in Figure 3.

All the calculation results were sorted in the order of costs because the increase of costs shall yield more reduction of risk result. By viewing this plot, one can confirm graphically the optimum solution for specific costs of risk strategy.

The optimum risk strategy set was identical with the result by branch-and-bound method, which corresponded to ¥0.98M.

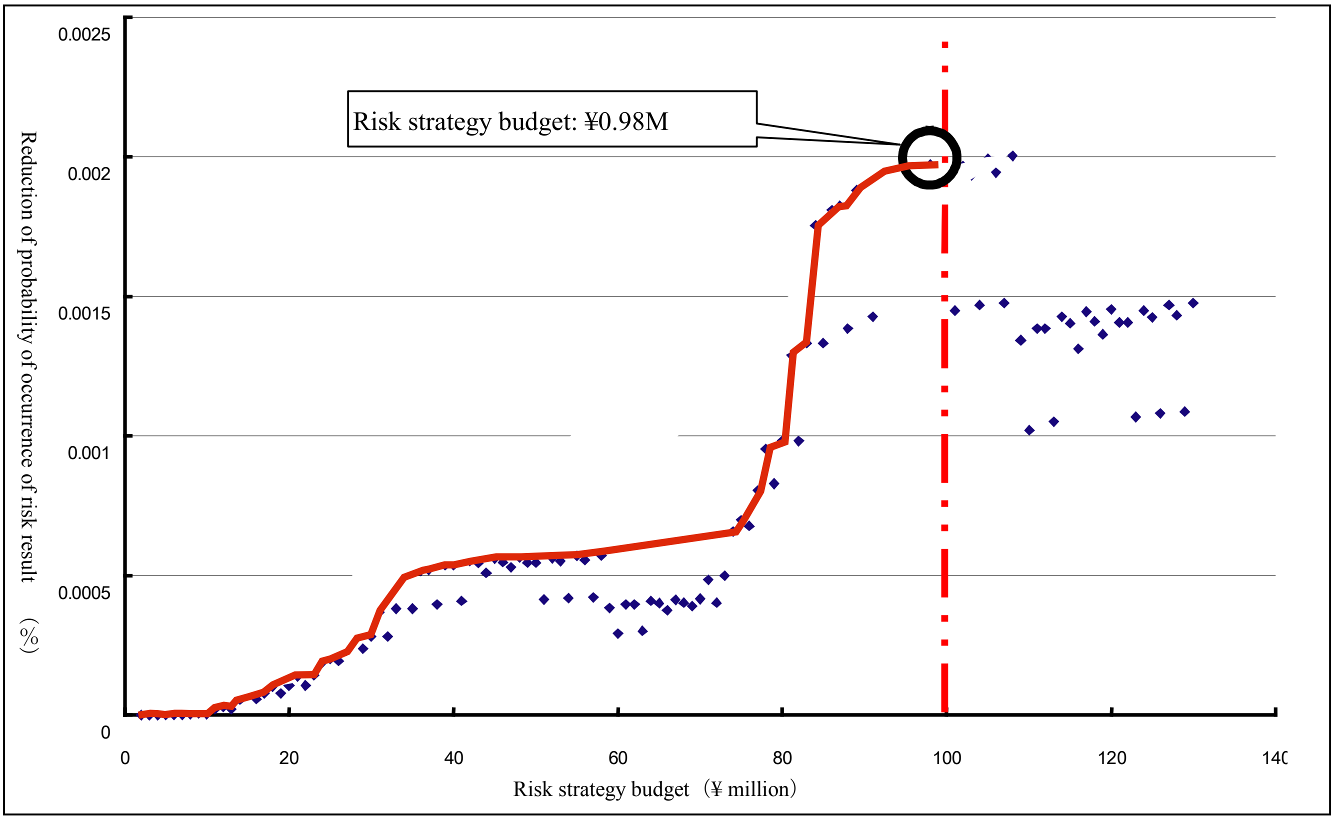

Fig. 3. Optimum combination by enumeration method

7. CONCLUSION

In this study, risks were collected in a real construction project of super high-rise residence. By analyzing the risks, an optimum combination of risk strategy sets was searched by branch-and-bound method and by enumeration method. Both methods were found effective in searching optimum combination. It was also found that the number of feasible combinations rationally could be limited by branch-and-bound method, and that enumeration method could show the relationship between costs of risk strategy and reduction of probability of risk results.

The next step of this research would be as follows;

1) At this step of development, risk analysis corresponds only with production. In the future, more risk areas such as structural and environmental engineering are needed to be incorporated to develop reliable system.
2) By applying this system to real construction project to support risk management, system shall be improved to be more practical and easy to use.
3) In general, importance of risk management of individual project should be informed to society. For this purpose, applicability to construction project should be improved to easily use risk management support system. The needs for risk management should be recognized.

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