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A decision support system (DSS) for construction risk efficiency in Taiwan

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Abstract. Many studies in risk management have been focused on management process, contract relation, and risk analysis in the past decade, but very few studies have addressed project risks from the perspective of risk efficiency. This study started with using Fault Tree Analysis to develop a framework for the decision-making support system of risk management from the perspective of risk efficiency, in order for the support system to find risk strategies of optimal combination for the project manager by the trade-off between project risk and cost of project strategies. Comprehensive and realistic risk strategies must strive for optimal decisions that minimize project risks and risk strategies cost while addressing important data such as risk causes, risk probability, risk impact and risk strategies cost. The risk management in the construction phase of building projects in Taiwan upon important data has been analyzed, that provided the data for support system to include 247 risk causes. Then, 17 risk causes were extracted to demonstrates the decision-making support system of risk management from the perspective of risk efficiency in building project of Taiwan which could reach better combination type of risk strategies for the project manager by the trade-off between risk cost and project risk.

Keywords: risk management; risk strategy; fault tree analysis; risk efficiency; decision-making support system(DSS)

1. Introduction

The construction industry has become more uncertain and complex. The project managers should operate the project in the uncertainties of environmental of conditions, and control the risk of schedule delay or cost overrun. As a result the need for risk management has increased.

Many studies in risk management focused on management process, contract relation and risk analysis in the past decade (Tsai and Yang 2009). Particularly in Taiwan, most risk management studies focused only on the relationships between stakeholders and the locations of responsibility, and were merely qualitative discussions (Wang and Chou 2003, Charoenngam and Yeh 1999). As risk management in Taiwan was generally processed empirically at jobsites, a theoretical algorithm was therefore necessary for the analysis of the reality of risk management, so that risk strategies could be set up and jobsite project risks could be quantitatively clarified in the construction phase of risk management.

In order to remedy the deficiency of risk management in Taiwan, there are two main purposes. The first is to extract the most important risk causes in Taiwan. The second is to investigate the correlations among risk cause, risk strategy, and risk strategy cost while applying Fault Tree Analysis (FTA) and Reliability Graph Analysis (RGA) to develop a framework for the decision-making support system of risk management from the perspective of risk efficiency in order for the support system to find optimal combination type of risk strategies for the project manager by the trade-off between project risk and cost of project strategies. The first purpose for this study has already been analyzed in Tsai and Yang (2009), this study is focused on support system.

A basic definition of “risk efficiency” is simply “the minimum risk decision choice for a given level of expected performance”, in which “expected performance” means a best estimate of what should happen on average, and “risk” means “the possibility of adverse departures from expectations” (Chapman and Ward 2004). The application of this concept can allow project managers to distinguish good luck from good management, and bad luck from bad management.

2. Review of risk management in Taiwan

Risk management in the construction phase of building projects in Taiwan has been analyzed that indirectly elicits important data such as risk causes, risk probability, risk impact. A brief review of the data is presented here. A detailed description of the data can be found in Tsai and Yang (2009).

Tsai and Yang (2009) adopted risk causes and categories from Tsai *et al.* (2001), who brainstormed with 40 project managers to yield 650 clearly defined risk causes related to risk results and project stages in the construction phase (Tsai and Yang 2009, Tsai *et al.* 2001). According to Table 1, 105 risk categories were found containing 247 risk causes generalized from the 650 originally suggested risk causes.

Then, the accumulation contributing ratio of risk and

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distance of controllability are utilized as the two proposed criteria to extract the consensus critical risks of practitioners. The data are analyzed from multiple points of view to explore the co-relationship among risk cause, risk strategy, risk result and project stage, and to clarify the risk mechanism and the realities of risk management. It was found that 17 risk causes were significance ranking of risk with temporal sequencing change over different project stages (e.g. before commence of construction, structure work, finish work and after final inspection) and project risk result over different project problem (e.g. safety problem, schedule delay, cost overrun, low quality and reputation down). These risk causes are listed as bellow

1. B201.Higher construction cost due to material price rise
2. B901.Low profit due to unexpected low market demand
3. B1001.Low profit due to excessive competition
4. C102.Contract amount not proportionate to amount of work contracted
5. C401.Unspecified client/designer/contractor's liability
6. C402.Liability of incomplete design got carried over
7. C601.Relative engineering change cost is overlooked
8. C902.Drawing specifications not included in estimate
9. D605.Administration management having different interpretations on regulations
10. D1302.Malpractice of subcontracting for subcontractor referred by the client or local representative
11. E903.Neighboring community claims extra compensation
12. F709.Construction process fails to follow schedule
13. Gb202.Incompetent subcontractor
14. Ha602.Not using safety belt / safety measure properly
15. Hc501.Too many engineering change and too slow instruction fails approval on project amount
16. Hd402.Payment-related dispute
17. Hd801.Client's financial problem

According to above analysis, extracted 17 risk causes which were important in temporal sequencing change over different project stages and project risk result over different project problem. The 17 risk causes would be used in the questionnaire was built to investigate the changes of the additional risk strategy; the correlations among risk cause, risk strategy, sub-contracting, strategy cost, and probability and impact of the 17 risk causes.

3. Investigation

The questionnaire survey was sent to 50 site managers with 10–15 years experience of building construction in Central of Taiwan from August to September 2015. Thirty-three effective samples were collected to develop a framework for the decision-making support system of risk management (as shown in Table 1).

In this research, risk strategy was used to reduce risks. However, managers always select simply risk strategy of construction plan rely on experience. Standard risk strategy means single risk strategy; it was listed in the construction plan of the building project. Additional risk strategy means numbers of risk strategies; it may contain two or three above risk strategies to reduce risks. For instance, standard risk strategy of "E903. Unexpected community compensation claim" was "verify the title of the premise prior to construction while build friendship with the local residents" but additional risk strategies were "implement protective measures" and "provide information session prior to construction and keep communication open with local residents"

4. Development of quantitative analysis

4.1 Fault tree analysis

FTA is an analytical method for the finding the major causes of failures and to assess the probabilities of failures in systems or facilities.

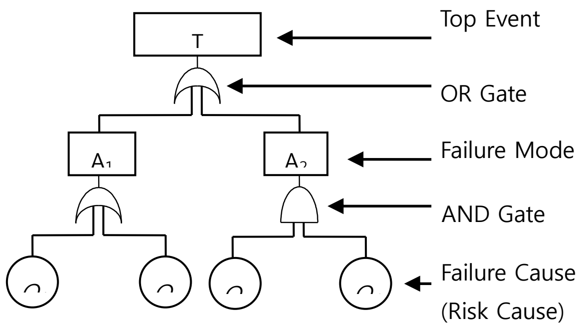

Fig. 1 Legend of Fault Tree (FT) and risk cause

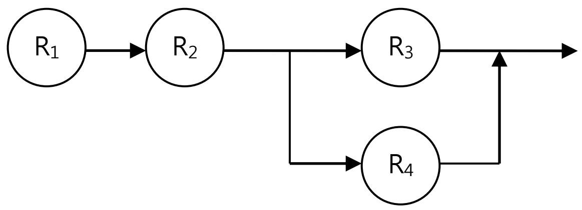

Fig. 2 Reliability graph

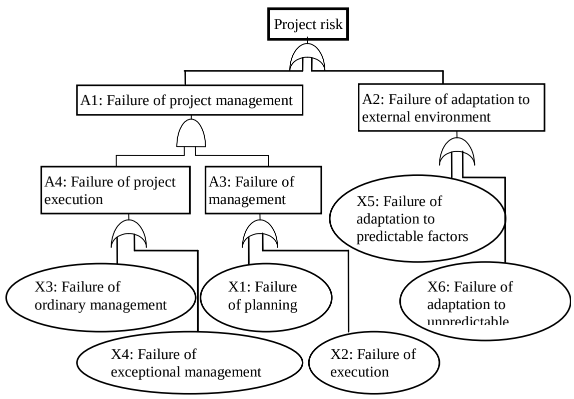

Fig. 3 FT of general model

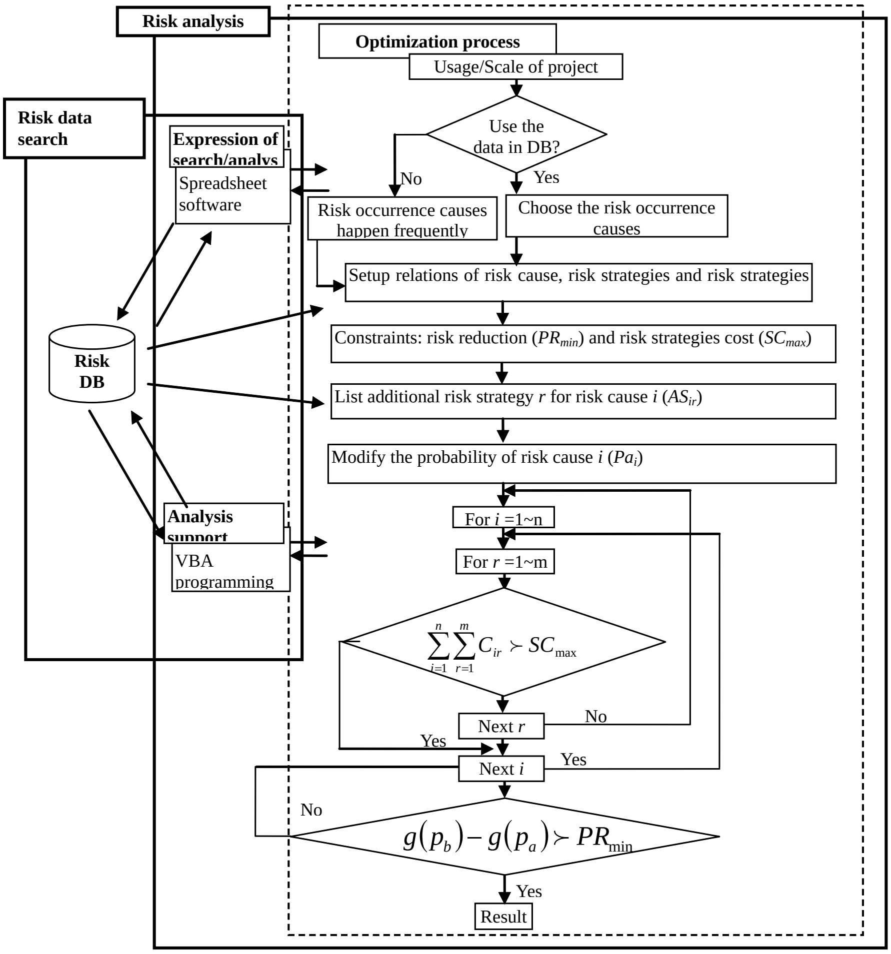

Fig. 4 The framework of the decision support system

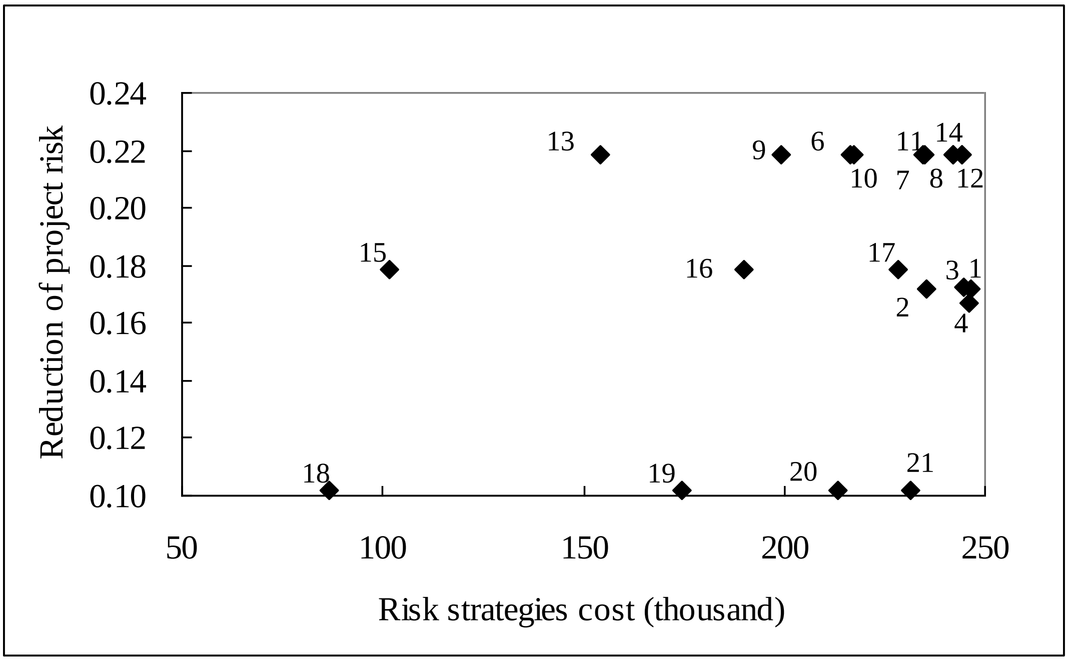

Fig. 5 Combination types of risk strategies

Table 1 The co-relationships among risk strategy, strategy cost of 17 risk causes

No	O_i	AS_{ir}	OP_{ir}	C_{ir}	Pa_i	SS_i	C_i	Pb_i
1	B201	Allocate reasonable amount of reserve for construction expense Allow reasonable price hike in material cost estimation as contingent buffer Conduct market price survey in pragmatic manner	Proprietor Headquarters Headquarters	69.87 88.83 16.96	0.36 0.26 0.40	Conduct thorough market price evaluation	214.94	0.55
2	B901	Improve the quality of construction Fully knowledgeable about the market	Site office Headquarters	74.41 38.11	0.29 0.32	Apply scrutiny in cost-related spending, while upholding construction project quality	177.71	0.34
3	B1001	Cost analysis and price estimation	Headquarters	18.26	0.31	Set reasonable selling price and competition mechanism	207.52	0.47
4	C102	Implement contingent plans Cost analysis and estimation	Headquarters Headquarters	51.75 15.10	0.31 0.31	Cost analysis and reasonable price estimation	150.57	0.41
5	C401	Specify the liability of each party involved in the contract Hold periodical sessions for contract-related affairs discussions and liability definition	Proprietor Proprietor	11.68 9.21	0.33 0.40	Have the relevant liability clearly specified in the contract	103.31	0.48
6	C402	Reviews on relevant information and contribute suggestions Request the designing unit to provide drawing and construction manual	Headquarters Designer	18.64 11.16	0.36 0.36	Allow sufficient communication to reduce pre-construction uncertainty	100.91	0.50
7	C601	Specify the design modification fees in the contract	Proprietor	74.93	0.33	Have the relevant liability clearly specified in the contract	73.96	0.45
8	C902	Reasonable estimation on construction cost	Headquarters	21.28	0.39	Detect the cause prior to construction	231.68	0.78
9	D605	Specify the liability in the contract in case of regulation change proprietor	Proprietor	9.82	0.29	Set up a law information center	33.96	0.38
10	D1302	Implement feasibility evaluation	Headquarters	15.20	0.20	Implement a sound communication system	61.01	0.34
11	E903	Implement protective measures Provide information session prior to construction and keep communication open with local residents	Site office Site office	24.98 13.68	0.35 0.33	Verify the title of the premise prior to construction while build friendship with the local residents	85.74	0.53
12	F709	Respond and tackle problems in timely manner Lay out plans for construction projects with progressing schedule	Site office Site office	18.83 18.86	0.36 0.34	Improve the competence of construction planning and progress scheduling as well as managing ability	99.47	0.50
13	Gb202	Conduct stringent qualification review for contract bidding parties Respond and tackle problems while working on solution	Headquarters Site office	13.09 10.72	0.35 0.38	Have the qualification requirements clearly defined, and implement bidding party evaluation	76.69	0.52
14	Ha602	Tighten up surveillance Further education on personnel safety	Site office Site office	10.00 8.58	0.30 0.32	Provide training programs on workers safety on regular basis	55.90	0.50
15	Hc501	Proprietor requested to simplify engineering change procedure and paperwork	Headquarters	10.30	0.36	Arrange to have the clause specified in the contract	54.26	0.53
16	Hd402	Keep close contact with the proprietor Report expense in timely manner, while allowing periodical account settlement	Headquarters Site office	24.03 17.90	0.31 0.28	Carry out the construction plan as per the schedule, and writing out expense slip in timely manner	85.85	0.41
17	Hd801	Rely on bank guarantee	Proprietor	44.51	0.25	Have the mechanism of the payment terms stipulated in the contract	92.08	0.34

O_i : risk cause *i*, *i*=1,…,247
AS_{ir} : additional risk strategy *r* for risk cause *i*, *r*=1, …,*m*
OP_{ir} : contractor who executes additional strategy *r* for risk cause *I*
C_{ir} : the average cost of additional risk strategy *r* for risk cause *i* (thousand)
Pa_{ir} : after additional risk strategy *r* for risk cause *i*, the average probability of risk cause *I*
SS_i : standard risk strategy for risk cause *i*
Pb_i : the average probability of standard risk strategy for risk cause *i*
C_i : the average cost of standard risk strategy for risk cause *i* (thousand)

Table 2 Risk Strategies of Type 13

Risk Cause	Risk Strategy	Subcontractor
C102.	Implement contingent plans Cost analysis and evaluation	headquarters headquarters
C902.	Reasonable estimation on construction cost	headquarters
D1302.	Conduct feasibility evaluation	headquarters
Hc501.	Proprietor requested to simplify engineering change procedure and paperwork	headquarters
E903.	Implement protective measures	Site office
	Provide information session prior to construction to improve communication with local residents	Site office

It is widely used in safety engineering of mechanic and aviation industry. Basically, it uses logic gates of AND gate and OR gate to describe the relationship of these failure factors by Fault Tree (FT) (Fig. 1). FT can establish a causal scenario that is called accident sequence, which is composed of various failure interactions across devices, software, materials, and humans. When the probabilities of failure causes are given as input, the occurrence probability of top event can be assessed, and the quantitative/qualitative importance of failure causes can be identified in the mean time.

4.2 Minimal cut-sets

In order to develop the quantitative analysis of this study, FTA was used to analyze project risks. Normally, there are a number of cut-sets in an FT, but minimal cut-sets mean these sets are the necessary and sufficient conditions for the occurrence of top event. The minimal cut-sets of Fig. 4 can be identified by using Boolean algebra to be minimal cut-sets {O_1}, {O_2} and {O_3, O_4}. In the premise in which the basic events of risk causes are independent from one another, the probability of risk occurrence is defined as Eq. (5) in FTA (Inoue 1979). As the interpretation in minimal cut-sets, the meaning Eq. (1) is when every risk cause *i* in any minimal cut-set K_j (*j*=1, …, *k*) occurs, then risk will occur.

$$g(q) = \coprod_{j=1}^{k} \prod_{i=K_j} q_i \tag{1}$$

where

g(q): probability of risk occurrence

q_i: probability of risk cause *i* including minimal cut-sets K_j

4.3 Dual structure of FTA and RGA

In reliability engineering, RGA is used to analyze the reliability of systems in production. Some redundancy devices may be added to increase the reliability of such systems to an acceptable level. Further, the character of dual structure between FT and RG is facilitated. For example, the failure causes of O_1, O_2, O_3 and O_4 in the FT of Fig. 1 can be transferred to the activities labeled with R_1, R_2, R_3, and R_4 in the RG of Fig. 2. By comparing the failure probabilities of different FT's, the effectiveness of risk strategies can be assessed.

5. Analytical procedures

5.1 Risk identification and risk relationship

The risk causes of the projects can be categorized into internal risks and external ones (Zhi 1995, Lin *et al*. 2015). Normally, the rational plans are used to deal with the internal risk in project management, and emergent plans are adapted to external risk of external environment. So the risk occurrence of project is associated with management and failure of adaptation to external environment (Fig. 3). In order to clearly interpret and demonstrate the analysis steps, this research uses the method of modularization that takes partial FT as a cut-set or a basic event of top event. Thus, the analysis level is close to the independent risk causes of X1 to X6.

With the classification of the 17 important risk causes for construction projects were identified, which were used to survey the data of all stakeholders and analyze the project risks.

5.2 Preparing and analyzing FT

The risk strategies of project can be regarded as the redundancy devices of system in reliability engineering, and therefore should be regarded as partial processes of the project, which allows the new RG to be built with risk strategies. Besides, according to dual structure of FTA and RGA, the new project RG to be built with risk strategies which could be transferred to FT. After the risk strategies, the amount of risk could be assessed by transferring each new RG to a corresponding FT with FTA. By comparing the risk of these FTs, the effectiveness of such risk strategies (redundancy devices) could be ascertained.

Through the dual analytical FT and RG structure mentioned above, the project risk before the additional risk strategy could be calculated by Eq. (2), and in order to show the reduction of project risk through comparison, the modified probability of risk cause *i* with the additional risk strategy could be computed by Eq. (3), which allows the probability of risk cause to show the changes from the additional risk strategy. The Eq. (4) is concerned with the modified probability of project risk after the additional risk strategy, and Eq.(5) is concerned with the cost of risk strategy, which would be used to evaluate risk cause *i*.

Thus, the project risk reduction and additional risk strategies cost can be calculated, by the additional risk strategy before and after. The reduction and additional cost would be used to evaluate risk strategy efficiency.

$$g(Pb) = \coprod_{j=1}^{k} \prod_{i \in K_j} Pb_i \tag{2}$$

where

g(Pb): before additional risk strategy *r*, the probability of project risk occurrence

Pb_i: before additional risk strategy *r*, the average probability of risk cause *i*

k: amount of minimal cut-sets in an FT

K_j: minimal cut-sets *j* in an FT

$$Pa_i = Pb_i \prod_{r=1}^{m} \frac{Pa_{ir}}{Pb_i} \tag{3}$$

where

Pa_i: modified the probability of risk cause *i*

Pa_{ir}: after additional risk strategy *r*, the average probability of risk cause *i*

m: numbers of risk strategies

$$g(Pa) = \coprod_{j=1}^{k} \prod_{i \in K_j} Pa_i \tag{4}$$

where

g(Pa): after additional risk strategy, the probability of project risk occurrence

$$SC = \sum_{i=1}^{n} SC_i = \sum_{i=1}^{n} \sum_{r=1}^{m} C_{ir} \tag{5}$$

where

SC: amount of the cost of risk strategy, used to evaluate risk cause

SC_i: the cost of risk strategy, used to evaluate risk cause *i*

C_{ir}: the average cost of additional risk strategy *r* for risk cause *i*

n: numbers of risk cause *i*

5.3 Comparing the effectiveness of risk strategies

As shown in Table 2, many risk strategies were used to deal with various risk causes to reduce project risk. For instance, risk strategies "Develop alternative plan" and "Cost analysis and estimate" were used to deal with designer-related risk cause "C102. Contract amount unproportionate to amount of work contracted" and "Hc501.Too many engineering change and too slow instruction fail project amount to be confirmed", and the combination type of risk strategies would turn out to be "Proprietor requested to simplify engineering change procedure and paperwork", etc.

The results of the calculation from preparing and analyzing FT along with the risk strategy cost and the amount of reduction by the risk strategy could be used to evaluate the risk strategies.

6. Framework of decision support system

The framework of the decision-making system in risk management was proposed from two viewpoints of data search and risk analysis, as illustrated in Fig. 4(Hajrya and Mechbal 2015, Sperl-Hillen *et al.* 2016, Gómez *et al*. 2016, Plitsos *et al.* 2017, Olson *et al*. 2017).

6.1 Risk data search system

The system of data search was composed of three parts, which were “risk data base”, “analysis support”, and “presentation of search”. In order for the decision-making system to be used easily at the jobsite, the spreadsheet (for instance, Microsoft Excel) was mainly adopted as the interface for the presentation of search and analysis. The data was retrieved form the database by the analysis support designed by VBA (Visual Basic for Application Edition) programming, and the result was shown on the spreadsheet in a dialogue mode.

The risk data retrieval was divided into hierarchies, and these hierarchies were linked mutually. First, some elements of risk causes concerning the project were retrieved. For instance, risk causes often generated for some types of projects could be selected from the elements of project usage, project scale, and project location, etc., and then possible risk results and the value of the risk reduction were presented by the risk strategies often used for these risk causes. In addition, the scenario of the trade-off of risk and cost in the project was simulated from the relations among the risk, the cost of the forecast damage, the risk strategies, and the strategies cost, etc. through the selection in a dialogue mode. In other words, a primary/qualitative analysis concerning each risk occurrence cause in the project risk could be preceded according to historical data.

6.2 Risk analysis system

The system of risk analysis was composed of three parts, which were “process of optimization”, “analysis support”, and “expression of search/analysis”. The result of the analysis was presented on the spreadsheet. The computational algorithm of the data exchange with the database in the optimization process was supported mainly by using the VBA programming in the analysis support. Optimization was divided into two levels, of which the first was called partial optimization, which was used to select risk strategies against individual or multiple risk causes.

The second level of optimization was called total optimization, which was used to search the proper risk strategies by the combination type of constrained conditions of the project risk. The optimization process was a process for which the alternative provided by certain constrained conditions.

First, the data used for the analysis should be identified by the elements concerning the project. For instance, the elements might be the project usage, the project scale, and the project location etc. And, the risk data about risk causes, often generated for such project types, should be inputted.

Next, the user decided whether to use historical data of database or not. And, the user should determine whether to use the relations provided by the database among the risk cause, the cost of the forecast damage, the risk strategies, and the strategies cost, etc., or to simply reset the data. In addition, the constrained conditions concerning the project and the objectives of the analysis were set up with the risk strategies being set at the condition of certain cost or the necessary cost; for instance, in order for the project risk generated by the quantitative analysis to be kept at certain level. As to the question of whether the results meet the demands, it all depended on the setting of such conditions.

Finally, the system would show the alternatives that meet the conditions of the constraints, thus providing support for the user in decision-making.

6.3 Selection of risk strategies

In order to reduce project risk, the combination type of risk strategies and the cost were evaluated by the risk analysis system mentioned above. The condition was to search for the combination type of risk strategies, with the project risk reduction being kept above 0.1, and the risk strategy cost below US 250 thousand. Fig. 5 showed the risk strategy search result, and was compared with all other combination types of risk strategy, while #8 combination type appeared to allow the largest amount of potential for the reduction of project risk, and #18 combination type appeared to allow the smallest amount of potential.

As to the question of what combination type was the best, the answer might vary from person to person. Normally, #13 combination type of risk strategy appeared to require the least cost while allowing the most reduction of project risk; therefore, it could be regarded as the best combination type. Table 3 illustrated risk strategies of Type 13 combination, which is believed to be the optimal type of combination.

In a particular case where the management was expected to apply risk strategy management by spending about 5 million dollars to reduce 0.22 of the project risk, the types of risk strategy combinations for the contract-related risk causes of “C102. Contract amount is not suitable to scope of work” included “Develop alternative plan” and “Cost analysis and estimate”, with only one type of risk strategies combination “implement feasibility evaluation” for the risk cause “D1302.Malpractice of subcontracting for subcontractor referred by the client or local representative”, and also only one type of risk strategies combination “Reasonable construction cost estimation” for the risk cause “C902. Cost details on drawing not included in Quotation”. The combination type of risk strategy for the designer-related risk cause “Hc501. Too many engineering change and too slow instruction fail project amount to be confirmed” was “Proprietor requested to simplify engineering change procedure and paperwork”. With regard to the safety & environment-related risk cause “E903 Unexpected community compensation claim”, the risk strategies included the combination types of “Implement protective measure” and “Provide information session prior to construction and keep open communication with neighboring community”.

On the other hand, it should be noted that optimal risk strategies were not only found in technical aspect but also in other aspects of construction projects such as contract, safety and environment, partners (e.g., designers), if the goal of improvement on risk management was going to be reached.

7. Conclusions

Project managers are normally accustomed to conventional ways of project operation and they tended to regard project risks as accidents. When a project is run under the uncertainty of the construction environment, the managing of diverse situations at jobsite may lead to difficulties such as schedule delay and risk cost overrun, making project operation even more complex.

In this research, the fundamental data of project risk was analyzed from some viewpoints through the investigation of actual situations of the construction site. The important risk causes were extracted by Pareto diagram, and distance of controllability. Otherwise, used FTA to develop a quantitative analytical method and developed a user-friendly interface for decision-making system by the correlation of risk cases, risk strategy and risk strategy cost. As a result, the following two achievements were obtained:

- Clarifying the important risk causes, and
- Proposing framework of the decision-making system of risk management from the perspectives of risk efficiency in building project of Taiwan which could search better combination type of risk strategies for the project manager by the trade-off between risk cost and project risk.

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Data generated or analyzed during the study are available from the corresponding author by request.

References

Chapman, C. and Ward, S. (2004), "Why risk efficiency is a key aspect of best practice projects", *Int. J. Project Management*, **22**, 619-632.

Charoenngam, C. and Yeh, C.Y. (1999), "Contractual risk and liability sharing in hydropower construction", *Int. J. Project Management*, **17**(1), 29-37.

Gómez, J.C.O., Duque, D.F.M., Rivera, L. and García-Alcaraz, J. L. (2017), Decision Support System for Operational Risk Management in Supply Chain with 3PL Providers. In *Current Trends on Knowledge-Based Systems*,205-222, Springer International Publishing.

Hajrya, R. and Mechbal, N. (2015), "Perturbation analysis for robust damage detection with application to multifunctional aircraft structures", *Smart Struct. Syst*., **16**(3), 435-457.

Inoue, I. (1979), FTA safety engineering Research institute of safety engineering, Tokyo, Japan.

Lin, C.W., Hsu, W.K., Chiou, D.J., Chen, C.W. and Chiang, W.L. (2015), "Smart monitoring system with multi-criteria decision using a feature based computer vision technique", *Smart Struct. Syst*., **15**(6), 1583-1600.

Olson, D.L. and Wu, D.D. (2017), Data Mining Models and Enterprise Risk Management. In *Enterprise Risk Management Models*, 119-132, Springer Berlin Heidelberg.

Plitsos, S., Repoussis, P.P., Mourtos, I. and Tarantilis, C.D. (2017), "Energy-aware decision support for production scheduling", *Decision Support Systems*, **93**, 88-97.

Sperl-Hillen, J.M., Crain, A.L., Ekstrom, H.L., Margolis, K.L. and O'Connor, P.J. (2016), "A clinical decision support system promotes shared decision-making and cardiovascular risk factor management", *J. Patient-Centered Res. Rev*., **3**(3), 218.

Tsai, T.C. and Yang, M.L. (2009), "Risk management in the construction phase of building projects in Taiwan", *J. Asian Architect. Build. Eng*., **8**(1), 143-150.

Tsai, T.C., Furusaka, S. and Kaneta, T. (2001), "Risk analysis in construction phase of construction projects", *J. Architect. Planning Environ. Eng*., **549**, 239-246.

Wang, M.T. and Chou, H.Y. (2003), "Risk allocation and risk handling of highway projects in Taiwan", *J. Management Eng*., **19**(2), 60-68.

Zhi, H. (1995), "Risk management for overseas construction project", *Int. J. Project Management*, **13**(4), 231-237.

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