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RISK ASSESSMENT OF DESIGN-BID-BUILD AND DESIGN-BUILD BUILDING PROJECTS

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Abstract Projects managers normally seek to lower the extent of risk by signing contracts, such as Design-Bid-Build (DBB) or Design-Build (DB) project delivery systems to transfer or share risk over to other project entities. The main purpose of this study is doing risk assessment from the perspective of clients, comparing project delivery systems mentioned above to see, firstly, what risk factors are, and, secondly, to analyze the ranking of risk factors and amount of risk with temporal sequencing change over different project stages (e.g. proposal surveying, scheme designing, procurement contracting, and construction receiving). Thus, identify risk factors using literature reviews and conduct survey with clients; utilize the fuzzy numbers with integral value to simulate the changes of ranking of risk factors and the amount of risk with temporal sequencing, given different the attitude of decision makers in risk management (pessimistic, neutral, or optimistic) of the decision-makers towards risk, meanwhile, consider information accuracy in decision-making environment. The result shows that Design-Bid-Build mainly concern about quotation, cost, drawing specification, etc. Furthermore, many risks arise in earlier stage, such as proposal surveying stage and scheme designing stage, that the practice of Design-Build should exert precaution to prevent likelihood of contractors using inferior materials to cheat profit out of affirmed bidding assignment, drawings, etc., and that risks are higher in proposal surveying stage and procurement contracting stage.

Keywords: Risk management, design-bid-build, design-build, project delivery system, fuzzy sets

1. Introduction

Building project must consider the environmental impact of the job, the successful scheduling, budgeting, site safety, availability of materials, logistics, inconvenience to the public caused by construction delays, preparing delivery system documents, etc. From the perspective of risk management, given building projects featuring high risk and complex risk structure, clients normally seek to lower risk by adapting some kind of risk strategies, such as project delivery system, to transfer risk or share risk to other project entities [7, 12, 18, 31]. Literature also agree that risk can be tactically controlled to some certain extent [6, 21, 26, 34], with specific means that tend to allow risks to be transferred or shared to other project entities [12, 18]. A project delivery system is defined as a method for procurement by which the clients' transfer or share risks to other project entities. These entities typically are a design entity who takes responsibility for the design and a contractor who takes responsibility for the performance of the construction. In Taiwan, Design-Bid-Build (DBB) is a conventional way that is also widely used in different countries and has been applied in different building projects, while Design-Build (DB) is another alternative providing clients with various options of choices. For the clients, the selection of project delivery system in the past would mostly rely on personal experiences [19], and as found by Mok [22], 80% of project managers still depend on subjective views or experience to weigh risks without the assessment of risk strategies in effective and systematical manner, and these are the options available for project delivery systems.

By demonstrating a schematic chart of risk allocation from the perspective of risk management, Iweeds [31] indicated project delivery systems being effective strategies for risk that allow the transferring and sharing of risk (as shown in Figure 1). Some recent studies that developed to assist project managers in selecting project delivery systems. Gordon [10] adapted the method of cancellation, by the assessment index of project delivery system selection, to remove those non-conforming project delivery systems and keep the appropriate ones; Spink [28] divided the considerations for project delivery system selection into two groups, with one being the considerations given to conditions available for the clients, the other given to project-related factors, while decision-makers are allowed to weigh the significance of one factor against the other, and render pros and cons of the project delivery systems; Khail [15] and Mahdi [23] applied the method of Analytical Hierarchy Process (AHP) in their studies to calculate the weighed rating of the assessment index for project delivery systems, which provides clients with reference in the selection of project delivery systems; Konchar and Chong [14] applied the statistic method of multivariate regression analysis to compare the advantages of construction management, DBB, and DB against the assessment indices of cost, delivery and quality; furthermore, Ling et al. [20] compared the advantages and disadvantages of DB and DBB project delivery systems by the construction progression and completion schedules.

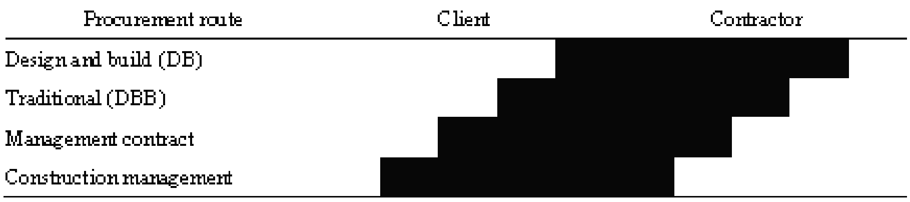

Figure 1: Schematic chart on risk transferring and distribution [31]

Although these studies are useful for risk strategies selection, they are limited in their applicability to real construction risk identification and analysis. Many clients are first confronted with the problems of not knowing, what risk factors need to be evaluated, and not knowing the significance ranking of each risk factor nor the amount of risks that might occur over different project stages, given the project delivery system they have selected, so that they cannot take appropriate strategies against the risks based on the kind of managerial advantages they have.

As suggested by literatures of previous studies, prior to the decision on project delivery system, considerations should be given to the matter of risk transferring or sharing in order to save time, cost and to improve quality [12, 18]. That meant selecting the appropriate project delivery system from risk management perspective, requires evaluating large amount of risk data, that are extensive and consensus will be able to serve as reference for the clients to do subsequent risk analysis and to effectively manage project risks in order for the project goal to be achieved [2]. The main purpose of this study, therefore, is to do risk assessment from the perspective of clients, comparing the project delivery systems of DBB and DB from the viewpoint of risk management, to firstly see what the risk factors are, and secondly analyze the significance ranking of these risk factors and amount of risk with temporal sequencing change over different project stages (e.g. proposal surveying, scheme designing, procurement contracting, and construction receiving).

The significance of the first objective of seeing what the risk factors are likely to emerge during the project progression, with the operation of DBB and DB project delivery systems, while allowing these risk factors can provide risk analysis. The second objective is significant because with the advancement of time, such as the progression of project stages from proposal surveying, through scheme designing and procurement contracting, to construction receiving, in addition to the difference in the significance ranking of risk factors, the amount of risk also varies with difference of project stage.

As pointed out by Grey [11], "once the risk factors in a building project are defined, the clients usually are short of time or resource for all risk factors management, and the issue coming next is to get the actual ranking clearly defined", but since most of the organizations are unable to put in that kind of resource to manage all those risk factors, the determination of the significance ranking of risk factors and the change of risk sequencing using risk as criterion can allow the clients to select the appropriate system of project delivery, ahead of time, based on the kind of managerial advantages they have, or determine what they need to make investment in later on in the future to manage those risk factors with higher risk and project stages.

2. Risk Identification

Building project has unique characteristics of its own and different type of project delivery systems; this results in extremely different groups of risk factors. However, some similarity of risk factors can be found existing in building projects across different countries, regions and different internally or externally environment, apart from the differences in the probability and impact. For instance, in some regions, there still exist risk factors relating to the change of governmental policy, weather condition and contract-related issues, while the identification of these risk factors are of particular significance for research [38].

Based on the notion that there exists similarity among risk factors across different building projects, and that the approach by literature review is suggested by a number of researchers for the identification of risk factors [1, 8, 25, 30, 32, 36], this study intends to gather, through literature review, risk factors recognized with consensus, while also compiling those risk factors that might be described in different wording. Take the category of natural phenomenon as an example. Such a risk factor as 'A01. Earthquake' is likely to factor impact on the goal of building projects for being 'A0101. Project loss incurred by earthquake', proving this risk factor being widely recognized [1, 25, 32]; likewise, 'A0201. Improper management of flammables', and 'A0301. Project loss incurred by high wind' is the same cases (see Table 1). The risk factors are categorized by above-mentioned study methods according to the types of their sources and serve as the questionnaire items, while also serving as the basic data for significance ranking of these risk factors and amount of risk with temporal sequencing change over different project stages, as shown in Table 2, where these risk factors are categorized into 11 categories and 62 items, with each risk item further being divided into a number of risk factors with specific descriptions for the risk item, making a total of 106 risk factors, such as the risk item of 'G03. Incompetent coordinator', which is further, divided into three risk factors of 'G0301. Chang order can not be approved shortly', 'G0302. Lack of effective communication', and 'G0303. Insufficient information collection' [1, 25, 32, 33].

3. Project Delivery Systems

To allow more choices for different types of clients for the choosing of project delivery systems, various types of project delivery systems have been developed in the last ten years.

Table 1: Risk definition and identification

Risk Category A. Natural Phenomenon		
Risk Items	Risk Factor	References
A01. Earthquake	A0101. Project loss incurred by earthquake	Perry [25], Al-Bahar [1], Tummala [32]
A02. Fire	A0201. Improper management of flammables	Perry [25], Al-Bahar [1], Tummala [32]
A03. High gale	A0301. Project loss incurred by high wind	Al-Bahar [1], Tummala [32]
A04. Rainfall	A0401. Project loss incurred by heavy rain	Kangary [13]

Hibberd and Basden (1996) suggest that risk is the prominent criterion that will determine the selection of a delivery system [12]. From the perspective of risk management, selecting an appropriate system of project delivery involves the assessment of many risk factors. Therefore, choosing an appropriate system of project delivery can lower the risk for clients and improve the possibility of success for the projects. Examples of the most common systems are described below.

3.1. Design-bid-build

As clients sign contracts individually with designers and contractors, there is no contractual bond between designers and contractors, except the channels for coordination and communication. The designer prepares a design package, including contract documents; next the owner submits the package for bidding and selects the best contractor to undertake construction of the project. This system is common method used and is found to suit clients of all types, particularly government institutions. Due to the feature of linear progression, this system provides better management for the client, but it gives little considerations to the designing, information communication and construction delivery [3].

3.2. Design-build

Design-Build has grown is popularity as the perfect solution in addressing the limitations of other methods. This system provides singular managerial interface in projects for both design and construction. If the goal of the building project is clearly defined prior to the beginning of construction, this system of project delivery allows clients to demand for project cost, delivery and so on. Due to the simplification of managerial interface throughout the building project, the likelihood of design change and the delay of delivery is eliminated, and the risk for clients is reduced [24], but yet due to reduced amount of communication and coordination between clients and designing party, and the designing party and the building party being the same one, there is concern as in the case when the player also act as the referee [3].

However, the difference in project delivery systems has direct impact on the relations, roles, liability and obligation of project members, and even on the relation of potential risks. Above the project delivery systems, as the ranking of risk factors and the amount of risks may vary with different stage of project. The project stage, normally progress through a universal sequence of four stages, i.e. (1) proposal surveying: referring to analysis and evaluation on whether the plan desired by the client is technically and financially feasible; (2) scheme designing: referring to the design package, including measuring, geological surveying, drawings, budget, etc.; (3) procurement contracting: referring to selecting the contractor and handling all business related to project delivery such as procurement of equipment, materials etc.; (4) construction receiving: referring to the contractor completing the project and turn-over to the client.

Table 2: Project risk structure

A. Natural Phenomenon	G03.Incompetent coordinator
A01.Earthquake	**H. Safety / Environment**
A02.Fire	H01.Environment damage/pollution
A03.High gale	H02.Accident-related loss
A04.Rainfall	H03.Traffic or work hour restriction
B. Economics/Finance	H04.Third partyfs objection
B01.Increased materials cost	**I. Client**
B02.Exchange rate fluctuation	I01.Feasibility study
B03.Difficulty of financing	I02.Unreasonable demand
B04.Low market demand	I03.Reference by subcontractors
B05.Strong Competitor	I04.Relation with the third party
C. Politics/society	I05.Late payment
C01.Change of laws	I06.Reliance on architect/consultant
C02.War/revolution/riot	I07.Jobsite superintendent being incompetent
C03.Bribery/corruption	I08.Financial problem/bankruptcy
C04.language/cultural barrier	I09.Difficulty in choosing business dealer
C05.Lobby (legal/illegal)	**J. Designer**
C06.Rigid bureaucracy	J01.Constructability
D. Industrial characteristics	J02.Vague drawing specifications
D01.Monopolied bidding	J03.Incomplete construction area
D02.Labor union	J04.Incompetent supervision skills
E. Contract	J05.Frequent design change
E01.Unequal contractual provisions	J06.Lack of fair stance
E02.Dispute among entities	**K. Contractor**
E03.Unjust arbitrator	K01.Stringent contractual terms
E04.Inadequate insurance coverage	K02.Deficit contracting
E05.Defect warranty	K03.Short of manpower or experience
E06. Misjudged cost estimation	K04.Higher cost than bid taking
F. Construction	K05.Short of capital/equipment
F01.New technology implementation	K06.Local jobsite particularity
F02.Too high quality standard	K07.Shortage in machine tools and workers
F03.Faulty job field survey	mobilization due to clashes of several projects
F04.Inadequate construction planning	K08.Low safety awareness
F05.Inadequate procurement planning	K09.Errenous allocation of human resource
G. Job site	K10.Lack of trustworthy support by subcontractor
G01.Incompetent planning	K11.Low working morale
G02.Incompetent management	K12.High personnel mobility

4. Methodologies and Theories

During the gathering of risk factors through literature review to generate questionnaire items, the consideration are given not only to quantitative risk factors but also non-quantitative risk factors, which are usually difficult to be presented in precise and quantitative form, thus rendering overall evaluation process and result uncertain and fuzzy. Beside, there are various methods of risk evaluation of building projects. In general, they can categorized as classical model (i.e., probabilistic) and conceptual model (i.e. fuzzy sets). Some of the probabilistic factors affecting a building project are date based. That is, sufficient numerical information is available for a statistical characterization of these factors. However, much of the information related to risk analysis is not numerical to develop a statistical pattern.

For this reason, even experts in most cases cannot provide accurate answer to the probability of particular risk factors; they can merely verbally describe as “high”, “low”, or “very low”, while naturally using linguistic variables to basically describing the probability of particular risk factors. Zadeh [37] proposes to deal with risk-related issues through fuzzy sets by using linguistic variables, while converting the description of risks in mathematic statement to effectively solve the problems with the decision-making theories purported in the past, and deal with risk-related issues.

In order to see the variance of the ranking of risk factors and amount of risk with temporal sequencing change over different project stages between DBB and DB project, it is important to rank the risk fuzzy numbers. However, the two-dimensional analysis depicted the value of "Risk" is determined as "Probability times Impact", is likely to ignore a risk factor with "high probability and low impact" or with "low probability and high impact" [35]. In other words, the risk should not be measured only from the value of risk without the fact that risk factor evaluation is still subject to the influence by the attitude of decision makers towards risk management (pessimistic, neutral, or optimistic), meanwhile, consider accuracy of information provided in decision-making environment as well as. Therefore, this study not only use two-dimensional analysis to render quantitative the ranking and amount of risk with temporal sequencing change, but also the attitudes of decision-makers toward risks to serve as the variables for the simulation of decision-making environments, while applying the ranking method of Liou and Wang [17]. Therefore, the accuracy of information provided in decision-making environment also integrated in order for clients to see the possible change of ranking of risk factors and amount of risk with temporal sequencing change over different project stages.

4.1. Theory of fuzzy sets

4.1.1. Selecting appropriate membership function

Membership function $f_A(R)$, the basis of fuzzy sets, is derived from characteristic function. Representing factor-to-set membership grade, member function ranges between 0 and 1. By the theory of fuzzy sets, if the membership grade of a factor to a set is higher, its membership grade is closer to 1; otherwise, and it is closer to 0. Therefore, the concepts of characteristic function in ordinary sets can be extended and become a concept of membership function in fuzzy sets.

Membership functions normally come in shapes of trapeziums, triangles, lines, and bells or in irregular shapes. Triangular membership function is adapted in this study for data evaluation for its easy application in evaluation of decision-making, as shown in Figure 2.

Let $x, a, b, c \in R$ (real number), the membership function of triangular fuzzy number A $f_A : (R) \to [0, 1]$ can be represented as:

$$f_A(R) = \begin{cases} (x-a)/(b-a), & a \le x \le b, \\ (c-x)/(c-b), & b \le x \le c, \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

When represented in (a, b, c), and if $a \le b \le c$, triangular fuzzy number A has the highest membership grade with a given parameter b, that is, $f_A(b) = 1$, representing the possible maximum of the data evaluated. Parameters a and c representing the upper limit and lower limit, respectively, are used to respond to the fuzziness of the data evaluated.

4.1.2. Selecting appropriate rating scales and linguistic variables

Linguistic variables refer to the using of natural wording of language as variable values to deal with scenarios that are complex or difficult in defining, or those that are difficult to be reasonably represented in conventional quantitative rendition, therefore making it necessary for these scenarios to be dealt with from the perspective of linguistic variables. In this study, linguistic variables are mainly used in conjunction with the following two

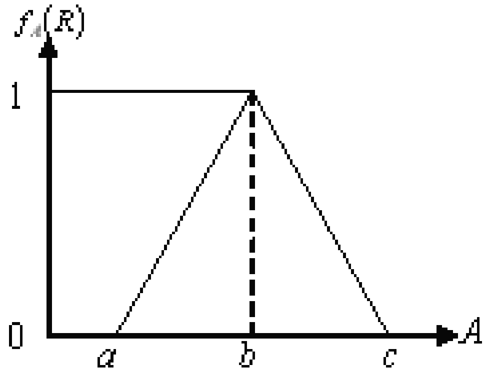

Figure 2: Triangular membership function

questions in order for decision-makers to evaluate "probability" and "impact" of risk factors by means of linguistic variables based on their own experience and expertise. The evaluation by "probability" of risk factors, for instance, will have the linguistic variables divided into five scales and represented in such rating as "very low", "low", "mean", "high", "very high", so as to allow decision-makers to choose their appropriate linguistic expression to describe the likelihood of risk occurrence, while allowing the above-mentioned linguistic rating and the linguistic variables to be expressed by the scales of fuzzy numbers as suggested by Chen and Hwang [9] to achieve the purpose of quantitative rendition, as shown in Figure 3.

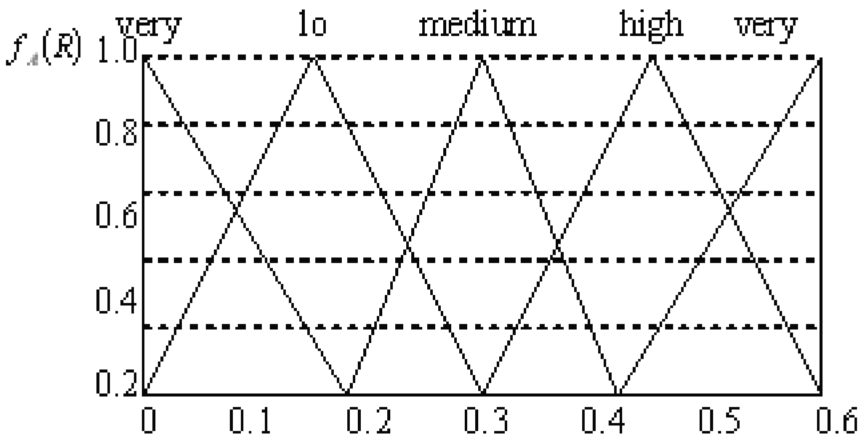

Figure 3: Linguistic scales [9]

4.1.3. Calculate the risk mean fuzzy number

By the characteristic of triangular fuzzy numbers, according to Liang and Wang [16], and the extending principle, according to Zadeh [37], supposed triangular fuzzy number $A = (a_1, a_2, a_3)$, and $B = (b_1, b_2, b_3)$, the algorithm can be as follows:

$$A \oplus B = (a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{2}$$

$$A \ominus B = (a_1, a_2, a_3) \ominus (b_1, b_2, b_3) = (a_1 - b_1, a_2 - b_2, a_3 - b_3) \tag{3}$$

$$A \otimes B = (a_1, a_2, a_3) \otimes (b_1, b_2, b_3) = (a_1 b_1, a_2 b_2, a_3 b_3) \tag{4}$$

$$A \oslash B = (a_1, a_2, a_3) \oslash (b_1, b_2, b_3) = (a_1/b_1, a_2/b_2, a_3/b_3) \tag{5}$$

where $\oplus, \ominus, \otimes, \oslash$ representing the algorithmic factors for the addition, subtraction, multiplication and division of the fuzzy numbers, respectively.

This study adapts the algorithm of mean to integrate the expert or group-contributed fuzzy values towards the evaluation of risk factors, and by the extending principles of Equation (2) through Equation (5) with Equation (6) to calculate the mean fuzzy number of the risk factor probability over each project stage, and Equation (7) to calculate the mean fuzzy number of the risk factor impact over each project stage. Besides, the risk mean fuzzy number (R_{ij}) of risk factor i at project stage j can be obtained by the multiplication of P_{ij} with I_{ij}, as shown in Equation (8):

$$P_{ij} = (\tfrac{1}{N}) \otimes (P_{ij1} \oplus P_{ij2} \otimes \cdots \otimes P_{ijN}); \quad i = 1, 2, \ldots, 106; \quad j = 1, 2, 3, 4 \tag{6}$$

$$I_{ij} = (\tfrac{1}{N}) \otimes (I_{ij1} \oplus I_{ij2} \otimes \cdots \otimes I_{ijN}); \quad i = 1, 2, \ldots, 106; \quad j = 1, 2, 3, 4 \tag{7}$$

$$R_{ij} = (P_{ij} \otimes I_{ij}); \quad i = 1, 2, \ldots, 106; \quad j = 1, 2, 3, 4 \tag{8}$$

P_{ij}: probability of the mean fuzzy number evaluated of the risk factor i in the project stage j
I_{ij}: impact of the mean fuzzy number evaluated of the risk factor i in the project stage j
P_{ijN}: probability of the fuzzy number evaluated of the risk factor i in the project stage j that is evaluated by the n serial number of expert
I_{ijN}: impact of the fuzzy number evaluated of the risk factor i in the project stage j that is evaluated by the n serial number of expert
R_{ij}: risk mean fuzzy number evaluated of the risk factor i in the project stage j
i: risk factor i of a project
j: four project stages, respectively; $j = 1$ proposal surveying, $j = 2$ scheme designing, $j = 3$ procurement contracting, $j = 4$ construction receiving
N: numbers of respondents who answer the risk factor i in the project stage j n: n serial number of respondents who answer the risk factor i in the project stage j

4.1.4. α-cuts

For a fuzzy number A, given a real number α, where $\alpha \in [0, 1]$, the accurate set that is formed by the α-cuts from fuzzy set A will be $A_\alpha = \{x \mid f_\alpha(x) \geq \alpha\}$, where α is referred to as "confidence level", also known as "threshold value"; the larger the α value, meaning high confidence level or threshold value, the smaller the area it corresponds with; accordingly, the smaller the α value, meaning low confidence level or threshold value, the larger the area it corresponds with, as shown in Figure 4 [37]. Hence, α-cut sets can be defined as the Equation (9).

$$A_\alpha = [(b - a)\alpha + a, b, c - (c - b)\alpha] \qquad 0 \leq \alpha \leq 1 \tag{9}$$

4.2. Ranking fuzzy numbers

Liou and Wang [17] proposed a method of ranking fuzzy numbers with total integral value. The left integral value is used to reflect the pessimistic viewpoint and the right integral value is used to reflect the optimistic viewpoint of the decision maker. A convex combination of right and left integral values through an index of optimism is called the total integral value. It is used to rank fuzzy numbers [17]. The triangular fuzzy number can be denoted by $(a, b, c; 1)$, and the membership function f_A of the fuzzy number A can be expressed as Equation (10).

$$f_A(R) = \begin{cases} f_A^L, & a \leq x \leq b, \\ f_A^R, & b \leq x \leq c, \\ 0, & \text{otherwise} \end{cases} \tag{10}$$

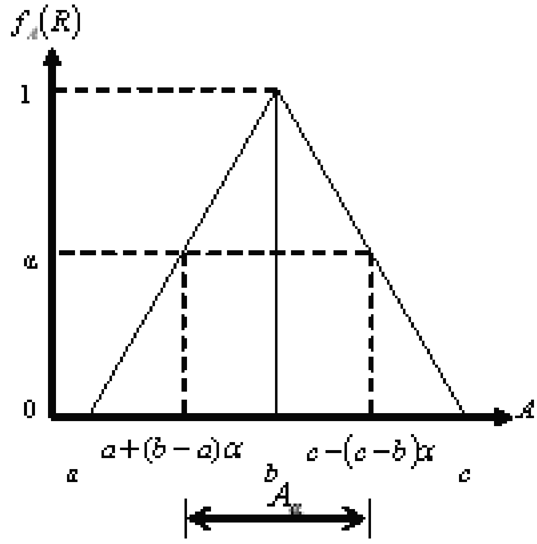

Figure 4: α-cut

A is a Fuzzy number with left membership function f_A^L and right member function f_A^R. Suppose that g_A^L is the inverse function of f_A^L and g_A^R is the inverse function of f_A^R, then the left integral value of A is defined as Equation (11) and the right integral value of A is defined as Equation (12). Thus, the total integral value with index of optimism β is defined as Equation (13), then triangular fuzzy number can be simplified as Equation (14).

$$I_L(A) = \int_0^1 g_A^L(y)dy \tag{11}$$

$$I_R(A) = \int_0^1 g_A^R(y)dy \tag{12}$$

$$I_T^\beta = \beta I_R(A) + (1-\beta)I_L(A) \tag{13}$$

$$I_T^\beta = \frac{1}{2}[\beta c + b + (1-\beta)a] \tag{14}$$

where $I_R(A)$ and $I_L(A)$ are the right and left integral values of A, respectively, and $\beta \in [0,1]$.

The index of optimism β is representing the degree of optimism of decision maker. As shown in Equation (14), using β optimism index $[0,1]$ in order to reflect the attitude of professionals or experts towards risks, so as to have the professional comments integrated. If $\beta = 0$, then it means professionals or experts are pessimistic when dealing with risks, while, if $\beta = 1$, it means professionals or experts are higher degree of optimism when dealing with risks. Besides, $g_A^L(y)$ and $g_A^R(y)$ as the inverse functions of $f_A^L(y)$ and $f_A^R(y)$, respectively, are directly related to the α-cut, which are defined by Equation (9). The higher α value, is the smaller sets of triangular membership, which means information is more accuracy. When used triangular fuzzy numbers, Liou and Wang have shown that $g_A^L(y) = a + (b-a)y$ and $g_A^R(y) = c+(b-c)y$, which immediately leads to $g_A^L(\alpha) = a+(b-a)\alpha$ and $g_A^R(\alpha) = c+(b-c)\alpha$. In other words, the effect of α (degrees of accuracy of information) on ranking is already included in $I_L(A)$ and $I_R(A)$ through integration.

In order to ranking of risk factors and the amount of risk with temporal sequencing, this study adopted ranking fuzzy numbers with total integral value based on Liou and Wang [17]. After the risk mean fuzzy numbers of each risk factor (R_{ij}) are calculated by

Equation (2) through Equation (8) as referred in Sec. 4.1.3, this study first divide decision-making environment by different extent of optimism into 11β values $[0, 1]$, generating 11 sets of simulated scenarios with different extents of optimism attitude of the decision-makers towards risk management; meanwhile, according to $g_A^L(y)$ and $g_A^R(y)$ with respect to α, the α on ranking is already included in $I_L(A)$ and $I_R(A)$, that would reflected the accuracy of information provided in decision-making environment.

4.3. Analysis on ranking and amount of risk with temporal sequencing change

The variance of ranking of risk factors and amount of risk with temporal sequencing change were used risk as criterion, which will benefit the selection of project delivery system and the selection of risk strategy of risk management. Because the significance ranking of risk factors and the degrees of risks are likely to vary with different risk factors or project stages given the parameters of β, Equation (15) by statistic analysis of fuzzy sets is used to locate the ranking for the risk factors. The F_i was simply calculated the average of ranking of the risk factor i with different scenarios or 11 sets.

$$F_i = \frac{W}{ST} \tag{15}$$

where F_i representing the frequency of ranking occurrence, W representing X serial number in ranking, and ST being the total number of simulations (11 sets).

Furthermore, the degrees of risk vary along with transitions in time and with different resources invested in the projects through the four project stages such as the stages of proposal surveying, scheme designing, procurement contracting, and construction receiving, namely, the sequencing change over time, making it necessary to compare the risks over different project stages. Therefore, the risk mean fuzzy numbers in a project stage (r_j) can be calculated with Equation (16). For instance, if an expert interviewer experienced that risk factors i are more likely to occur in project stage j than in other stage, it can be supposed that project risk in the said stage is higher than other stage.

Therefore, the risk mean fuzzy number of each project stage should sum up to the total of the risk mean fuzzy numbers of the 106 risk factor in different stages, and various degrees of risks over different project stages will be able to show along with the fluctuation of their sequencing over time.

$$r_j = \sum_{i=1}^{106} R_{ij} \tag{16}$$

r_j: risk mean fuzzy numbers as evaluated in the project stage j
i: risk factor i of a project
j: four project stages, respectively; $j = 1$ proposal surveying, $j = 2$ scheme designing, $j = 3$ procurement contracting, $j = 4$ construction receiving

5. Survey and Analysis

The questionnaire of the survey was sent to relevant managers in the companies of clients. The survey took place in April through June of 2006. 100 copies were sent to managers with DBB project delivery systems and another 100 copies were sent to managers with DB systems, making a total of 200 being surveyed. A total of 66 copies returned with valid responses, making an overall valid response rate of 33%, including 33 DBB responses and 30 DB responses. As indicated by the survey responses, the majority of the professionals surveyed are mostly aged 31∼35 or over 40, college graduated, having engineer as job title, having 11∼15 years of work experience; the applications of their projects are mainly residential buildings, the floor space area ranging 10,000∼50,000 square meters, the number of construction storey being mainly under five storey, and the total costs of construction are mainly in the range of US$3 million to US$15 million. This study adapts the analysis by internal consistency, using Cronbach's α to measure the consistency of the survey, and the overall reliability of the survey is found to be up to 0.78, indicating that the questions in the questionnaire are highly consistent. The study further includes the interviewing with the professionals and reviewing of the questionnaire so as to verify the validity of survey contents for the purpose of meeting requirement on the accuracy of the survey.

As shown in Table 3, respondents have to answer the probability and impact of risk factor i in project stage j. For example, the 'C0501.Threat or interference by illegal parties' will happen in procurement contracting and construction receiving, respectively has medium and very high occurrence probability, and has high and very high impact. That will helpful to analysis significance ranking of these risk factors and amount of risk with temporal sequencing change over different project stages.

Table 3: Questionnaire form

	(1) risk factor occurrence with temporal sequencing change over different project stages				(2) probability				(3) impact			
	A. proposal surveying B. scheme designing C. procurement contracting D. construction receiving (multiple selections accepted)				1. very low 2. low 3. medium 4. high 5. very high				1. very low 2. low 3. medium 4. high 5. very high			
	A	B	C	D	A	B	C	D	A	B	C	D
C0501.Threat or interference by illegal parties			✓	✓			3	5			4	5
⋮												
K0301. Insufficiency of company's competent skillful staffs		✓	✓	✓		3	4	4		5	5	4

5.1. Ranking of project risk factors

According to ranking fuzzy numbers with total integral value based on Liou and Wang [17], 11β values to represent the attitude of decision maker towards risk by Equation (14), meanwhile, α on ranking is already included in $I_L(A)$ and $I_R(A)$, that would reflected the accuracy of information provided in decision-making environment. For instance, with the risk factor 'I0801. Client's financial capability is a problem', which is classified under risk category of 'I. Client', its ranking index ($I_T^\beta(A)$) in the project stage of procurement contracting by DBB building project delivery system can be calculated using Equation (14) as between 0.230 and 0.515, the 20th and 29th ranking. Consequently, some risk factor i might have the highest frequency of the rank of the risk factor i in project stage j than others with different β values, the calculation of F_i would be applied to represents the average of the rank of the risk factor i. The risk factor i may have different rank in project stage j with different β values, nevertheless, the highest frequency of risk factor i always means the most important. For instance, 'I0801. Client's financial capability is a problem' got 20th-29th in the project stage of procurement contracting by DBB building project delivery system, the highest frequency of rank of the risk factor respectively was 24th.

Table 4 and Table 5 shows the ranking of risk factors over the four stages of proposal surveying ($j = 1$), scheme designing ($j = 2$), procurement contracting ($j = 3$), construction receiving ($j = 4$) of DBB and DB building projects. The risk factors in the 1$\sim$10 ranking at each of the four stages are highlighted in black, and those in the 11$\sim$20 ranking are highlighted in dark gray, with risk factors of higher extents of risk being highlighted in darker colors.

In DBB project delivery system, as shown in Table 4, the designers and construction receiving over to the contractors as practiced in DBB project delivery system also show the intention of the clients to transfer or share the risks by the procurement contracting in the DBB project delivery system. Nevertheless, with the risk ranking viewed by project stages, clients are concerned more about whether the designing drawing and documents are accurate, and whether the actual building costs are duly reflected in the quotation, etc. As shown in this risk significance ranking of DBB building projects, the interviewees mostly believe risk occurrence generally originates mainly from external factors, not related to the clients but the contracts, construction or design. For instance, the risk factors found with higher significance ranking would be the ones requiring particular attention in management, such as 'K0301. Insufficiency of company's competent skillful staffs' in proposal surveying stage, 'K0104. Contractors tend to choose projects requiring easier construction over those with better design' in scheme designing stage, 'G0102. Too slow list change order and too slow instruction make price' in procurement contracting stage, and 'J0204. Inconsistency between drawing descriptions and specification requirements' in construction receiving stage. Additionally, some risk factors are found to rank equally higher over the four project stages, such as 'K0301. Insufficiency of company's competent skillful staffs', 'J0101. Lack of accuracy on assessment of project feasibility'.

Even though the designer or contractor takes most of the risks passed on to them, the competence of the designer and contractor needs to be taken into consideration in project proposing and surveying, while in planning and designing stage, the considerations are given to the competence and resources of contractors available in the market, so as to design reasonable building contracts and drawing specifications, allowing building projects to progress smoothly, and hence reducing the uncertainty; that is to say, if the feasibility of the construction can be taken into consideration in the planning and designing stage or if the database on competent venders can be established, the impact of the project goal will become less for the contractor later. The risk factors occurring in the procurement contracting stage are mostly related to costs and project duration, while the risk factors occurring in construction receiving stage are mostly affected by factors relating to planning and designing, as the performance of planning and designing actually matters with many risk factors related to designing or contracting to be confronted in construction receiving stage, such as the drafting of contracts, the selection of designer or contractor; in other words, if risks can be managed well in proposal surveying stage or designing stage, the impacts of the risks on building projects would be reduced effectively.

In DB project delivery system, as shown in Table 5, since the designing and construction jobs are all commissioned to the DB contractor, the risks are mostly transferred or shared to DB contractor. The contracts for building projects of DB project delivery system tend to be more complicated, and, therefore, the risks involved in the earlier project stages of proposing surveying, scheme designing and procurement contracting are factors related to the polities/society, and the contractual issues. For instance, the risk factor ‘C0603. Extra expenditure due to administrative supervision’ was found significant important in proposal surveying stage, the others were not. Furthermore, the risk factors normally under the management of DB contractor in proposal surveying stage, generally involve ‘Economics/Finance’, ‘C. politics/society’, ‘E. contract’, and ‘F. construction’, but ‘J. Designer’, ‘K. Contractor’ in scheme designing, procurement contracting or construction receiving. The clients are seldom concerned about risk factors in such categories as ‘D. Industrial characteristics’, ‘H. Safety/Environment’ in project stages of DB project delivery system.

By comparing the ranking of risk factors as shown in Table 4 and Table 5, it was found that while 32 risk factors were found significant in both DBB and DB project delivery systems, they are also the ones ranking higher in terms of significance with higher extent of consensus. For example, the three risk factors ‘K0301. Insufficiency of company’s competent skillful staffs’, ‘K1101. Contractors lack professional ethic’, ‘B0501. Profit is too low due to over competition’ were found significant in proposal surveying, scheme designing and procurement contracting stage, respectively, in both DBB and DB building projects. However, those risk factors other than these 32 factors were found to be unique risk factors in either DBB or DB building projects; in other words, due to the choice of project delivery systems, the grouping of risk factors were found to take different forms. ‘E0102. Contract amount is not suitable to scope of work’, for instance, was found significant in construction receiving stage in DB building projects but not in DBB building projects. Understanding the characteristics of project delivery system, and the significance ranking of risk factors and the extent of risk in project stages will help clients establish the mechanism for risk management and different management strategy with the amount of time and resource given, by weighing the advantages available in their management based on the characteristics of their building projects, so as to reduce the impact of risks on building projects.

Table 4: Risk factor of DBB project delivery system

Risk Factor (*i*)		Proposal Surveying	Scheme Designing	Procurement Contracting	Construction Receiving
A0401	Schedule is not smooth due to rainy weather	68	44	98	16
B0101	Sudden rise in material, equipment, land price causes cost up	10	59	12	15
B0201	Fluctuation of price on purchases overseas	13	70	65	65
B0401	Sudden depression of market demand causes profit down	19	84	81	79
B0501	Profit is too low due to over competition	4	63	34	17
C0502	Decision of contractor selection is wrong by policy	8	50	49	101
C0601	Strictness of regulation, administration and inspections	9	27	62	90
C0603	Extra expenditure due to administrative supervision	14	26	79	78
C0604	Different explanation of regulations due to different government official	11	16	78	69
E0101	Contract schedule is not enough	73	7	13	11
E0103	Unjust contractual provisions	71	24	16	8
E0104	Drawing and document is not clear	16	6	21	4
E0105	Cost caused by change order is neglected	73	11	9	24
E0106	Insufficient of design drawing and document	38	14	46	38
E0107	Contract is not disclosure, such as private agreement	17	40	66	91
E0301	Responsibly of client is neutral	73	8	19	87
E0601	Quotation to contract is not suitable	12	10	5	46
E0602	Estimation is not compatible with contract document	47	5	7	49
F0201	Quality demand is too high	56	41	18	53
F0401	Safety precaution is not enough at jobsite	39	93	84	6
F0402	Submission of prospectus is no on schedule	73	89	72	10
F0403	Misjudgment on critical paths or sequence	68	2	64	31
F0504	Labor/materials/equipment is difficult to acquire	7	87	39	35
F0505	Requirement for special equipment , cause monopolizing or source limitation of the market	18	9	31	41
G0102	Too slow list change order and too slow instruction make price	33	95	1	28
G0202	Controllable of work is not enough	20	55	83	47
G0301	Too slow list and approve change order	73	38	56	14
G0302	Communication of participant is not effective	21	54	67	18
H0202	Additional compensation is asked by neighbors	50	98	58	19
I0101	Accuracy on Assessment of project feasibility	5	36	95	88
I0701	Insufficient ability of client's supervisor	73	98	17	73
I0901	Selection of contractor is hard due to difference of design drawing and plan	30	64	71	20
J0101	Concept design is first priority, before structure, repair, etc.	3	17	14	5
J0102	Unreasonable of Value Evaluation/review	26	52	20	95
J0103	Designer meet client's demands or reflection project characteristic	15	32	47	93
J0201	Troubling cause by interface of design material	23	15	11	13
J0202	Realization of detail design drawing	73	18	8	2
J0203	Unreasonable of design drawing do not have query comment	73	53	41	9
J0204	Inconsistency between drawing descriptions and specification requirements	73	34	27	1
J0301	Incomplete scope of work	62	74	10	32
K0101	Ignore the project situation, pursue company's interests to maximize	6	13	6	39
K0104	Contractors tend to choose projects requiring easier construction over those with better design	56	1	99	51
K0201	Being unable to offer subcontractor due to uniform price for the building	73	33	4	34
K0301	Insufficiency of company's competent skillful staffs	1	3	15	7
K0401	Bid cost effect wish of tender	73	88	29	12
K0501	Insufficiency of capitals, machine tools and equipment	42	4	38	45
K0603	Capability of subcontractor is not enough	65	19	36	60
K0701	Insufficiency of human resource supported project due to plural project	71	19	28	36
K0801	Workers don't use safety belt and security equipment	73	98	99	3
K0901	Allocation of human resource is wrong	2	12	3	50
K1101	Ethic of subcontractor is not enough	73	80	2	42

ranking of risk factor: 1~10 11~20 21~

Table 5: Risk factors of DB project delivery system

Risk Factor (i)		Proposal Surveying	Scheme Designing	Procurement Contracting	Construction Receiving
A0401	Schedule is not smooth due to rainy weather	42	97	96	3
B0101	Sudden rise in material, equipment, land price causes cost up	13	42	6	1
B0201	Fluctuation of price on purchases overseas	34	67	8	6
B0301	Difficulty of financing	13	68	39	45
B0501	Profit is too low due to over competition	4	80	14	43
C0101	Modification of policy about project	12	50	23	52
C0301	Bribe / corrupt	7	42	13	36
C0501	Threat or interference by illegal parties	26	76	11	14
C0601	Strictness of regulation, administration and inspections	10	27	80	57
C0602	Schedule delayed due to administrative supervision	8	62	34	64
C0603	Extra expenditure due to administrative supervision	1	40	79	46
C0604	Different explanation of regulations due to different government official	10	29	36	37
E0101	Contract schedule is not enough	55	17	37	26
E0102	Contract amount is not suitable to scope of work	55	35	46	10
E0103	Unjust contractual provisions	1	31	33	12
E0104	Drawing and document is not clear	1	30	25	8
E0105	Cost caused by change order is neglected	13	21	82	21
E0106	Insufficient of design drawing and document	13	16	22	29
E0503	The maintenance cost keeps difficult	55	12	44	72
E0601	Quotation to contract is not suitable	13	36	17	40
E0602	Estimation is not compatible with contract document	13	15	49	34
F0101	Construction method is not familiar with	25	18	51	95
F0201	Quality demand is too high	5	30	53	30
F0501	Quotation of purchase is wrong	55	55	20	42
F0503	Improper timing of purchasing	26	64	11	7
F0504	Labor/materials/equipment is difficult to acquire	13	63	4	20
F0505	Requirement for special equipment , cause monopolizing or source limitation of the market	6	78	24	84
G0101	Scope of construction is not understanding	22	24	15	19
G0102	Too slow list change order and too slow instruction make price	55	1	58	77
G0103	Insufficient ability of drawing recheck	39	13	58	33
G0301	Too slow list and approve change order	55	11	92	47
G0303	Insufficient information, such as subcontractor’s	52	20	57	56
I0201	Additional demands with client or designer	13	80	101	94
I0601	Confidence between client and designer is week	37	17	71	71
I0901	Selection of contractor is hard due to difference of design drawing and plan	11	49	56	23
J0101	Concept design is first priority, before structure, repair, etc.	55	51	18	105
J0102	Unreasonable of Value Evaluation/review	55	70	19	76
J0103	Designer meet client’s demands or reflection project characteristic	32	62	21	2
J0202	Realization of detail design drawing	39	28	6	39
J0204	Inconsistency between drawing descriptions and specification requirements	55	28	78	13
J0501	Too many change order and too slow instruction make price be not approved	55	9	75	22
J0502	Designer is persistent individual opinion, cause submission of drawing is not on schedule	55	19	35	70
J0601	Serve as designer and supervisor simultaneously is not neutral	55	56	10	86
K0101	Ignore the project situation, pursue company's interests to maximize	55	14	14	31
K0102	Contractor using inferior materials to scoop out profit from the fixed price, after bidding is finalized	55	6	1	4
K0103	Contractor using substitutes material to scoop out profit from the fixed price, after bidding is finalized	55	6	9	11
K0104	Contractors tend to choose projects requiring easier construction over those with better design	55	6	1	28
K0201	Being unable to offer subcontractor due to uniform price for the building	55	97	3	66
K0301	Insufficiency of company’s competent skillful staffs	47	10	27	13
K0603	Capability of subcontractor is not enough	55	1	30	9
K0604	Insufficiency of management of human resource by local subcontractors	55	1	46	5
K0901	Allocation of human resource is wrong	50	94	58	16
K1001	Credit of subcontractor is not enough	55	1	83	15
K1101	Ethic of subcontractor is not enough	55	5	5	39

ranking of risk factor: 1~10 11~20 21~

5.2. Amount of risk with temporal sequencing change

As shown in Figure 5 and Figure 6, since building project risks change over time along with the progression of building projects, the risks in each project stage can be analyzed from the perspective of project progress sequencing; therefore, with Equation (12), the assessment of risk mean fuzzy number (r_j) in the four project stages can be analyzed by the progression sequence. Despite that the risk mean fuzzy number (r_j) in each project stage is likely to be larger than 1, the indication of risk extent in each project stage will allow the clients to clearly see the variance of risks over the project stages along with the change of resource or time.

As shown in Figure 5, the triangular risk mean fuzzy number (r_j) for each project stage by DBB project delivery system was figured out as proposal surveying (1.13, 4.17, 11.07), scheme designing (1.52, 4.76, 9.92), procurement contracting (1.26, 3.61, 7.16), and construction receiving (0.72, 1.86, 3.29). DBB project delivery system, with given accuracy of information and the attitude towards risk management, the risk in project survey stage and scheme designing stage is the highest; compared with the two preceding stages, procurement contracting stage is relatively lower, while the risk involved in construction receiving stage is relatively the lowest, with considerable amount of consensus. With DBB project delivery system, in proposal surveying and scheme designing stages when the activities involve laying out drawing specifications, figuring out project costs and writing out contract related documents, etc. the risks are mainly the liability of the client or designer, and the risks are to carry over later to the contractor to realize the project to accomplish the building project goal while bearing the relevant risk prior to the handover to the client. Since the clients are liable for relatively higher amount of risk involved in proposal surveying stage or scheme designing stage, they should, therefore, prioritize the management of the project stages with higher risk to lower impact on the building project.

As shown in Figure 6, the triangular risk mean fuzzy number (r_j) for each project stage by DB project delivery system was figured out as project survey (1.92, 6.31, 12.74), scheme designing (2.55, 6.19, 10.37), procurement contracting (2.42, 6.90, 13.47), and construction receiving (1.44, 3.45, 6.20). DB project delivery system, with given accuracy of information and the attitude towards risk management, the risks involved in procurement contracting stage and surveying stage are relatively the highest, followed by proposal surveying stage and scheme designing stage, while the risk in construction receiving stage is relatively the lowest, with considerable amount of consensus.

The fact that the client only provides 5% to 30% of the overall designing documents but determines the building project goal, and render the DB contractor, as the designer and contractor, to be liable for every details regarding the activities of designing and constructing indicates the competence of the DB contractor will matter with the success or failure of building projects, and, therefore, clients are more concerned about procurement contracting stage and scheme designing stage. Since the DB contractor is fully in charge of the project activities in project constructing stage, the risk involved naturally is the liability of the DB contractor. For this reason, for clients with DB project delivery system, the risk involved in project constructing stage is lower than any other project stage.

6. Conclusions

There have been many studies aimed at the developing of methods for selecting building project delivery system, but taking the approach by risk management for the analysis on selecting project delivery system, this study first confronted with problems about the def-

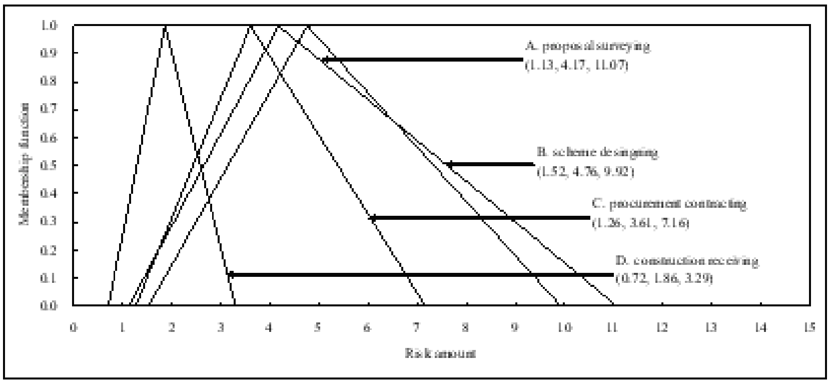

Figure 5: Risk at each building stage in DBB project delivery system

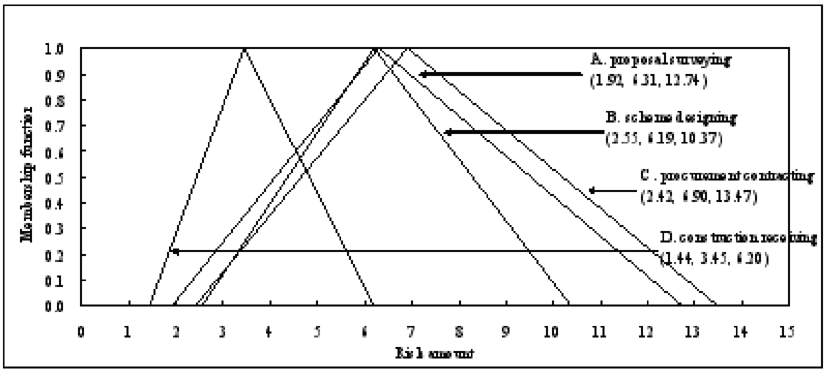

Figure 6: Risk in each building stage in DB project delivery system

inition and recognition of risk factors, and, in the meantime, the lacking of basic data regarding risks, such as the significance ranking of risk factors or amount of risk with temporal sequencing change. The negligence over documentation and the limitation of access to resources, as observed in the building industry, actually hinder the definition of all risk factors that are likely to occur; therefore, understanding the significance ranking and amount of risk with temporal sequencing change can assist clients in laying out risk management mechanism or risk strategies in an appropriate manner, allowing the building resources to be actually employed in managing the groups of risk factors and the project stages with high impact of risk.

This study achieved the collection of risk factors by compiling risk factors found in literatures on relevant studies in the past, while using the risk factors as the items for questionnaire (see Table 1) for applying the theory of fuzzy sets. After the interview with professionals about their choice of different types of project delivery systems, the fuzzy numbers on the probability of risk factors in each project stage along with their impact are figured out, while the algorithm by the mean is applied to calculate the mean fuzzy number of the probability of risk factor (P_{ij}) and the mean fuzzy number of the impact of risk factor (I_{ij}), as shown in Equation (6) and Equation (7). Since the risk mean fuzzy number of risk factors (R_{ij}) is the parameter that determines the significance ranking of risk factors, it is therefore calculated by the multiplication of the mean fuzzy number of the occurrence possibility of risk factor (P_{ij}) and the mean fuzzy number of the impact of risk factor (I_{ij}), as shown in Equation (8).

In addition, with the consideration given to the influence in decision-making environment, such as the attitude of the decision makers towards risk management and the accuracy of information, the variance of risk factors are further demonstrated by the simulation of $I_T^\beta(A)$, as shown in Equation (14), showing 11 sets of simulating results for each of the 106 risk factors. Afterwards, by Equation (15), the optimal significant ranking of risk factors in each project stage can be determined, as shown in Table 4 and Table 5, which can provide reference for clients about the high risk factors they may encounter, regardless they choose DBB or DB project delivery system, and, this, correspondingly, allows them to see the difference of risk factors in different project delivery systems. These risk factors are probably the ones that require particular management in the proceeding of building projects in the future. Moreover, regarding the analysis on the amount of risk with temporal sequencing change, the consideration is given to the risk mean fuzzy number of project stages (r_j), as shown in Equation (16), which compares the relationship between project stages and risks, allowing the understanding on the temporal sequencing change of risks, as shown in Figure 5 and Figure 6.

By means of above-mentioned research process and findings, this study has achieved in extensively defining the risk factors involved in building projects from the standing of the clients, and, in the meantime, touched upon the discussion over the variance of risk by significance ranking and temporal sequencing change over different project stages (proposal surveying, scheme designing, procurement contracting and construction receiving), given applications of different project delivery systems, (DBB or DB), as the premise.

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