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Risk/Reward Compensation Model for Integrated Project Delivery

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In an Integrated Project Delivery (IPD) project, the main participants share risk and reward, a characteristic used to incentivize collaboration as the compensation method. This study aims to propose a specific risk/reward compensation model to highlight the characteristic of IPD. An analysis of the differences between IPD and project alliancing reveals that the compensation strategy can be determined using a cooperative and non-controversial contract in the early stages of a project because of the application of Building Information Modeling and the early stage collocation of the main participants. Therefore, this study proposes the compensation method based on cooperative game theory to determine the risk/reward sharing in the early stages of a project to incentivize the participants and align the goals of all participants. The innovation of our work is to combine risk perception and Nash Bargaining Solution (NBS) in the risk/reward compensation model. It is not easy to measuring the risk borne by participants in the early project stages; thus, this study explores the problem from the perspective of risk perception. The perceived level of risk influences the utility of the participants. The research problem is formulated as an n-person bargaining problem; thus, NBS provides the optimal and fair compensation strategy. Moreover, to overcome the limitation of information loss and reflect the bounded rationality of the participants, 2-tuple linguistic representation and prospect theory are used as complementary methodologies to develop the utility function. This study provides an explicit, comprehensive, and systematic framework for risk/reward allocation practice in an IPD project, which has both theoretical and practical significance.

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Keywords: *Integrated Project Delivery, Risk Perception, Nash Bargaining Solution, Prospect Theory, 2-Tuple Linguistic Representation.*

Introduction

A study by the U.S. Department of Commerce and Bureau of Labor Statistics shows that construction is the only industry in which productivity has decreased since 1964, whereas all other non-farm industries have increased by almost 200 % (AIA, 2010). To change this situation, the construction industry has actively explored various methods to improve project performance. One example is the Project Management Office (PMO), a method especially designed for companies operating in a multi-project environment. (Spalek, 2013) identified the determinants of the success of PMO during a short-term period (up to one year) and a long-term period (above one year), and found that the challenges the PMO faces are different in the two periods. These approaches mostly focus on traditional project delivery. In traditional contracting systems, the financial success of an individual participant is not necessarily tied to the success of the project; therefore, the egocentric and inefficient behavior of a participant is sometimes detrimental to the project and to other participants (Xue *et al.,* 2010). Clearly, traditional contracting systems are inappropriate for improving overall performance, especially with construction projects becoming more complex and dynamic. In response to this need, Integrated Project Delivery (IPD) is attracting great interest from the construction industry owing to its characteristic of integration. The American Institute of Architects (AIA) defines IPD as "a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all project participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction" (AIA, 2007a). In an IPD project, the main participants integrate in the early stages and share risk/reward. Thus, the individual objective is consistent with the project objective, and the individual success relies on the project success. IPD seeks to improve project performance through a collaborative approach of aligning the goals of all participants. Currently, the use of Pure IPD is small but growing, and key IPD tools, such as Building Information Modeling (BIM) and the application of Lean technologies, are being used in many projects (Sive, 2009). (Kent & Becerik-Gerber, 2010) researched the current status of IPD use and its future widespread adoption in the construction industry and found that the most common benefits include fewer change orders, cost savings, and shorter schedule. El (Asmar *et al.,* 2013) evaluated the performance of IPD projects compared with traditional project deliveries and indicated that IPD achieves statistically significant improvements in quality, schedule, project changes, communication among stakeholders, and environmental and financial performance, especially in providing high-quality facilities faster at no significant cost premium.

Research problem. Shared risk and reward is one of the most important characteristics of IPD and is used to motivate collaboration as a compensation method. Allocation of risk/reward to project performance aligns the participants to the project goals and elicits their interest in optimizing the whole project, not just a single system or element. The participants share the risk/reward of the project outcomes to obtain compensation through a cooperative and non-controversial contracting relationship while creating incentives for the participants to achieve project success (Ashcraft, 2009). The risk/reward compensation scheme that needs to satisfy all those involved should consider the respective contributions of the participants to the project, and not simply base compensation on a percentage of costs (AIA, 2007b). Thus, numerous integrated contractual agreements are emerging to allocate risks and rewards for compensation. AIA (2007b) introduced three general forms of multi-party agreements, namely, project alliances, single purpose entities, and relational contracts, and discussed their respective compensation structures. (Thomsen *et al.,* 2009) determined three common approaches to sharing risks for IPD projects: sharing risk of cost overruns and benefit of cost savings, placing profit pooling in risk for cost overruns, and sharing any amount remaining of contingency after project completion. These approaches are consistent with the three general multi-party agreements. Although sharing risk/reward for compensation in IPD projects has received extensive attention in existing literature, the present study only demonstrates the compensation structure instead of exploring how to share risk and reward to compensate each participant in an equitable manner. (Love *et al.,* 2011) introduced a typical alliance compensation model that is also applicable to the IPD project. The compensation model consists of three components, which are often referred to as “limbs.” The first limb, guarantee, is the direct project costs, including direct cost and field overheads. The owner bears primary responsibility for cost overrun because the non-owner participants never place their direct project costs at risk. The second limb, pain share, is the corporate overhead and normal profit. The third limb, gain share, is a bonus if the project exceeds its goals. From the above discussion, we know that compensation is directly tied to project success, and thus participants must cooperate to maximize individual and project returns. According to the above strategy, the present study will further explore the allocation of risk/reward, which is important for the aggressive collaboration of an IPD team.

Research purpose. IPD, to some extent, has common characteristics with project alliancing. Project alliancing is a project delivery method where owner and non-owner participants work together as an integrated and collaborative team in good faith while jointly managing all project risks and sharing the project outcome. Although IPD is similar to project alliancing in many respects, several key points of difference exist between them. The most notable of these key points are the application of BIM and the early stage collocation of main participants (Lahdenpera, 2012). The mandated use of BIM positions IPD as a more advanced procurement model than alliancing (Raisbeck *et al.,* 2010). In IPD, BIM enables 3D model integration in the design and construction process and shares data between team members. Furthermore, key participants are involved early in the project, typically before the design even starts, and one multi-party agreement governs their relationships (El Asmar *et al.,* 2013). On the basis of this condition, the participants should determine the risk/reward compensation strategy in the early stages of the project to realize their individual compensation before the project starts and schedule tasks within reason. One method for calculating shared percentages of risk/reward is based on the relative proportions of the direct project costs; however, the compensation should consider the respective contribution of each IPD participant, and not simply be based on percentages of costs (AIA, 2007b). (Ashcraft, 2009) pointed out that compensation is the key negotiation issue that influences aggressive collaboration. The application of game theory in decision making is not new. (Turskis *et al.*, 2009) used game theory to assess the multi-criteria of external walls and presented a multi-criteria decision support system intended for problem solution in construction design and management. (Peldschus *et al.,* 2010) creatively applied a two-person zero-sum game for the selection of sustainable construction sites. However, cooperative game theory is considered as a more powerful tool for allocation than non-cooperative game when fairness is concerned in conjunction with efficiency. Participants jointly discuss how to fairly allocate the risk/reward to satisfy each party; therefore, cooperative game theory is suitable to solve this problem. This study aims to explore sharing risk/reward based cooperative game theory in the early project stages.

Novelty of the article. In the early project stages, sharing the risk/reward equally between participants is not easy. In addition, alliance decision-makers are actually bounded rational rather than completely rational. Risk perception provides a particular perspective for studying this problem. Risk perception that influences the behavior of parties is considered a key ingredient in strategic decision making (Das & Teng, 2001a). (Hsieh *et al.,* 2010) proposed a risk analysis framework for the relationship between risk perception and post-formation control and tested this framework using a sample of international joint ventures located in Taiwan. They found that the higher the level of risk that partners perceive, the greater the extent these partners apply post-formation control mechanisms. (Veland & Aven, 2013) discussed how the risk perspective influences risk communication and to what extent differences in risk perspectives can cause barriers as well as problems in communication. They concluded that the main barriers are the risk analysts who do not perform their job in a professional manner, rather than the poor understanding of risks and risk assessment tools. Das and (Teng, 2001a) suggested that the structural preferences of partners on strategic alliance are based on their risk perception, and then presented an alliance structuring model to minimize the total risk. (Badenfelt, 2008) pointed out that several factors influence the selection of sharing ratio between owner and contractor in target cost contracts, with the perceived level of risk being one of the key factors. Thus, the present study proposes the risk/reward compensation model from the perspective of risk perception. The research problem is formulated as an *n*-person bargaining problem. This study proposes the compensation model based on the Nash Bargaining Solution (NBS) from cooperative game theory, which not only provides the Pareto optimal allocation strategy, but is also consistent with the fairness axioms of game theory. NBS is widely applied in networks to share resources fairly. (Ni & Zarakovitis, 2012) proposed a new NBS scheduling framework for joint channel and power allocation in cognitive radio systems to guarantee proportional fairness and efficient power distribution among users. (Zhang *et al.,* 2008) presented a symmetric system model comprising two users and an access point, and then formulated a cooperation bandwidth allocation strategy based on the NBS to solve problems. (Moreover *et al.,* 2008) reviewed two-person bargaining models to allocate the profit of the supply chain, and then discussed the relationship between risk preference and negotiation power. (Lippman *et al.,* 2013) used Nash bargaining to design project procurement contracts to determine the best cost sharing between a risk-neutral project manager and a risk-averse contractor when the cost for completing the project is uncertain. NBS is widely applied to these research fields and successfully resolves some problems. For these reasons, this study uses NBS to settle the problem. The innovation of our work is to combine risk perception and NBS in the compensation model to acquire satisfactory results from risk/reward sharing in the early project stages.

Research object. This study is focused on the IPD project rather than on traditional project alliancing. Although the solution of project alliancing applies to some extent to IPD, an in-depth analysis of solutions specifically for IPD is essential. We propose the risk/reward compensation model in view of the differences between IPD and alliancing to highlight the characteristic of IPD. IPD can determine the risk/reward compensation strategy in the early stages of a project because of its use of BIM and the early involvement of key participants, whereas project alliancing cannot.

Research tasks. The overall research framework in this study includes four sections. First, the influencing factors for risk perception are identified through a comprehensive literature review. Second, the study adopts the 2-tuple linguistic representation model to deal with the linguistic information, and then determines the risk perception of participants based on the perceived risk criteria. Third, prospect theory is used to explore the utility of the participants, which is influenced by the perceived level of risk. Finally, an NBS based on cooperative game theory is proposed to maximize overall utility, enabling the participants to reach an agreement in terms of sharing risks and rewards. In this study, cooperative game theory, prospect theory, and 2-tuple linguistic representation are used as complementary methodologies to develop the risk/reward compensation model for IPD. Figure 1 shows the overall research framework.

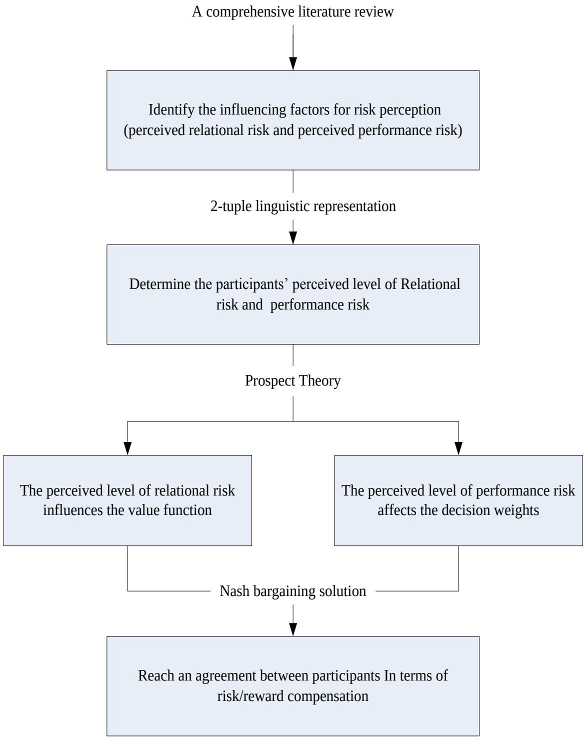

Figure 1. Flow of the overall research framework

Formulation of the Compensation Model

In this section, we present a brief introduction of the structure of the IPD compensation model, which is the necessary arrangement for the following research. A three-limbed project alliance compensation model that is also suitable for IPD is used, as shown in Figure 2 (AIA, 2007b; Raisbeck *et al.*, 2010; Love *et al.*, 2011). The first limb, guarantee, includes direct project costs and project-specific overheads. All these costs are reimbursed in limb1 because the non-owner participants never place direct costs and field overheads at risk. The second limb, pain share, is the corporate overhead and normal profit. The third limb, gain share, is a bonus if the project exceeds its goals. In general, gain/pain sharing is directly tied to outstanding/poor performance. Two key terms should be explained. Initial target outturn cost (TOC) refers to the jointly agreed anticipated project cost in the design phase of IPD. Actual outturn cost (AOC) is the total cost of the project when completed, and equals the sum of actual direct project costs and overheads (limb1). Whether participants can receive reward compensation depends on the comparison between TOC and AOC. If the AOC of a project exceeds its TOC, the owner continues to pay direct costs for the part above the target, and non-owner participants can obtain their actual costs (limb1). The amount of "at risk" profit (limb2) to be distributed is similarly decreased. This sharing of costs continues until the "at risk" profit (limb2) is exhausted. If a project is completed for less than the TOC, a portion of the savings as the gain share bonus and any "at risk" profit are paid to non-owner participants, while the owner receives the rest of the savings.

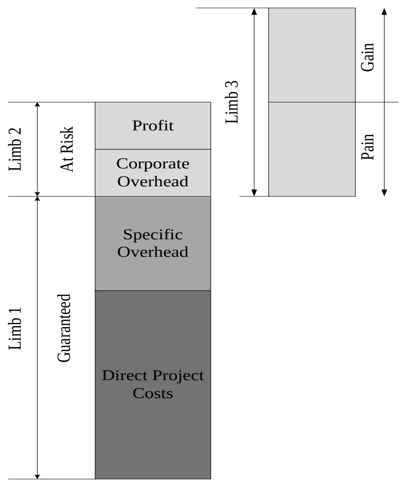

Figure 2. Structure of the IPD compensation model

Identification of Influencing Factors for Risk Perception

Risk perception refers to those ambiguities, as perceived by prospective alliance partners, about future events that may negatively affect the performance of the alliance (Das & Teng, 2001a). Different decision makers may have different estimates about the level of risk in a given situation because risk perception is the subjective assessment of a decision maker on outcome probabilities and possible negative consequences (Das & Teng, 2001b). (Das & Teng, 1996) classified alliance risk into relational risk and performance risk. Generally, relational risk is concerned with the probability and consequences when the partners in alliance do not fully commit themselves to the alliance in the desired manner, whereas performance risk refers to the probability and consequences when strategic objectives are not successfully achieved even with the full cooperation of partners. Performance risk is common to all strategic decisions, but relational risk is unique to strategic alliances (Das & Teng, 2001a). Therefore, in IPD projects, both perceived performance risk and perceived relational risk affect the perceived level of risk.

Many scholars studied the influencing factors of risk perception in alliance. (Das & Teng, 2001b) examined the inter-relationship between trust, control, and risk perception, and proposed an integrated framework in the context of strategic alliances. (Teimoury *et al.,* 2010) studied the effect of mediated power asymmetry on relational risk perception through a survey research of new product development and found that perception influences intention-based trust negatively and unilateral control positively. (Liu *et al.,* 2008) determined that the effects of relationship length and dyadic solidarity on relational risk can be indicated through goodwill trust and competence trust, with guanxi helping to weaken the perceived relational risk of buyers in marketing channels. (Delerue & Simon, 2009) analyzed risk perception in 344 alliance relationships and demonstrated that national cultural values influence the perceived levels of relational risk in an alliance. In addition, many alliance partners integrate their information systems for information sharing with others, which brings benefits of more efficient transactions, knowledge sharing, and so on. Information system integration is also positively associated with perceived relational risk (Nicolaou & Christ, 2011). After conducting the comprehensive literature review, the main influencing factors for risk perception are identified, as shown in Table 1.

Table 1

Influencing factors of risk perception for IPD

Influencing factors of risk perception	Perceived relational risk	Perceived performance risk
Goodwill trust	✓	
Behavior control	✓	
Asymmetry between partners	*	
History of cooperation	✓	
Social control	✓	✓
Building Information Modeling	*	✓
Competence trust		✓
Output control		✓

*Note: * and ✓ indicate positive and negative correlation respectively.*

Goodwill trust refers to one’s reputation, such as good faith, good intention, and integrity, whereas competence trust is concerned with the ability to accomplish given tasks instead of the intention to do so. Behavior control is also called process control because the appropriateness of the process must be ensured. In comparison, output control relies on accurate and reliable performance assessment, while social control establishes common culture and values to reduce the discrepancy between organizational members. Asymmetry means that the power and control of the partners are unequal, which can lead to opportunistic behaviors. History of cooperation is the number of previous alliances between the same partners. Integrated Information System is also a key factor and specifically refers to BIM in this article.

An expert team is organized to evaluate the risk perception of each participant. Selecting potential members to constitute the panel of experts is important because the validity of the study is directly related to this selection process. The members are experts who have been involved in IPD projects or have a detailed knowledge of IPD. These experts find it difficult to express the perceived level of risk with precise numerical values. In practice, using fuzzy linguistic information is common when solving decision-making problems. However, an important limitation for this approach is the information loss from the need to express the results in the initial expression domain (Herrera & Martinez, 2000a). (Herrera & Martinez, 2000a) developed a 2-tuple fuzzy linguistic representation model that is continuous in its domain and overcomes the limitation of information loss. To deal with multi-granular linguistic contexts, (Herrera & Martinez, 2001) presented a type of linguistic hierarchy term set and developed different functions based on the 2-tuple linguistic representation to transform linguistic terms between different linguistic term sets without information loss. (Martinez & Herrera, 2012) presented an overview of the 2-tuple linguistic model for computing with words in complex frameworks and proposed new linguistic computing models based on the said overview. The 2-tuple linguistic model has been applied to different problems and extended in different ways. Thus, we use the model to transform initial linguistic terms into quantitative values.

The 2-tuple fuzzy linguistic representation model represents linguistic information through a 2-tuple, (s_i,α). Let $S=\{s_0,\dots,s_6\}$ be a linguistic term set, which has seven terms and can be given as follows:$S=\{s_0=None, s_1=Very\ Low, s_2=Low, s_3=Medium, s_4=High, s_5=Very\ High, s_6=Perfect\}$. $\alpha\in[-0.5,0.5)$ is a numerical value called symbolic translation. The membership functions are triangular, as graphically shown in Figure 3.

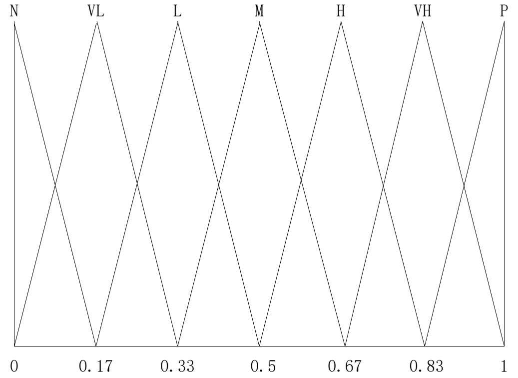

Figure 3. A set of seven terms with their semantics

This study aims to obtain the value $\nu\in[0,1]$ that supports the information represented by(s_i,α). To accomplish the above objective, Herrera and Martinez (2000b) presented a transformation process, as shown in Figure 4. The expert team evaluates perceived relational risk and perceived performance risk that can be expressed by 2-tuple linguistic (s_i,α). A function δ computes two 2-tuples based on the membership degree, from the initial linguistic 2-tuple. Then, the correspondent numerical value assessed in $[0,1]$ can be obtained using the function κ from the two 2-tuples based on the membership degree.

$$\delta(s_i,\alpha)=\{(s_i,1-|\alpha|),(s_{i+1},|\alpha|)\} \tag{1}$$

$$\begin{aligned}&\kappa\{(s_i,1-|\alpha|),(s_{i+1},|\alpha|)\}\\&=CV(s_i)(1-|\alpha|)+CV(s_{i+1})(|\alpha|)\end{aligned} \tag{2}$$

where $CV(\cdot)$ is a function providing a characteristic value. This study uses the maximum membership function as the characteristic value. $[0,1]$ values can accurately express the perceived relational and performance risk through the transformation process.

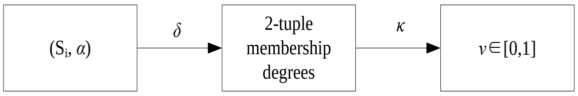

Figure 4. Transforming linguistic 2-tuple into [0,1] value

Utility Function

The research problem is described as an *n*-person game. When employing NBS to solve this kind of problem, we first have to determine the utility function that reflects the payoff of the participants. Expected utility theory as a normative model of rational choice is widely applied as a descriptive model to analyze the economic behavior of decision makers. AI-Harbi (1998) showed that the attitude toward risk has an important effect on decision-making behavior and used utility theory to set the best sharing fraction between owners and contractors in a cost-plus-incentive-fee contract. Broome and Perry (2002) believed that using utility theory to set the share fractions is insufficiently pragmatic compared with the more feasible result obtained through interview with practitioners. Expected utility theory illustrates that people should be entirely rational. Decision makers are not always completely rational, but have a bounded rationality in the actual decision-making process. Thus, describing practical problems with expected utility theory is sometimes not adequate. Prospect theory, an improved expected utility theory, is used as a behavioral model of decision making under risk. In prospect theory, the value function is (a) expressed using the gains and losses from a reference point, which proposes that the values are attached to changes rather than to final states; (b) concave above the reference point, which reflects the risk aversion in the face of gains; and the convex part below the reference point reflects the risk preference in the case of losses; and (c) steeper for losses than for gains, which means that the experiences of one in losing a sum of money appears to be greater than the pleasure associated with gaining the same amount; moreover, the decision weights measure the effect of prospects, and not the stated probabilities (Kahneman & Tversky, 1979). As the behavioral model under conditions of risk, prospect theory has been successfully used to explain a range of decision-making problems. Krohling and de Souza (2012) combined prospect theory and fuzzy numbers to handle risk and uncertainty in multi-criteria decision-making problems. Liu et al. (2011) proposed a multi-attribute decision-making method based on prospect theory to resolve the problems with interval probability, in which attribute values take the form of uncertain linguistic variables. Pasquariello (2014) studied equilibrium trading strategies and market quality in an economy that has speculators displaying preferences consistent with prospect theory, and demonstrated that speculators with these preferences yield important predictions for the properties of equilibrium market depth, price volatility, trading volume, market efficiency, and information production.

Tversky and Kahneman (1992) proposed the value function and the weighting function to explain the characteristic of risk attitudes. The value function used in prospect theory is described in the form of a two-part power function according to the following expression:

$$v(x)=\begin{cases}x^{\alpha}, x\ge 0\\ -\lambda(-x)^{\beta}, x<0\end{cases} \tag{3}$$

where α and β are parameters related to gains and losses respectively. The parameter $\lambda>1$ represents the characteristic that the experiences of one in losing a sum of money appears to be greater than the pleasure associated with gaining the same amount. The weighting function is the following one-parameter functional form for the probability transformation, where γ is the only parameter.

$$w(p)=\frac{p^{\gamma}}{[p^{\gamma}+(1-p)^{\gamma}]^{1/\gamma}} \tag{4}$$

IPD project participants have bounded rationality instead of being completely rational. Thus, this study proposes the utility function based on prospect theory. In contrast with expected utility, both utility function and probability weighting function influence the risk attitude of a decision maker under prospect theory. The perceived levels of risk affect the utility of the participants in the following three aspects.

1. In IPD project, risk/reward coincides with the outcomes expressed through the gains and losses from a reference point. If the project exceeds its goal, then participants share the reward (gain); if the project does not achieve its goal, then participants allocate the risk (losses).
2. The perceived relational and performance risk influence the shape of the value function. In other words, participants with different perceived levels of risk have different utilities in a given situation. For example, one with a high-perceived risk tends to have low utility for a given prospect. The variation of parameter α, β reflects the difference.
3. The weighting function is mainly affected by the perceived risk, which is reflected by the variation of parameter γ. For example, one with a high-perceived risk tends to have low weight for gain and high weight for losses. The probabilities of gain and losses also influence the decision weight.

The parameters α, β, and γ can be acquired using the perceived risk, and the utility function can be set accordingly. Let us suppose that each participant i has a utility function U_i $i = 1, 2, \ldots, n$, and w_i is the decision weight associated with the probability of sharing risk or reward; v_i is the value function reflecting the subjective value of risk or reward compensation. The risk and reward (gain and losses) are represented by r^+, r^-, and θ_i indicate the rate allocation of gain and losses; the probabilities of gain and losses are p^+ and p^- respectively. According to prospect theory, the utility of the IPD participants is given by:

$$\begin{aligned} U_i &= w_i^+(p^+)v_i^+(r^+\theta_i) + w_i^-(p^-)v_i^-(r^-\theta_i) \\ &= \frac{(p^+)^{\gamma_i}}{[(p^+)^{\gamma_i} + (1-p^+)^{\gamma_i}]^{1/\gamma_i}}\left(r^+\theta_i\right)^{\alpha_i} \\ &+ \frac{(p^-)^{\gamma_i}}{[(p^-)^{\gamma_i} + (1-p^-)^{\gamma_i}]^{1/\gamma_i}}[-\lambda(-r^-\theta_i)^{\beta_i}] \end{aligned} \tag{5}$$

Compensation Strategy Based on NBS

In cooperative game, players coordinate with each other. When an agreement is reached, players can act accordingly, or they can act in a non-cooperative manner. Therefore, two concepts have an important function in the analysis of a bargaining problem (S, d). Let S be the set of feasible outcomes that the players can obtain if they all work together, which is a subset of $\mathfrak{R}^n$ and d is the disagreement point, a vector in $\mathfrak{R}^n$. (S, d) is called a cooperative bargaining problem and satisfies the following properties:

(1) S is convex and closed.

(2) $d \in S$ and $x \in S$, such that $x > S$.

When analyzing the *n*-person bargaining problem, the cooperative solution should satisfy the following four axioms:

Linearity: if $s_i' = a_i s_i + b_i$, $i = 1, \ldots\ldots, N$, then the solution satisfies $F(S') = a_i F(S) + b_i$.

Pareto optimality: if S is the outcome of the bargaining process, it is impossible to improve the utility of each player at the same time.

Independence of irrelevant alternatives: if the bargaining solution of S is obtained in a small set S', then the bargaining solution assigns the same solution to the smaller game.

Symmetry: if any player position is exchanged, then the outcome is constant at the end of the bargaining process.

NBS is a unique solution function for n-person bargaining problem that satisfies all the four axioms:

$$F(S) = \max \prod_{i=1}^{n} (U_i - U_i^0) \tag{6}$$

In this study, let U_i^0 be the utility of the ith player at the disagreement point d. If participants quit the IPD project, then they will not receive any risk/reward compensation; thus, we assume $\mathrm{U}_\mathrm{i}^0 = 0$. In addition, S is convex and closed, and thus we must only ensure $U_i \geq U_i^0 = 0$. Hence, the bargaining solution of risk/reward compensation should be expressed as:

$$\begin{aligned} &\max_{U_i > U_i^0} \prod_{i=1}^{n} (U_i - U_i^0) \\ &= \max \prod_{i=1}^{n} [w_i^+(p^+)v_i^+(r^+\theta_i) + w_i^-(p^-)v_i^-(r^-\theta_i) - 0] \\ &= \max \prod_{i=1}^{n} \left[\begin{aligned} &\frac{(p^+)^{\gamma_i}}{[(p^+)^{\gamma_i} + (1-p^+)^{\gamma_i}]^{1/\gamma_i}}\left(r^+\theta_i\right)^{\alpha_i} \\ &+ \frac{(p^-)^{\gamma_i}}{[(p^-)^{\gamma_i} + (1-p^-)^{\gamma_i}]^{1/\gamma_i}}[-\lambda(-r^-\theta_i)^{\beta_i}] \end{aligned} \right] \end{aligned} \tag{7}$$

Subject to

$$w_i^+(p^+)v_i^+(r^+\theta_i) + w_i^-(p^-)v_i^-(r^-\theta_i) \geq 0 \tag{8}$$

$$0 \leq p^+ + p^- \leq 1 \text{ and } 0 \leq p^+, p^- \leq 1 \tag{9}$$

$$\sum_{i=1}^{n} \theta_i = 1, \theta_i > 0 \tag{10}$$

$$r^+ > 0, r^- < 0 \tag{11}$$

Numerical Example

An illustrative example is provided in this section to demonstrate the risk/reward compensation model. For simplicity, we assume that an IPD project has three key participants: owner, contractor, and designer sharing risk/reward. TOC is 1000, and the probability is 0,7 when AOC is equal to TOC; the probability is 0,2 when AOC is 900; the probability is 0,1 when the AOC is 1060. Three distribution strategies are employed for the three participants: A (50 %, 20%, and 30 %), B (70 %, 20 %, and 10 %), and C (50 %, 30%, and 20 %). The optimal strategy must be selected from them. According to the research process described above, the procedures for the illustration are as follows:

First, the expert team that is composed of five experts evaluates the perceived level of relational and performance risks in view of the different strategies for the owner, contractor, and designer. The expert team then determines the value of parameters α, β, γ for key participants in accordance with their perceived level of relational and performance risks. In this example, we only have the expert team evaluating the risk perception of the contractor in distribution strategy C as an example to demonstrate the process. The processes of evaluating risk perception for the owner and designer are same as those for the contractor.

When applying strategy C, each expert provides his linguistic value of the perceived relational risk of the contractor, as shown in Table 2. These criteria are consistent because several criteria are positively correlated with perceived relational risks while others are negatively correlated with the said risks. Goodwill trust, behavior control, history of cooperation, and social control are negatively correlated with perceived relational risk. Therefore, a linguistic term set should turn into $S = \{s_0 = Perfect, s_1 = Very\ High,\ s_2 = High,\ s_3 = Medium,\ s_4 = Low,\ s_5 = Very\ Low, s_6 = None\}$ when the expert team expresses the linguistic information according to these criteria.

Table 2

Linguistic value of contractor perceived relational risk

Criteria Expert	c_1	c_2	c_3	c_4	c_5	c_6
e_1	H	VH	M	M	H	M
e_2	VH	H	M	VH	H	M
e_3	M	H	L	H	VH	L
e_4	H	M	VL	L	M	H
e_5	VH	VH	H	H	M	L

Suppose the weights of all experts are the same and criteria weights are given in Table 3, then the criteria weights are computed as$(0.18, 0.21, 0.15, 0.15, 0.15,$ and $0.16)$. The perceived relational risk of the contractor should be expressed using the linguistic 2-tuple $(s_2, 0{,}23)$, in which the perceived relational risk of contractor is low. The membership degree is $\delta(s_2, 0{,}23) = \{(s_2, 0{,}77), (s_3, 0{,}23)\}$, and thus the corresponding numerical value assessed in $[0{,}1]$ is 0,37. Similarly, the expert team assesses the perceived performance risk of the contractor and obtains the numerical value 0.31. Tversky and Kahneman (1992) experimentally determined the parameters $\alpha = \beta$. The perceived relational risk and performance risk jointly influence the value of parameters α, β, γ, and their weights are given in Table 4. We can determine the contractor parameters $\alpha = \beta = 1 - (0{,}37 \times 0{,}6 + 0{,}31 \times 0{,}4) = 0{,}65$ and the corresponding value of$\gamma = 1 - (0{,}37 \times 0{,}2 + 0{,}31 \times 0{,}8) = 0{,}68$ because α, β, γ are negatively correlated with the perceived level of risk. Similarly, we can obtain the contractor parameters in other distribution strategies, as shown in Table 5. The expert team evaluates the perceived risk of owner and designer, and then obtains the value of corresponding parameters in the same way.

Table 3

Linguistic value of contractor criteria weights

Criteria Expert	c_1	c_2	c_3	c_4	c_5	c_6
e_1	VH	M	L	VL	H	M
e_2	M	H	M	M	L	M
e_3	L	VH	H	H	M	VL
e_4	H	M	VL	M	VL	VH
e_5	M	H	M	L	M	L

Table 4

Weights of perceived relational and performance risk

Risk Parameter	Relational risk	Performance risk
α, β	0,6	0,4
Γ	0,2	0,8

Table 5

Values of contractor corresponding parameters

	Relational risk	Performance risk	α, β	γ
A	0,46	0,29	0,61	0,68
B	0,68	0,11	0,55	0,77
C	0,37	0,31	0,65	0,68

Second, based on the above, let $\lambda = 2{,}0$ and the utility of the three key participants can be obtained according to the formulae (3)-(5), as shown in Table 6. In the formulae, r^+ and r^- are the gain and losses respectively, which are obtained based on the comparison between TOC and AOC. For example, the value of r^+ is 100 when AOC is 900, and the value of r^- is -60 when AOC is 1060. θ_i indicates the distribution rate of gains and losses for key participants in the given three distribution strategies. p^+ and p^- are the probabilities of gains and losses, and their value is 0,2 and 0,1 respectively in the example.

Table 6

Utility of key participants

Participant Strategy	Owner	Contractor	Designer
A	0,05	0,01	0,16
B	0,01	0,18	0,17
C	0,05	0,15	0,06

Third, we calculate the total utility of three strategies based on formula (7), and then select the maximum total utility strategy. In the example, the values of the total utility of the three distribution strategies are 0,00008, 0,00031, and 0,00045, respectively. Strategy C is the optimal risk/reward compensation strategy because the total utility is maximum. This illustrative example indicates that the risk/reward should be shared among the owner, contractor, and designer with proportions of 50 %, 30 %, and 20 %, respectively. These proportions are consistent with the practical risk/reward allocation of the IPD project.

Conclusion

Practical Implications

IPD is an emerging construction project delivery system that is distinguished through a multi-party contractual agreement that typically allows risk/reward to be shared among key participants and collaboratively involves key participants early in the project timeline, which is often before the design begins. Thus, how to determine the risk/reward compensation system in the early project stages is a realistic problem in the engineering field that requires an urgent solution. The purpose of this study is to solve this issue. Although this study focuses on theoretical study, the proposed method has sufficient pragmatic significance.

The present study provides a risk-perception-based approach rather than actual risk-based approach to decide on risk/reward compensation for IPD and overcome the practical problem that actual risk finds difficulty in measuring in the early project stage. In practice, the risk perception of participants is easy to measure based on the perceived risk criteria identified through a comprehensive literature review. Initial risk awareness can prompt participants to alter the contract to better fit their needs. Moreover, risk perception rather than risk itself influences the shared risk/reward in most cases because of the bounded rationality of participants.

This study also contributes in a practical way through using NBS to acquire the satisfactory result of risk/reward sharing. In IPD, key participants jointly determine how to share risk/reward. Thus, instead of using the traditional Stackelberg game, in which the owner usually acts as the leader and specifies the contract, and non-owner participants act as the followers through responding to the contract that the owner offers, NBS is employed as a cooperative approach to design the compensation contract. NBS is more realistic than other non-cooperative methods, and this realism especially holds in the construction industry.

Overall, this study proposes an explicit, comprehensive, and systematic framework for risk/reward allocation practice in an IPD project.

Limitations and Opportunities for Future Research

Similar to all studies, our study has limitations that highlight areas for future research. First, the perceived risk criteria in this study may not be comprehensive enough. In fact, determining the perceived risk criteria is a complex process. Although the criteria, to our knowledge, are identified through a comprehensive literature review, developing the influencing factors in further research is necessary. Second, if possible, the utility function can be established through analyzing a large number of engineering data in future research. The perceived risk of the participant may be reflected more precisely. Additionally, this study not only gives a novel and distinct theoretical perspective to explore the risk/reward compensation for IPD, but also serves as a trigger to instigate follow-up empirical research. With future research, exploring this issue through empirical analysis is necessary, which may be more pragmatic in the engineering field.

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