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Quantitative Risk Allocation in Construction Projects: A Fuzzy-Bargaining Game Approach

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KEYWORDS

Quantitative risk allocation,
Bargaining game theory,
Fuzzy logic,
Negotiation

ABSTRACT

The quantitative approaches to risk allocation, determine how much of a risk is borne by each party. An equitable risk allocation between the contracting parties plays a vital role in enhancing the performance of the project. This research presents a new quantitative risk allocation approach integrating fuzzy logic and bargaining game theory. Owing to the imprecise and uncertain nature of the costs imposed to the contracting parties at different percentages of risk allocation, fuzzy logic is employed to determine the value of players payoffs based on the opinion and subjective judgment of experts involved in the project. Having determined the value of players payoffs, bargaining game theory is then applied to find the equitable risk allocation between the client and the contractor. Four different methods including symmetric Nash, non-symmetric Nash, non-symmetric Kalai–Smorodinsky and non-symmetric area monotonic are finally implemented to determine the equitable risk allocation. To evaluate the performance of the proposed model, it is implemented in a pipeline project and the quantitative risk allocation is performed for the inflation as one of the most significant identified risks.

1. Introduction

Construction projects are unique and built only once [1].The outcomes of all construction projects can potentially be affected, adversely and positively, by a large number of constantly changing risks and opportunities [2]. Risk management is an essential tool to cope with such an uncertainties that is performed in five phases including plan risk management, identify risks, qualitative risk analysis, quantitative risk analysis and risk response planning [3].

There are different parties involved in a construction project including the client, contractor and consultant.

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Each of these parties is responsible for certain risks and should manage them.

It is therefore necessary to allocate risks equitably between the contracting parties before commencing the risk management process. Risk allocation is commonly performed through contract conditions and clauses disregarding different parties' capabilities in managing the risks. In fact, the clients commonly tend to transfer most of the risks to contractors. This one sided attitude regarding risk allocation, however, is not an efficient and effective way of managing and allocating risks [4].

The one-sided attitude regarding risk allocation results in the extra costs for clients due to a higher contingency (or premium) included in the bid price by the contractors, more resources for monitoring the risk management work, and lowering of quality work by the contractor [5]. Moreover, upon completion of the work, litigation of contractual claims might come after. In the worst case, the owner pays for the risks twice including one in bidding contingencies and the other one in court [6].

The risk allocation process can be performed qualitatively and quantitatively. The risk allocation matrix is the output of qualitative risk allocation. The risk allocation matrix basically attempts to identify what type of risk is allocated to whom [7]. The quantitative approaches, however, determine how much of a risk is borne by each party, which is the main difference and extension from the qualitative approaches [4].

There exist only few researches that have been conducted in the area of quantitative risk allocation. Yelin et al. (2010) developed a fuzzy synthetic evaluation model to determine risk allocation between the government and private sector in public private partnership (PPP) projects. The critical criteria for equitable risk allocation associated with PPP projects were identified and a quantitative model for risk allocation was developed by transforming the linguistic risk allocation principles into a quantitative decision making process [8]. Jin and Zhang (2010) proposed a theoretical framework for modelling the risk allocation decision-making process based on the transaction cost economics. They implemented artificial neural network models for modelling risk allocation decision-making process in PPP projects [5]. Medda (2007) developed a process of risk allocation between the public and private sector in transportation PPP infrastructure agreements through the final offer arbitration game. The model analysed the behaviour of players in a game framework when confronted with opposing objectives in the allocation of risks [9].

Yamaguchi et al. (2001) proposed a conceptual model of risk allocation developed for private finance initiative (PFI) projects. The theoretical model has been developed based on Borch's insurance theory. They focused on how costs and profit are allocated between the government client and the PFI contractor [7].

The literature review reveals that there exist only few researches in the area of quantitative risk allocation. These researches are faced with some major shortcomings and defects. None of the previous researches is capable of performing the quantitative risk allocation for each of the identified risks. In fact, the previous works can only share the total cost overruns of the project between the contracting parties. Moreover, the value of players payoffs which acts as an input for performing the bargaining game is simply assumed in the previous works.

Determining the exact value of players payoffs, however, is not normally possible owing to its imprecise and uncertain nature.

This research presents a new quantitative risk allocation approach by integrating fuzzy logic and bargaining game theory.

The proposed approach models the players (contracting parties) behavior in the quantitative risk allocation process. Owing to the imprecise and uncertain nature of players payoffs (contracting parties costs) at different percentages of risk allocation, fuzzy logic is implemented to determine the value of players payoffs based on the opinion and subjective judgment of experts involved in the project. The bargaining game theory is finally applied to find the equitable risk allocation between the client and the contractor. Four different bargaining methods including symmetric Nash, non-symmetric Nash, Kalai–Smorodinsky and area monotonic are implemented to determine the equitable risk allocation.

To evaluate the performance of the proposed model, it is implemented in a pipeline project and the quantitative risk allocation is performed for inflation as one of the most significant identified risks.

2. Model Structure

A flowchart representing different stages of the quantitative risk allocation carried out by the proposed fuzzy-bargaining game approach is shown in Fig. 1. As shown in this figure, at the first stage, the players payoffs are determined at different percentages of risk allocation by fuzzy inference system (FIS). FIS consists of three major components including fuzzification, fuzzy inference mechanism and defuzzification. At the second stage, quantitative risk allocation is performed by bargaining game using four different methods including symmetric Nash, non-symmetric Nash, Kalai-Smorodinsky and area monotonic.

To evaluate the performance of the proposed quantitative risk allocation model, it is implemented in a pipeline project. The quantitative risk allocation is performed for the inflation as one of the most significant identified risks. The following sections will explain in detail how different stages of the quantitative risk allocation process are performed by the proposed fuzzy-bargaining game model.

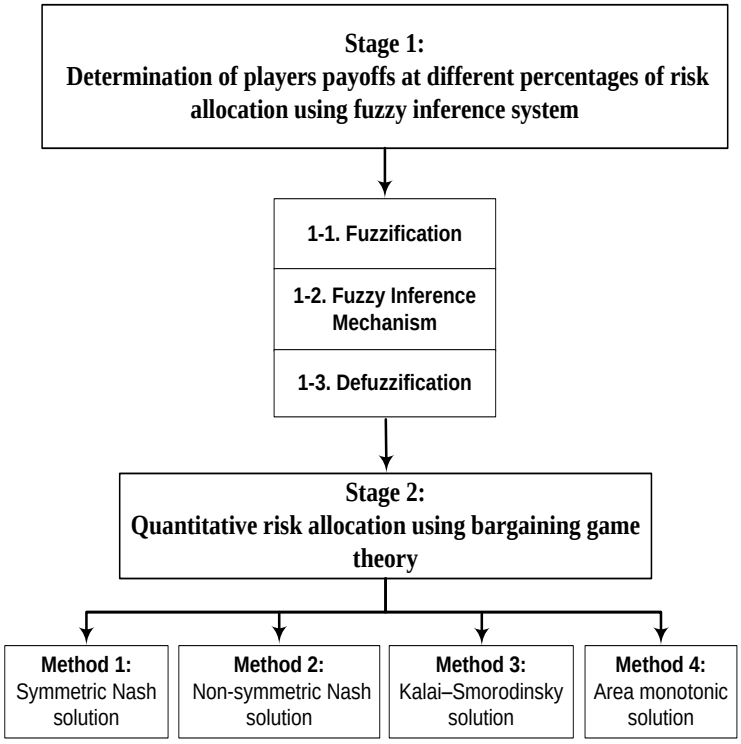


Fig. 1. Different stages of quantitative risk allocation process by the proposed integrated fuzzy-bargaining game model

3. Quantitative Risk Allocation Using Proposed Fuzzy-bargaining Game Model

3-1. Stage 1: Determination of the Players Payoffs at Different Percentages of Risk Allocation Using Fuzzy Inference System

There are some basic rules in a typical bargaining game: (1) strategies should be available to each player, (2) each player is a rational maximizer and (3) the payoffs for each player can be calculated at different strategies [10].

In this research, different strategies that may be implemented by each player are represented as different percentages of risk allocation. Moreover, it is assumed that the players act rationally. The 'rational behavior' of players, has two necessary conditions: (1) decision makers pursue well-defined, exogenous objectives and (2) decision makers take into account their knowledge and expectations of the behavior of other decision makers [11, 12].

To perform the quantitative risk allocation using bargaining game theory, first the payoffs for each player should be calculated. In this research, the cost imposed on the client and the contractor at different percentages of risk allocation is considered as the players payoffs.

Determining the exact value of players payoffs at different percentages of risk allocation, however, is not normally possible. Therefore, in this research, fuzzy inference system is implemented to determine the value of players payoffs based on the opinion and subjective judgment of experts involved in the project. Fuzzy set theory provides a useful tool to deal with decisions in which the phenomena are imprecise and vague, it enables us to qualify imprecise information, to reason and make decisions based on vague and incomplete data [13,14]. The fuzzy inference system consists of three major components including fuzzification, inference mechanism and defuzzification [15]. These components will be explained below briefly.

3-1-1. Fuzzification

Fuzzification is a process used to convert the value of input variables into corresponding linguistic variables [16]. In the classic logic, a member can belongs to a set of data or not. In contrast, when fuzzy logic is used, the degree of belonging of a member may be selected from a set of fuzzy numbers defined as fuzzy membership function [17]. A 'membership function' is a curve that defines how the value of a fuzzy variable is mapped to a degree of membership between 0 and 1 [18].

3-1-2. Fuzzy Inference Mechanism

Inference is the set of if–then rules that operate on linguistic variables and encode the control knowledge of the system. The rules connect the input variables with the output variables and are based on the fuzzy

state description that is obtained by the definition of the linguistic variables [19].
In this research, a "Mamdani style" inference mechanism [20] is implemented to determine the value of players payoffs at different percentages of risk allocation.

3-1-3. Defuzzification

Defuzzification is the operation of producing a non-fuzzy number, i.e., a single value that adequately represents the fuzzy number [21]. In this research, the centre of area method is utilized for defuzzification.

3-2. Stage 2: Quantitative Risk Allocation Using Bargaining Game Theory

The negotiation between the client and the contractor in the quantitative risk allocation is similar to a bargaining process and can be modeled using the tools of bargaining game theory [11]. A bargaining situation is a situation in which two players have a common interest to cooperate but have conflicting interests over exactly how to cooperate [10].
Having determined the client and the contractor payoffs, quantitative risk allocation is performed using bargaining game theory by four methods including (1) symmetric Nash solution (2) non-symmetric Nash solution; (3) Kalai-Smorodinsky solution; and (4) area monotonic solution (Fig. 1). The three latter alternative solution concepts are extended the original axiom set of symmetric Nash solution [22]. These methods are explained below briefly.

Method 1: Symmetric Nash Solution

Nash equilibrium is one of the most important basic concepts in bargaining game theory. Nash states that there exists a unique solution that satisfies the four axioms: pareto efficiency (PE), invariance with respect to affine transformation (IAT), independence of irrelevant alternatives (IIA), symmetry (SYM) [23]. Nash solution can be obtained by solving the following optimization problem:

$$Maximize\ (f_1 - d_1)(f_2 - d_2)$$

$$Subject\ to: \quad d_1 \le f_1 \le m_1$$

$$f_2 = g(f_1)$$

f_1 and f_2 are the unique payoffs corresponding to the percentages of risk allocation that are obtained from the solution. d_1 and d_2 are the minimum players payoffs or disagreement point. m_1 is the maximum payoff of player one. In the case of normalized objectives, $d_1 = d_2 = 0$ and $m_1 = 1$. Nash solution represents a feasible set (*S*) that is compact and convex. Each point of *S* represents a solution for the bargaining problem that can be an agreement between the players. It is assumed that the Pareto frontier is given by function g defined in interval $[d_1, m_1]$ where $g(m_1) = d_2$ (Fig. 2).

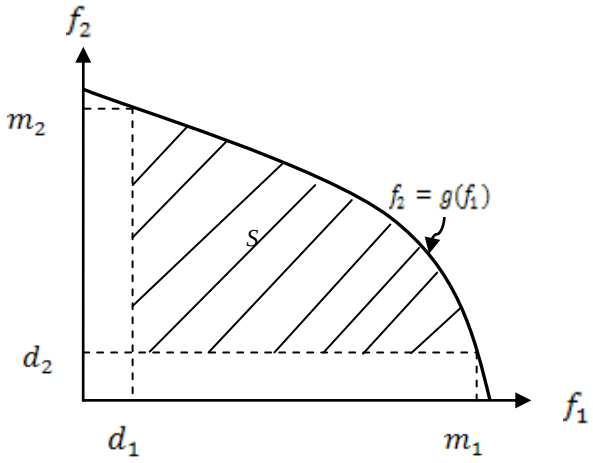


Fig. 2. Nash bargaining game over a convex set of S for two players

Method 2: The Non-Symmetric Nash Solution

Non-symmetric Nash solution was introduced by Harsanyi and Selten (1972), which allows to model the bargaining of parties with different powers [22]. This method is the unique optimal solution of problem:

$$Maximize \quad (f_1 - d_1)^{w_1}(f_2 - d_2)^{w_2}$$

$$Subject\ to: \quad d_1 \le f_1 \le m_1$$

$$f_2 = g(f_1)$$

Where w_1 and w_2 are the powers of the two players or the importance factor of their objectives. This method is generalization of symmetric Nash method with unequal weights.

Method 3: The Kalai-Smorodinsky Solution

Kalai and Smorodinsky (1975) showed that by replacing Nash's axiom of independence of irrelevant alternatives by a certain axiom of monotonicity, a different unique solution is obtained that is called monotonic solution [22]. The Kalai-Smorodinski solution is the optimal solution of the problem:

$$d_2 + \left[{}^{(m_2 - d_2)}/_{(m_1 - d_1)} \right](f_1 - d_1)({}^{w_2}/_{w_1}) - f_2 = 0$$

$$Subject\ to: \quad d_1 \le f_1 \le m_1$$

$$f_2 = g(f_1)$$

If both objectives are normalized, then $d_1 = d_2 = 0$ and $m_1 = m_2 = 1$, so the unique intercept between the Pareto frontier and the straight line $(f_1)({}^{w_2}/_{w_1}) = g(f_1)$ is the Kalai -Smorodinsky solution (Fig. 3).

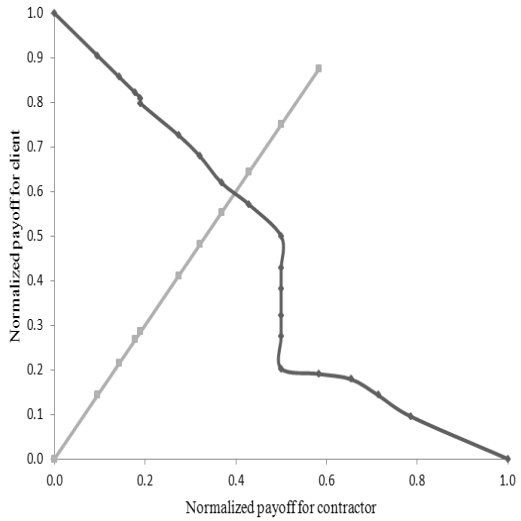


Fig. 3. Kalai -Smorodinsky solution for quantitative risk allocation between the client and the contractor ($w_1 = w_c = 0.4, w_2 = w_o = 0.6$)

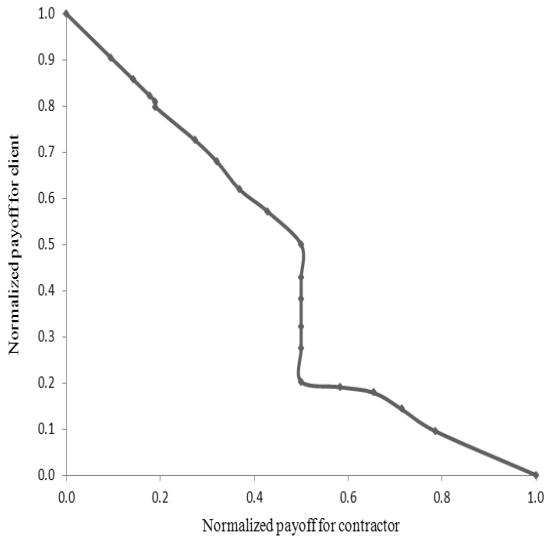


Fig. 4. The area monotonic solution for quantitative risk allocation between the client and the contractor ($w_1 = w_c = 0.4, w_2 = w_o = 0.6$)

Method 4: The Area Monotonic Solution

The area monotonic solution is based on a linear segment starting at the disagreement point that divides S into two subsets of equal area. If the powers of the two players are not symmetric, that is $w_1 \neq w_2$, then we might define the non-symmetric area monotonic solution by requiring that the ratio of the areas of the two subsets be w_1/w_2 [22]. Hence, the solution is the root of the nonlinear equation (Fig. 4):

$$w_2\left[\int_{d_1}^{x} g(t)\,dt - {}^1/_2\,(x-d_1)(g(x)+d_2)\right] = w_1\left[\int_{x}^{M_1} g(t)\,dt - (M_1-x)d_2 + {}^1/_2\,(x-d_1)(g(x)-d_2)\right]$$

4. Model Application

To evaluate the performance of the proposed quantitative risk allocation model, it was implemented in a 150 km pipeline project. The contract of this project is on a unit price basis equal to 650,000 dollars per kilometre. According to the preliminary estimates, the project will be executed within 930 days. In this project, the quantitative risk allocation was performed for the inflation as one of the most significant identified risks by the proposed fuzzy-bargaining game model.

4-1. Determination of the Client and Contractor Payoffs for the Inflation Risk at Different Percentages of Risk Allocation Using Fuzzy Inference System

As explained before, at the first stage the client and the contractor payoffs should be determined at different percentages of risk allocation by fuzzy inference system (FIS). FIS consists of three major components including fuzzification, fuzzy inference mechanism and defuzzification.

The membership function of different risk allocation strategies is depicted in Fig. 5. The membership function of different payoffs imposed to the client and contractor at different risk allocation strategies is also represented in Fig. 6. As shown, the ratio of the client and the contractor cost to the initial cost, would be between 1 and 2 depending on how the risk is allocated between two parties. This range was determined based on the opinion and subjective judgments of experts involved in the project. For example if the ratio of the client cost to the initial estimated cost is equal to 1.25, it means that in the case of occurrence of the inflation risk, the client cost is increased by 25%.

Tables (1) and (2) represent the fuzzy control system inference rules used for determining the client and the contractor payoffs at different risk allocation strategies, respectively. There are a total number of 25 fuzzy control rules in each of these tables. As an example, rule 1 in table (1) is expressed as below:

If risk allocation to the contractor is “very low” and risk allocation to the client is “very high”, then the client payoff would be “very high”.

As shown in tables 1 and 2, where the combination of two risk allocation strategies is not feasible, no value is given to the client and contractor payoffs by the expert.

For example, if the risk allocation to the client and the contractor is considered as "very low", it would be an infeasible combination of players strategies. In this case, therefore, no value has been assigned as the players payoff by the expert.

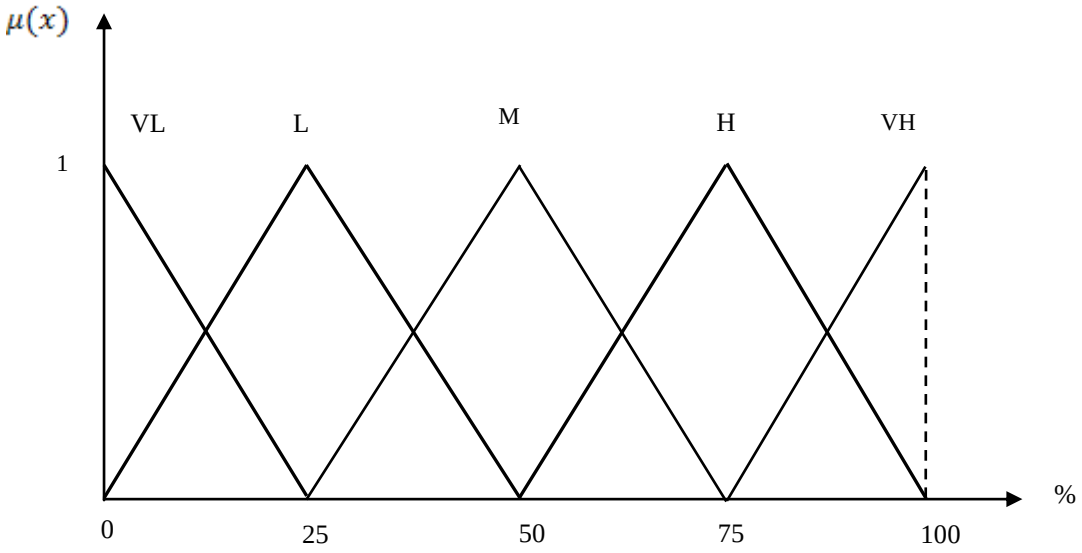


Fig. 5. Membership function of different risk allocation strategies

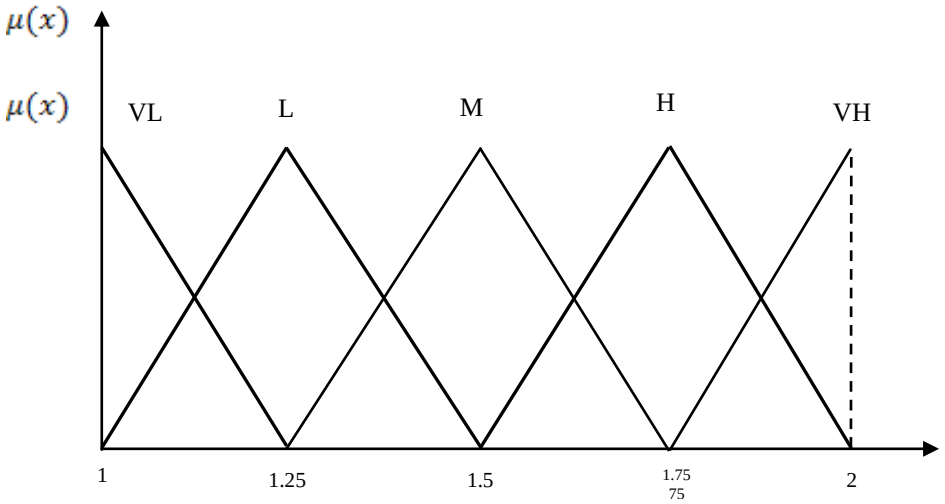


Fig. 6. Membership function of the client and the contractor payoffs

Tab. 1. Fuzzy inference rules for determining the client payoff

Risk allocation to the contractor \ Risk allocation to the client	Very low	Low	Medium	High	Very high
Very low	-	-	M	H	VH
Low	-	-	M	H	H
Medium	-	L	M	M	-
High	VL	L	L	-	-
Very high	VL	L	L	-	-

Abbreviations: VL: Very Low, L: Low, M: Medium, H: High, VH: Very High

Tab. 2. Fuzzy inference rules for determining the contractor payoff

Risk allocation to the client \ Risk allocation to the contractor	Very low	Low	Medium	High	Very high
Very low	-	-	M	H	VH
Low	-	-	H	H	VH
Medium	-	M	M	H	-
High	L	M	M	-	-
Very high	VL	L	M	-	-

Abbreviations: VL: Very Low, L: Low, M: Medium, H: High, VH: Very High

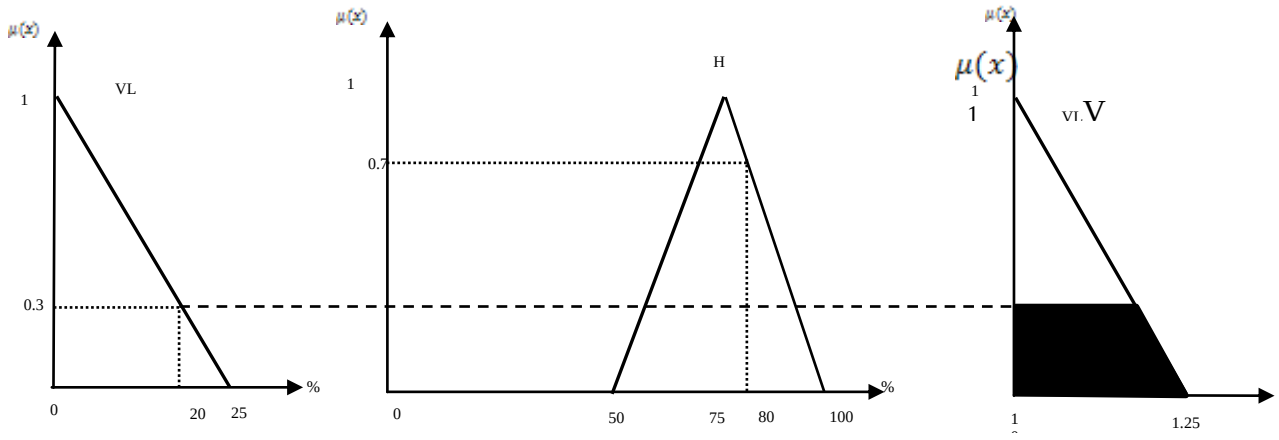
Tab. 3. The value of the client and the contractor payoffs at different percentages of risk allocation

The risk allocation percentage to the client	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Client Payoffs	1.08	1.16	1.2	1.23	1.24	1.25	1.31	1.35	1.4	1.44	1.5	1.56	1.6	1.65	1.69	1.75	1.76	1.77	1.8	1.84	1.92
Contractor payoffs	1.92	1.84	1.8	1.77	1.76	1.76	1.69	1.65	1.61	1.56	1.5	1.5	1.5	1.5	1.5	1.5	1.43	1.37	1.32	1.26	1.08

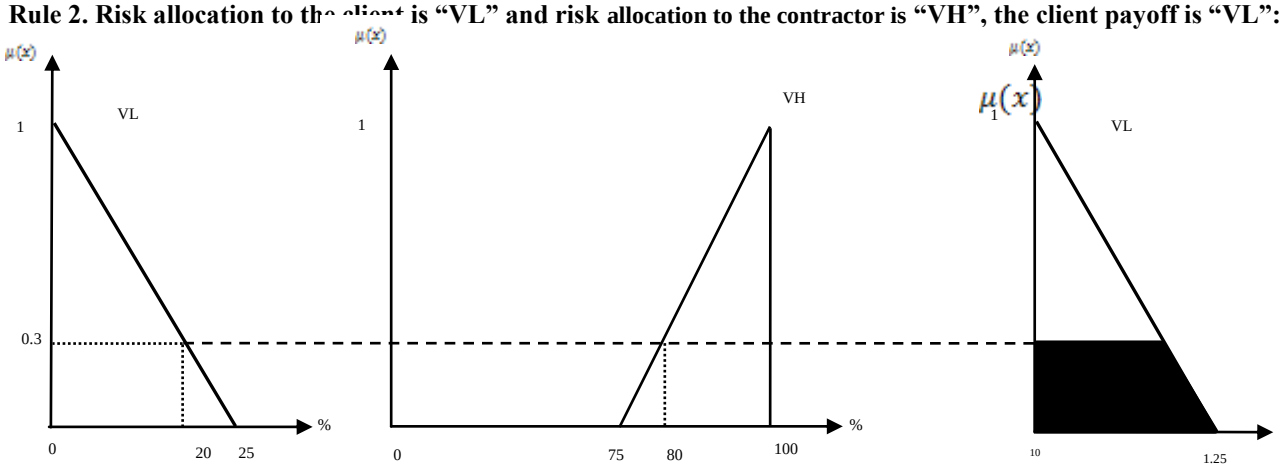
Finally, the client and the contractor payoffs at different percentages of risk allocation could be determined using proposed fuzzy inference system. Table (3) shows the calculated values of the client and the contractor payoffs determined by the proposed FIS at different risk allocation strategies for the inflation risk.

As an example, the fuzzification, inference and defuzzification processes are depicted graphically for one of the risk allocation strategies (Fig. 7). In Fig. 7, it is shown that how the client payoff is calculated for the risk allocation strategy in which 20 percent of risk is allocated to the client.

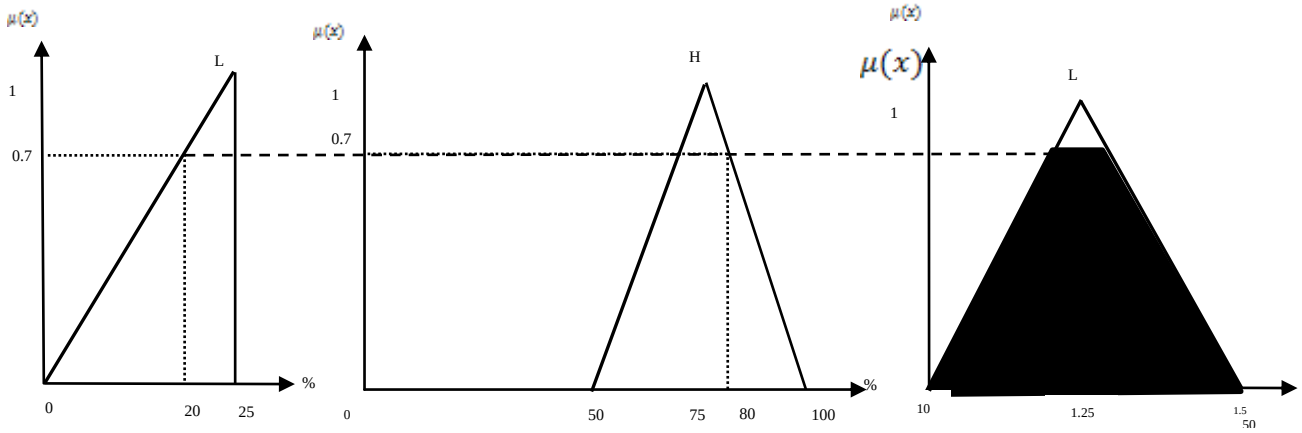
Rule 1. Risk allocation to the client is "VL" and risk allocation to the contractor is "H", the client payoff is "VL":



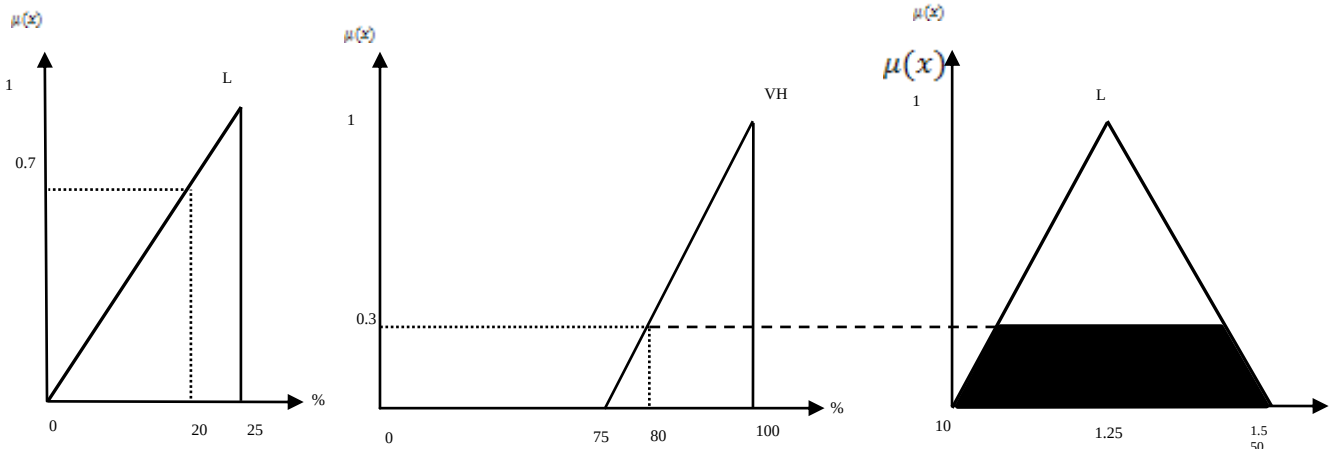
Rule 2. Risk allocation to the client is "VL" and risk allocation to the contractor is "VH", the client payoff is "VL":



Rule 3. Risk allocation to the client is "L" and risk allocation to the contractor is "H", the client payoff is "L":



Rule 4. Risk allocation to the client is "L" and risk allocation to the contractor is "VH", the client payoff is "L":



Risk allocation to the client = 20%

Risk allocation to the contractor = 80%

The ratio of the client and the contractor cost to the initial estimated cost in the event of inflation risk
The ratio of the client and contractor cost to the initial estimated cost in the event of inflation risk

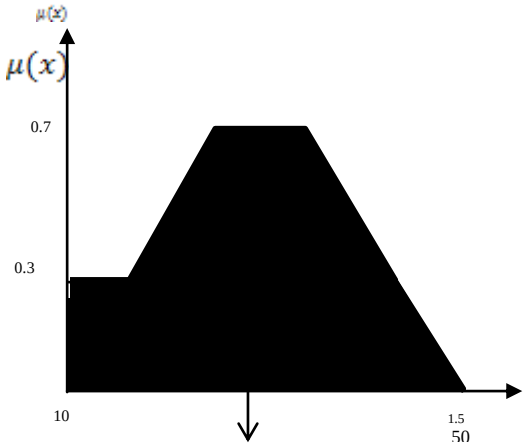


Fig. 7. Fuzzification, inference and defuzzification processes for determining the client payoff at a point in which the percentage of risk allocation to the client is equal to 20%

4-2. Quantitative Risk Allocation Using Bargaining game Theory

Having determined the client and the contractor payoffs, quantitative risk allocation is performed using bargaining game theory by four methods including symmetric Nash solution, non-symmetric Nash solution, Kalai-Smorodinsky solution and area monotonic solution. Table 4 represents the results of bargaining using four mentioned methods. It should be stated that before commencing the bargaining process, first the client and the contractor payoffs were normalized in a range between 0 to 1, where 0 and 1 are corresponded to the worst and best outcomes, respectively.

To perform the quantitative risk allocation between the client and the contractor, the bargaining power of the client and the contractor is assumed to be 0.6 and 0.4, respectively. Since, the proposed four bargaining methods represent the fairness from different points of view, the results would be different. Therefore, one or more of the proposed methods could be used for quantitative risk allocation by the contracting parties. If it is decided to use a combination of the four methods, the average of final results may be considered as the final output.

In symmetric Nash solution, where $w_o = w_c = 1/2$, the percentage of risk allocated to the client is calculated as 50%.

In Non-symmetric Nash solution, Kalai-Smorodinsky solution and area monotonic solution, the percentage of risk allocated to the client is calculated as 45%, 42.3% and 26.06% using interpolation, respectively (Figs . 3 and 4). Table 5 shows the final results of quantitative risk allocation using four bargaining methods. As shown, if a combination of the four methods is used, the final percentage of risk allocated to the client and the contractor would be determined as 40.84% and 59.16%, respectively. The resulted quantitative risk allocation shows that the client and the contractor costs are increased from the initial estimated cost by 41% and 50%, respectively.

Tab. 4. Normalized payoffs for the client and the contractor and comparison between the results of bargaining using different methods

Risk allocation to the client	Normalized payoff for the client	Normalized payoff for the contractor	symmetric Nash solution	Non-symmetric Nash Solution	Kalai-Smorodinsky solution
0	1	0	0	0	-1
5	0.90	0.10	0.29	0.37	-0.76
10	0.86	0.14	0.35	0.42	-0.64
15	0.82	0.18	0.38	0.45	-0.55
20	0.81	0.19	0.39	0.45	-0.52
25	0.80	0.19	0.39	0.45	-0.51
30	0.73	0.27	0.45	0.49	-0.32

Risk allocation to the client	Normalized payoff for the client	Normalized payoff for the contractor	symmetric Nash solution	Non-symmetric Nash Solution	Kalai-Smorodinsky solution
35	0.68	0.32	0.47	0.50	-0.20
40	0.62	0.37	0.48	0.50	-0.07
45	0.57	0.43	0.49	0.51	0.07
50	0.50	0.50	0.50	0.50	0.25
55	0.43	0.50	0.46	0.46	0.32
60	0.38	0.50	0.44	0.42	0.37
65	0.32	0.50	0.40	0.38	0.43
70	0.27	0.50	0.37	0.35	0.48
75	0.20	0.50	0.32	0.29	0.55
80	0.19	0.58	0.33	0.30	0.68
85	0.18	0.65	0.34	0.30	0.80
90	0.14	0.71	0.32	0.27	0.93
95	0.10	0.79	0.27	0.22	1.08
100	0	1	0	0	1.5

Tab. 5. Equitable solutions of quantitative risk allocation using four bargaining game methods

Players	Description	Bargaining game methods				Final quantitative risk allocation
		Symmetric Nash solution	Non-symmetric Nash Solution	Kalai - Smorodinsky solution	Area monotonic solution	
The Client	Risk allocation	50%	45%	42.3%	26.06%	40.84%
	Corresponding ratio of the client cost to the initial estimated cost	1.5	1.44	1.42	1.26	1.41
The Contractor	Risk allocation	50%	55%	57.7%	73.94%	59.16%
	Corresponding ratio of the contractor cost to the initial estimated cost	1.5	1.56	1.58	1.74	1.5

5. Conclusions and Remarks

One sided attitude regarding risk allocation results in the extra costs for clients due to a higher contingency included in the bid price from contractors and lowering the quality of work by the contractor. It is therefore necessary to allocate risks fairly between the contracting parties before commencing the project.

In this research, the fuzzy logic and bargaining game theory was integrated to perform the quantitative risk allocation between the client and the contractor in a pipeline project. To perform the quantitative risk allocation using bargaining game theory, first the client and the contractor payoffs at different risk allocation strategies were determined. For this purpose, the costs imposed to the client and contractor at different percentages of risk allocation were considered as the players' payoffs. The players payoffs were determined by a fuzzy inference system based on the opinions and subjective judgment of experts. Having determined the client and the contractor payoffs, the players commence the negotiation process for the quantitative risk allocation. The negotiation process was modeled using bargaining game theory by four methods including symmetric Nash, non-symmetric Nash, non-symmetric Kalai–Smorodinsky and non-symmetric area monotonic. Since, the proposed four bargaining methods represent the fairness from different points of view, the provided results were different. One or more of the proposed methods could be used to perform the quantitative risk allocation between the contracting

parties. In the case that a combination of different bargaining methods is used, the average of final results is considered as the optimum percentage of risk allocation.

Finally, it was concluded that the proposed integrated fuzzy-bargaining game approach may provide an efficient tool for quantitative risk allocation since the existing risks and uncertainties as well as the behavior of contracting parties during the risk allocation process are taken into account.

The model proposed in this paper can be applied for the quantitative risk allocation in any other project in which decision-makers and stakeholders have conflicting interests.

6. Acknowledgement

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