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Integrating system dynamics and fuzzy bargaining for quantitative risk allocation in construction projects

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Abstract. Quantitative approaches to risk allocation have been developed to overcome the limitation of qualitative approaches, and to determine how the responsibility of risk should be shared between contracting parties. This paper integrates a system dynamics simulation scheme with fuzzy bargaining game theory for quantitative risk allocation. The behaviour of contracting parties in the quantitative risk allocation negotiation process is modelled as player behaviour in a game. A system dynamics based model is employed to determine the contractor and client costs (players' payoffs) at different percentages of risk allocation. Having determined the player payoffs, the common interval between player acceptable risk allocation percentages is determined. The bargaining process is then performed between two parties accounting for the common interval, and a desirable and equitable percentage of risk allocation is determined.

1. Introduction

Construction projects are one-off endeavours having many unique features, such as lengthy periods of time, complicated processes, financial intensity and dynamic organisation structures. Such organisational and technological complexity generates enormous risks [1]. The outcome of all construction projects can potentially be affected, adversely and positively, by these constantly changing risks and opportunities [2]. Employing an effective risk management process plays a vital role in enhancing the performance of the project.

Construction projects involve different parties, including the client, the contractor and the consultant. Each of these parties is responsible for, and should manage, certain risks. It is, therefore, necessary to allocate risks properly between the contracting parties before starting the risk management process.

Risk allocation is the process of identifying project risks and determining how they may be equitably and realistically shared by all parties in a construction project [3]. Risk allocation is commonly performed through contract conditions and clauses. It is common that the owner tends to contractually pass the responsibility for most of the risks to the contractor under traditional procurement processes [4]. However, a one-sided attitude toward risk allocation, where one party tries to dispatch all risk to the other, most likely has unfavourable results for both transferees and transferors [5,6].

The risk allocation process can be performed qualitatively and quantitatively [7]. In qualitative

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approaches to risk allocation, a matrix is developed to identify what type of risk is allocated to which party. However, qualitative approaches are limited in addressing issues, such as determining to what extent the involved parties share risk [5]. Therefore, quantitative approaches to risk allocation, which determine how the responsibility of risk should be shared between contracting parties, have been developed.

There has been little research conducted in the area of quantitative risk allocation. Yelin et al. developed a fuzzy synthetic evaluation model to determine an equitable risk allocation between the government and the 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 proposed a model in which the determinants of efficient risk allocation were identified based on the transaction cost economic theory and a resource-based view of organisational capabilities. Accordingly, a theoretical framework was proposed to model the risk allocation decision-making process in PPP projects [9]. Medda developed a process of risk allocation between the public and private sector in transportation PPP infrastructure agreements, as a bargaining process between the two agents. The model analyzes the behaviour of players in a game framework when confronted with opposing objectives in the allocation of risk [10]. Yamaguchi et al. proposed a conceptual model of risk allocation developed for Private Finance Initiative (PFI) projects. They focused on how cost and profit are allocated between the government client and the private PFI contractor [7]. Nasirzadeh et al. proposed an integrated fuzzy-system dynamics approach for quantitative risk allocation. Using the proposed model, the project cost was simulated at different percentages of risk allocation, and the optimum percentage of risk allocation was determined as a point at which the project cost is minimized [11,12].

In previous research, the behaviour of contracting parties in the quantitative risk allocation process that is similar to player behaviour in a game is not accounted for. Moreover, the quantitative risk allocation process is not performed on a cost-benefit basis.

This research presents a new quantitative risk allocation approach by integrating a System Dynamics (SD) simulation scheme and fuzzy bargaining game theory. A system dynamics based model is employed to determine the contractor and client costs (player payoffs) at different percentages of risk allocation. The proposed SD model simulates the contractor and client costs, taking into account all influencing factors, as well as the contractor's defensive strategies against unfair risk allocation.

Having determined the contractor and client costs at different percentages of risk allocation, an acceptable interval of risk allocation percentages is determined by each of the contracting parties (the players). The common interval between the players' acceptable risk allocation percentages is then determined. The players' discount factor is determined using a fuzzy inference mechanism. A bargaining process is then performed between two parties considering the common interval, and a desirable and equitable percentage of risk allocation is determined. To evaluate the performance of the proposed method, it is implemented in a real pipeline project, and a quantitative risk allocation is performed for inflation risk, which is one of the most significant identified risks.

2. Model structure

A flowchart representing the different stages of the quantitative risk allocation process, performed using the proposed integrated SD-bargaining game model, is shown in Figure 1. Each stage is explained in detail in the following sections.

Stage 1: Determination of players' payoffs using SD approach. Payoffs are numbers that represent

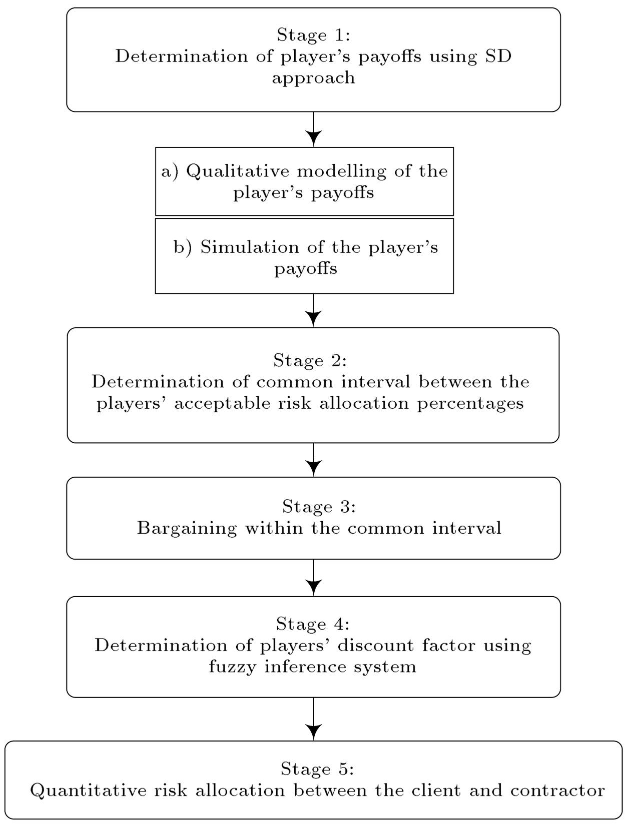

Figure 1. Flowchart of the different stages of quantitative risk allocation process by the proposed integrated SD-bargaining game model.

the outcome of players' combination of strategies. Payoffs may represent profit, quantity, utility, or other continuous measures (cardinal payoffs), or may simply rank the desirability of outcomes (ordinal payoffs) [13]. In this research, the costs imposed onto the client and contractor at different percentages of risk allocation are considered as the players' payoffs.

There are various factors affecting the client and contractor costs in different risk allocation strategies. SD introduced by Forrester [14] is an object-oriented simulation methodology enabling one to model the complex inter-related structure of different factors affecting the contractor and client costs (the players' payoffs) [11]. It is adequate for the modelling and simulation of systems that consist of multiple interdependent components, are highly dynamic, and which involve multiple feedback processes and non-linear relationships with both "hard" (quantitative) and "soft" (qualitative) data [15]. Therefore, SD is best suited for simulating player costs (players' payoffs) at different percentages of risk allocation [11]. The players' payoffs at different percentages of risk allocation are determined using the SD approach in two stages. First, a qualitative model of different factors affecting player payoffs is constructed. Having constructed the qualitative model of players' payoffs, the mathematical relationships (model equations) that exist between different factors are determined, and the qualitative modelling of the players' payoffs is performed. Thus, players' payoffs can be efficiently modelled, simulated and quantified for different risk allocation strategies using the proposed SD modelling approach.

Stage 2: Determination of a common interval between the players' acceptable risk allocation percentages. In order for there to be bargaining between the client and contractor regarding risk allocation strategies (Stage 3), a common interval between the players' acceptable risk allocation strategies should be determined. If a common interval does not exist, the bargaining process between the two sides will not succeed, and they will not reach an agreement.

It should be stated that in order to determine the common interval between two players, first, an acceptable interval of risk allocation percentages is selected by each player, accounting for his/her rational behaviour. The common interval between the players' acceptable risk allocation strategies is then determined.

Stage 3: Bargaining within the common interval. Quantitative risk allocation is often a multi-criteria, multi-decision-maker problem. Therefore, the behaviour of contracting parties in the risk allocation negotiation process is similar to players' behaviour in a game. The bargaining process is similar to a negotiation process that may be modelled using the tools of game theory [16]. A bargaining situation is a situation in which players have a common interest to cooperate, but have conflicting interests over exactly how to cooperate [13]. The bargaining process involves "alternating offers", where the client commences the bargaining by making an offer that the contractor can then accept or reject. Rejection leads to a counteroffer by the recipient [17].

The main component in the bargaining process is the "bargaining cost". The bargaining cost will be induced in each bargaining round in order to make a counteroffer if one player rejects the offer by his counterpart. It also reflects loss due to costly delayed agreements [13].

During the bargaining process, each player is aware of the maximum and minimum values of the other player's payoffs. Each player knows that if his/her offer is unfair, the other player will reject it, and the bargaining will continue to another stage. It is obvious that in order to avoid bargaining costs, it is better to reach an agreement at the first stage of bargaining.

Let M_o and m_o denote the maximum and minimum value of the client's payoff, respectively, and M_c and m_c denote the maximum and minimum value of the contractor's payoffs, respectively. The client makes the first offer, and knows that the contractor can obtain the maximum payoff of M_c and minimum payoff of m_c at the second stage if he rejects the client's offer at the first stage. If the client wants his offer to be accepted by the contractor, his offer should be between the present value of the maximum (PV_{M_c}) and minimum (PV_{m_c}) contractor's payoffs at the second stage, where $\mathrm{PV}_{M_c} = \delta_c M_c$ and $\mathrm{PV}_{m_c} = \delta_c m_c$. δ_i is the ith player discount factor. This transfers the value of the next stage to the present value and is defined as $\delta_i = \frac{1}{1+r_i}$, where r_i is the rate of return or time preference for player i, and $0 \leq \delta_i \leq 1$. A larger δ_i, means that the player is more patient and, in fact, indicates the bargaining power of the players [18]. The maximum and minimum of the client's payoffs are calculated as given below:

$$M_o \leq S - \delta_c m_c, \tag{1}$$

$$m_o \geq S - \delta_c M_c, \tag{2}$$

where S is the total benefit for which the players are bargaining. If the contractor rejects the client's offer, he will make a counteroffer. At the second stage, the contractor is aware of the maximum (PV_{M_o}) and minimum (PV_{m_o}) of the client's payoffs at the third stage. Therefore, the contractor's reasonable offer should be between $\mathrm{PV}_{M_o} = \delta_o M_o$ and $\mathrm{PV}_{m_o} = \delta_o m_o$.

The maximum and minimum of the contractor's payoffs are given below:

$$M_c \leq S - \delta_o m_o, \tag{3}$$

$$m_c \geq S - \delta_o M_o. \tag{4}$$

If the bargaining process were continued, the odd and even stages would be similar to the first and second stages, respectively. By applying $(-\delta_c)$ to Eq. (3) and comparing with Eq. (2), the results are as follows:

$$S - \delta_c M_c \geq S - S\delta_c + \delta_c\delta_o m_o, \tag{5}$$

$$m_o \geq S - \delta_c M_c \geq S - S\delta_c + \delta_c\delta_o m_o, \tag{6}$$

$$m_o \geq \frac{(1-\delta_c) \times S}{1-\delta_o\delta_c}. \tag{7}$$

Additionally, by applying $(-\delta_c)$ to Eq. (4) and comparing with Eq. (1), the results are as follows:

$$S - \delta_c m_c \leq S - S\delta_c + \delta_c\delta_o M_o, \tag{8}$$

$$M_o \leq S - \delta_c m_c \leq S - S\delta_c + \delta_c\delta_o M_o, \tag{9}$$

$$M_o \leq \frac{(1-\delta_c) \times S}{1-\delta_o\delta_c}. \tag{10}$$

Therefore:

$$M_o = m_o = \frac{(1-\delta_c) \times S}{1-\delta_o\delta_c}, \tag{11}$$

$$M_c = m_c = S - \frac{(1-\delta_c) \times S}{1-\delta_o\delta_c} = \frac{\delta_c(1-\delta_o) \times S}{1-\delta_o\delta_c}. \tag{12}$$

So, if at the first stage of the bargaining process, the client who initiates the bargaining makes an $S_c = \frac{\delta_c(1-\delta_o)\times S}{1-\delta_o\delta_c}$ offer, it would be acceptable for the contractor, and the client payoff would be $S_o = \frac{(1-\delta_c)\times S}{1-\delta_o\delta_c}$.

Stage 4: Determination of players' discount factors using a fuzzy inference system. The final results of the bargaining are highly dependent on the players' discount factors. In the other words, the value of the discount factor plays an important role in the final results and whether an equitable agreement is reached.

In this research, the value of the discount factor is assessed using a Fuzzy Inference System (FIS), based on the values of the input factors. The FIS performs approximate reasoning with imprecise or vague dependencies and commands. A fuzzy inference method consists of all the steps required to map some input to a crisp output by using fuzzy logic [19]. In this research, a "Mamdani style" inference mechanism [20] is implemented to determine the value of the players' discount factors. The fuzzy inference system consists of three major components: fuzzification, inference mechanism and defuzzification [21].

These stages will be explained below, in Stage 3 of the case study.

Stage 5: Quantitative risk allocation between the client and contractor. Having performed stages 1 to 4, a bargaining process is performed between the contractor and client considering the common interval, and, finally, a desirable and equitable percentage of risk allocation is determined.

3. Model application

To evaluate the performance of the proposed risk allocation model, it was implemented in a 150 km pipeline project, namely, the Dez-Qomrood Water Transmission Tunnel Project, which was carried out to transfer water from the sources of Dez and Karoon. The project is located in Iran and was constructed in 2012. The contract is on a unit price basis equal to 650,000 dollars per kilometre. According to preliminary estimates, the project would be executed within 930 days. In this project, the quantitative risk allocation process was performed for inflation risk; one of the most significant identified risks.

Stage 1: Determination of players' payoffs using SD approach. To determine the players' payoffs at different percentages of risk allocation, first, a qualitative model of different factors affecting the players' payoffs was developed. The qualitative model of the players' payoffs for inflation risk, which is one of the most important identified risks, is presented in Figure 2 [22]. SD consists of components, including the causal loop diagram, the stock and flow diagram and level and rate variables [23]. As shown in this figure [22], both the client and contractor costs consist of workforce, equipment and material costs. In the event of inflation risk, the workforce, equipment and material costs will increase, leading to an increase in the client and contractor costs (Figure 2).

The client and contractor costs are also influenced by the defensive strategies that may be implemented by the contractor against one-sided risk allocation. As shown in Figure 2, the amount of cost overrun arising from the inflation risk is shared by the contractor and client, based on the specified risk allocation percentage. Because of the cost overrun caused by the occurrence of inflation risk, the contractor may implement alternative defensive strategies, such as lowering work quality, lodging claims, dispute and litigation (Figure 2).

These defensive strategies may reduce contractor cost overruns arising from inflation risk. However, the

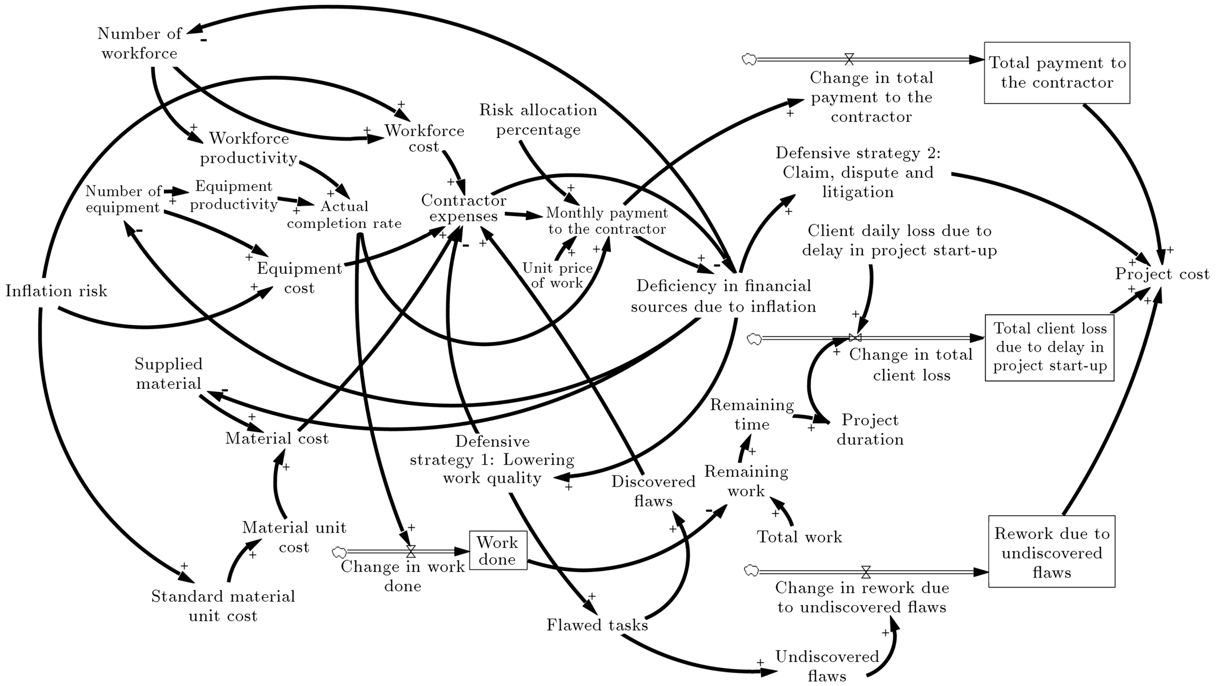

Figure 2. The cause-effect loops of qualitative model of players' payoffs at different percentages of risk allocation.

client costs arising from inflation risk are increased due to these defensive strategies.

Having constructed the qualitative model of player payoffs at different risk allocation strategies, the mathematical relationships (model equations) that exist between different factors were determined, so that the player payoffs at different risk allocation strategies could be efficiently modelled, simulated and quantified using the proposed SD modelling approach. Table 1 represents the simulated values of player payoffs at different percentages of risk allocation.

Stage 2: Determination of a common interval between the players' acceptable risk allocation percentages. Having determined the values of the players' payoffs at different percentages of risk allocation, the acceptable interval of risk allocation percentages was chosen by the client (R_o) and contractor (R_c) as follows:

$$25 \leq R_o \leq 60, \tag{13}$$

$$50 \leq R_c \leq 100. \tag{14}$$

The common interval existing between the players' acceptable risk allocation percentages was finally determined to be from 50 to 60.

Stages 3, 4: Determination of players' discount factors and bargaining within the common interval. The fuzzy inference system was first used to determine the value of the players' discount factor,

Table 1. The payoffs for the client and contractor (consequences of inflation risk) at different percentages of risk allocation.

Risk allocation to the client	Client costs ($)	Contractor costs ($)
0%	24672000	23999300
5%	24177000	22777300
10%	21723000	21247300
15%	21607000	20451300
20%	21503000	19433300
25%	19610000	17817300
30%	19608000	16885300
35%	19180000	15606300
40%	19140000	14543300
45%	18572000	13382300
50%	18722000	12044300
55%	19722000	10946300
60%	19766000	9660300
65%	20641000	8524300
70%	21119000	7335300
75%	21301000	6098300
80%	21681000	4821300
85%	22376000	3648300
90%	22739000	2426400
95%	23462000	1226000
100%	24126000	0

Table 2. The value of input factors affecting the client's discount factor (the values are based on a scale from 1-10).

Input factors	Value
Contractor's past performance	7
Work specialty	8
The significance of project commencement date	3

Table 3. The value of input factors affecting the contractor's discount factor (the values are based on a scale from 1-10).

Input factors	Value
Contractor's expertise in specific works	4
Demand to a new project	6
Contractor's past performance	7

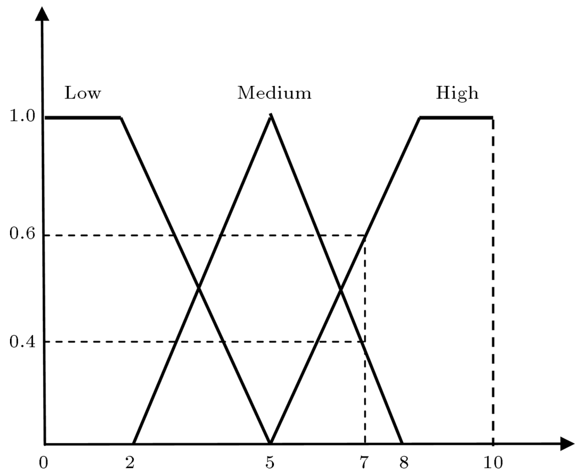

Figure 3. Membership functions of input factors affecting the client and contractor discount factors.

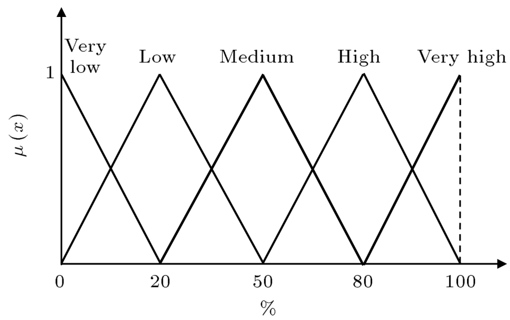

Figure 4. Membership functions of client and contractor discount factors.

based on the values of different influencing factors. Based on the interview conducted for this project, the most important factors affecting the client's discount factor were determined to be the significance of the project commencement date, work skills and the past performance of the contractor. Similarly, the most important factors affecting the contractor's discount factor were determined to be the contractor's expertise in specific work; the demands to a new project and the past performance of the contractor. Tables 2 and 3 show the values of the input factors affecting the client's and contractor's discount factors, respectively.

The players' discount factor was determined using three steps, namely, fuzzification, inference and defuzzification, as explained below.

Fuzzification: On the basis of fuzzy set theory, the possibility for a variable to belong to a group is the degree of membership of the variable in the fuzzy set [24]. The fuzzification module transforms the input data into a linguistic form. The terms of the linguistic variables are fuzzy sets with a certain shape [25]. It is popular to use trapezoidal or triangular fuzzy sets because of computational efficiency [21].

Figure 3 shows the membership function values for the variation of three input factors that affect the client and contractor discount factors. For example, if the contractor's past performance is chosen as 7 by the expert, it means that the contractor's past performance belongs to high and medium, with a confidence level of 0.6 and 0.4, respectively (Figure 3). Similarly, Figure 4 shows the membership function values for the variation of the output variable (discount factor).

Fuzzy inference mechanism: The fuzzy inference mechanism identifies the rules that apply to the fuzzified values of the input variables and deducts the output linguistic terms that describe the status of the output variable [26]. In other words, these rules connect the fuzzified inputs to fuzzy outputs. Tables 4 and 5 show the rules used for determining the client and contractor discount factors, respectively. In these tables, VH is "very high", H is "high", M is "medium", L is "low" and VL is "very low". There exist a total number of 27 fuzzy control rules for each player. As an example, rule 1 is expressed as follows.

If the significance of the project commencement date = Low, work specialty = Low and contractor's past performance = Low, then, the client's discount factor = Very High (Table 4).

Defuzzification: Defuzzification is the process of producing a non-fuzzy number; a single value that adequately represents the fuzzy number [27]. The centre of area method was utilized for defuzzification of the fuzzy sets determined by the inference mechanism.

Using the proposed defuzzification method, the value of the client's discount factor (δ_o) was calculated as 70.1%. Similarly, the value of the contractor's discount factor (δ_c) was calculated as 45.8%. Figure 5 graphically depicts the fuzzification, inference and defuzzification process performed for determining the contractor's discount factor.

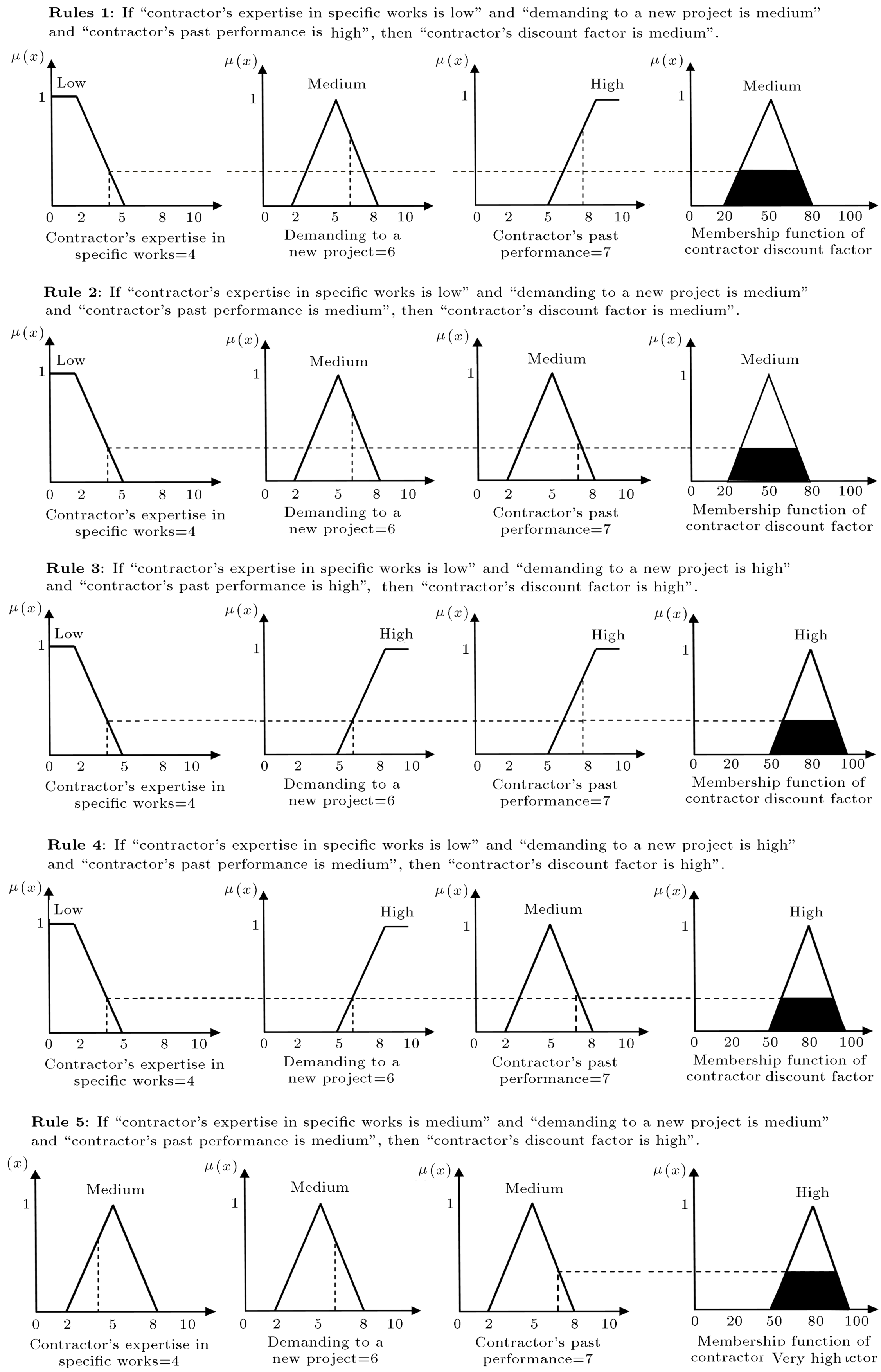

Figure 5. Fuzzification, inference and defuzzification process performed for determining contractor's discount factor.

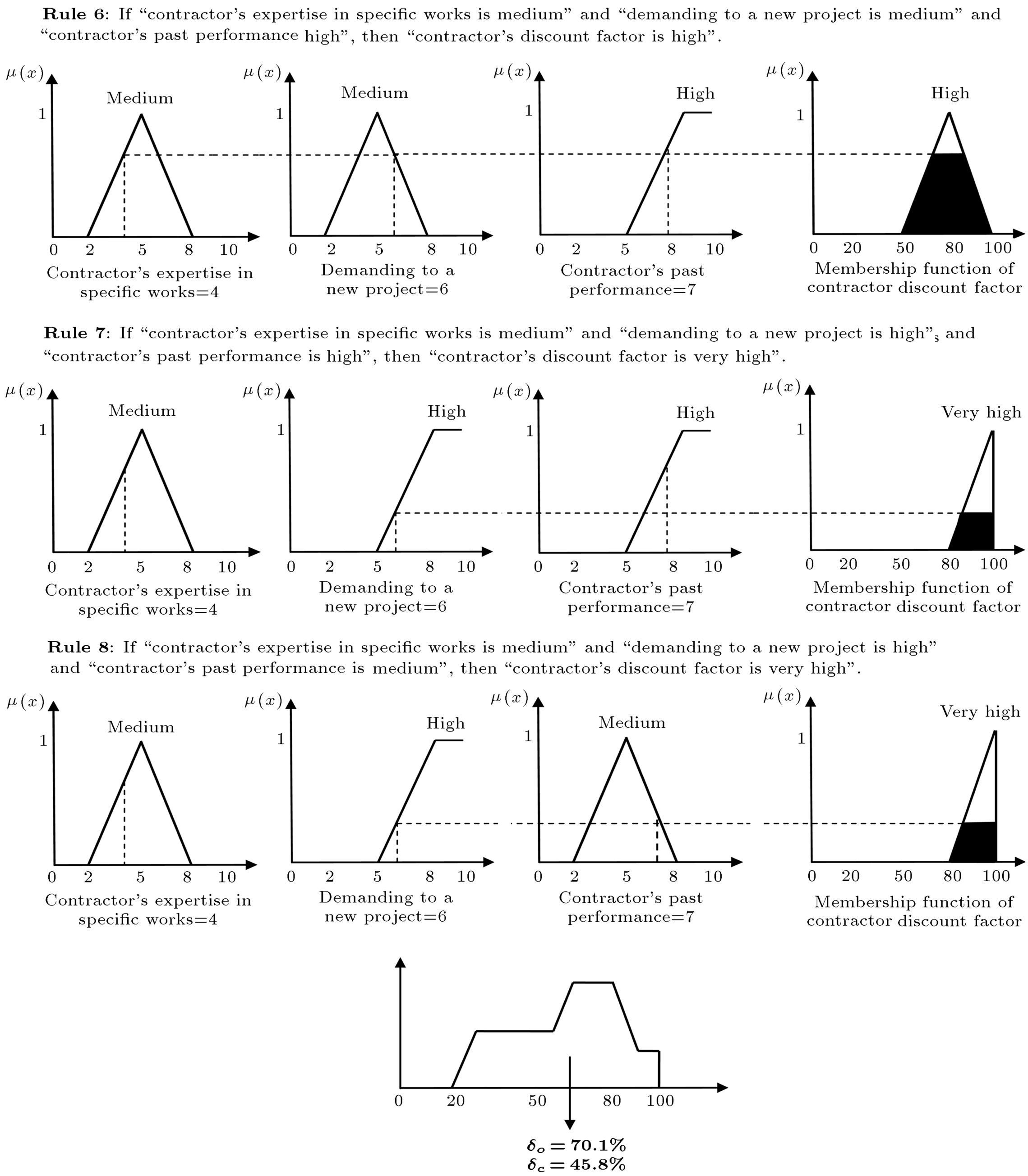

Figure 5. Fuzzification, inference and defuzzification process performed for determining contractor's discount factor (continued).

Having determined the client and contractor discount factors, bargaining was performed on the common interval existing between the players' acceptable risk allocation percentages to produce a desirable and equitable risk allocation strategy. The common interval existing between the players' acceptable risk allocation percentages was finally determined to be from 50 to 60. Therefore, the desirable and equitable percentage of risk allocation will be in the range of 50 to 60, and the bargaining would be performed within this common interval to determine the desirable and equitable percentage of risk allocation.

In fact, the players bargain on the benefit of $S = 10\%$. This benefit is shared between the client and contractor using Eqs. (11) and (12) as follows:

$$S_o = \frac{(1-\delta_c)\times S}{(1-\delta_o\delta_c)},$$

$$S_o = 80\% \times 10\% = 8\%, \tag{15}$$

$$S_c = \frac{(1-\delta_o)\times S}{1-\delta_o\delta_c},$$

$$S_c = 20\% \times 10\% = 2\%, \tag{16}$$

Table 4. Fuzzy inference rules for the client's discount factor.

Client's discount factor	Input factors affecting client discount factor		
	Contractor's past performance	Work specialty	Significance of project commencement date
VH	L	L	L
H	L	M	L
L	H	H	L
M	M	M	M
M	L	H	M
L	H	H	M
L	H	L	H
L	M	M	H
VL	H	H	H

Notes: L: Low, M: Medium, H: High.

Table 5. Fuzzy inference rules for contractor's discount factor.

Contractor's discount factor	Input factors affecting contractor's discount factor		
	Contractor's past performance	Demand to a new project	Contractor's expertise in specific work
VH	L	H	L
M	H	M	L
L	M	L	L
L	L	H	M
H	M	M	M
H	H	L	M
H	M	H	H
M	L	M	H
VH	H	L	H

Notes: L: Low, M: Medium, H: High.

where S_o and S_c denote client and contractor shares from the benefit, respectively.

Stage 5: Quantitative risk allocation between the client and contractor. Finally, the percentages of the risk allocated to the client and contractor are calculated as follows:

$$R_o = 60\% - 8\% = 52\%, \tag{17}$$

$$R_c = 50\% + 2\% = 52\%, \tag{18}$$

where R_o and R_c denote the percentages of the risk allocated to the client and contractor, respectively.

It is, therefore, concluded that to have a desirable and equitable risk allocation strategy, 52 percent of the consequences associated with the inflation risk should be allocated to the client, and the remaining 48 percent should be allocated to the contractor.

The achieved result may represent the desirable and equitable percentage of risk allocation efficiently, since the behaviour of contracting parties in the risk allocation negotiation process is taken into account. It is believed that the proposed integrated SD-fuzzy bargaining model offers a powerful tool by which a win-win sharing of risk responsibilities between the client and contractor may be achieved.

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Conclusions and remarks

Construction projects involve different parties, such as the client, the contractor and the consultant. Each of these parties is responsible for, and should manage, certain risks. It is, therefore, necessary to allocate risks properly between the contracting parties before beginning the risk management process.

In this research, a new quantitative risk allocation approach was presented by integrating a system dynamics simulation scheme and fuzzy bargaining game theory. A system dynamics based model was employed to determine the contractor and client costs (the players' payoffs) at different percentages of risk allocation. The proposed SD model simulated the contractor and client costs, taking into account all influencing factors, as well as the contractor's defensive strategies against unfair risk allocation. Having determined the contractor and client costs at different percentages of risk allocation, an acceptable interval of risk allocation percentages was determined by each of the contracting parties (the players). The common interval between the players' acceptable risk allocation percentages was then determined. The players' discount factor was determined using a fuzzy inference mechanism. A bargaining process was then performed between the two parties considering the common interval, and a desirable and equitable percentage of risk allocation was finally determined.

To evaluate the performance of the proposed risk allocation model, it was implemented in a pipeline project, and quantitative risk allocation was performed for inflation risk; one of the most significant identified risks. It was concluded that a desirable and equitable risk allocation strategy is attained with 52 percent of the consequences associated with inflation risk allocated to the client, and the remaining 48 percent allocated to the contractor.

The proposed model accounts for the behaviour of contracting parties in the risk allocation negotiation process. It is believed that the proposed integrated SD-fuzzy bargaining model offers a powerful tool by which a win-win sharing of risk responsibilities between the client and contractor may be achieved.

References

1. Zou, P.X.W., Zhang, G. and Wang, J. "Understanding the key risks in construction projects in China", *International Journal of Project Management*, **25**(6), pp. 601-614 (2007).

2. Loosemore, M. and McCarthy, C.S. "Perceptions of contractual risk allocation in construction supply chains", *Journal of Professional Issues in Engineering Education and Practice*, **134**(1), pp. 95-105 (2008).

3. The American Council of Engineering Companies and the Associated General Contractors of America (ACEC), *Enlightened Risk Allocation* (2005).

4. Lam, K.C., Wang, D., Lee, P.T.K. and Tsang, Y.T. "Modeling risk allocation decision in construction contracts", *International Journal of Project Management*, **25**(5), pp. 485-493 (2007).

5. Levitt, R.E., Logcher, R.D. and Ashley, D.B. "Allocating risk and incentive in construction", *Journal of the Construction Division*, **106**(3), pp. 297-305 (1980).

6. Pipattanapiwong, J. "Development of multi-party risk and uncertainty management process for an infrastructure project", PHD Thesis, Kochi University of Technology, pp. 1-236 (2004).

7. Yamaguchi, H., Uher, T.E. and Runeson, G. "RISK allocation in PFI projects", *Proceedings of 17th ARCOM Annual Conference*, University of Salford, UK (2001).

8. Yelin, X.U., Albert, P.C.C. and Yeung, J.F.Y. "Developing a fuzzy risk allocation model for PPP projects in China", *Journal of Construction Engineering and Management*, **136**(8), pp. 894-903 (2010).

9. Jin, X.-H. and Zhang, G. "Modeling optimal risk allocation in PPP projects using artificial neural networks", *International Journal of Project Management*, **29**(5), pp. 1-13 (2010).

10. Medda, F. "A game theory approach for the allocation of risks in transport public private partnerships", *International Journal of Project Management*, **25**(3), pp. 213-218 (2007).

11. Nasirzadeh, F., Khanzadi, M. and Rezaie, M. "Dynamic modeling of the quantitative risk allocation in construction projects", *International Journal of Project Management*, **32**(3), pp. 442-451 (2014).

12. Nasirzadeh, F., Khanzadi, M. and Rezaie, M. "System dynamics approach for quantitative risk allocation", *International journal of industrial engineering and production research*, **24**(3), pp. 237-246 (2013).

13. Shen, L.Y., Bao, H.J., Wu, Y.Z. And Lu, W.S. "Using bargaining-game theory for negotiating concession period for BOT-type contract", *Journal of Construction Engineering and Management*, **133**(5), pp. 385-392 (2007).

14. Forrester, J., *Industrial Dynamics*, MIT Press, Cambridge, England (1961).

15. Sterman, J.D., *System Dynamics Modeling for Project Management*, MIT Press, Cambridge, England (1992).

16. Osborne, M.J. and Rubinstein, A., *A Course in Game Theory*, Fifth Ed., MIT Press, Cambridge, England (1998).

17. Rubinstein, A. "Perfect equilibrium in a bargaining model", *Econometrica*, **50**(1), pp. 97-109 (1982).

18. Fishburn, P.C. and Rubinstein, A. "Time preference. International economic review", **23**(3), pp. 677-694 (1982).

19. Sabounchi, N.S.Z., Triantis, K., Sarangi, S. and Liu, S. "Fuzzy modeling of linguistic variables in a system dynamics context", *Proceedings of 29th International Conference of the System Dynamics Society*, Washington, DC: System Dynamics Society (2011).

20. Mamdani, E.H. and Assilian, S. "An experiment in linguistic synthesis with a fuzzy logic controller", *International Journal of Man-Machine Studies*, **7**(1), pp. 1-13 (1975).

21. Zimmermann, H.J., *Fuzzy Set Theory and Its Application*, Forth Ed., Kluwer Academic Publishers, Boston, Drodrecht and London (2001).

22. Nasirzadeh, F., Khanzadi, M. and Rezaie, M. "System dynamics approach for quantitative risk allocation", *International Journal of Industrial Engineering and Production Research*, **24**(3), pp. 237-246 (2014).

23. Youssefi, H., Saeid Nahaei, V. and Nematian, J. "A new method for modeling system dynamics by fuzzy logic: Modeling of research and development in the national system of innovation", *Journal of Mathematics and Computer Science*, **2**(1), pp. 88-99 (2011).

24. Shen, L., Wu, Y. and Zhang, X. "Key assessment indicators for the sustainability of infrastructure projects", *Journal of Construction Engineering and Management*, **137**(6), pp. 441-451 (2011).

25. Nasirzadeh, F., Afshar, A., Khanzadi, M. and Howick, S. "Integrating system dynamics and fuzzy logic modeling for construction risk management", *Journal of Construction Management and Economics*, **26**(11), pp. 1197-1212 (2008).

26. Li, J., Moselhi, O.P.E. and Alkass, S.P.E. "Forecasting project status by using fuzzy logic", *Journal of Construction Engineering and Management*, **132**(11), pp. 1193-1202 (2006).

27. Nieto-Morote and Ruz-Vila, F. "A fuzzy approach to

construction project risk assessment", *International Journal of Project Management*, **29**(2), pp. 220-231 (2011).

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