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Multi Agent System Based Risk Allocation Model for Public-Private-Partnership Type Projects (RAMP^3)

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ABSTRACT

The performance of the Public Private Partnership (PPP) projects depends on the efficiency of the risk allocation strategies between the public and private parties. Therefore, a multi agent system-based Risk Allocation Model for PPP projects (RAMP^3) was developed to determine the proper risk allocation decisions between the public and private parties within the study. The methodology of RAMP^3 involves i) identification of risks by agents, ii) assessment of each risk's importance and impact, iii) communication of agents to negotiate on risk allocation decision and iv) determination of strategies and utility functions to be used in negotiation process. Focus of the study is presenting the steps of negotiation process of agents using economic theory and Zeuthen bargaining strategy. RAMP^3 was validated on two real PPP projects and results show that the higher risk value of an agent gets, agent's utility due to counter agent in that concession round lowers. Preliminary findings also show that risk is allocated to the party that has a higher risk acceptability in negotiation process. The RAMP^3 will enable project parties to determine the appropriate risk allocation strategies by considering the effects of emerging risks in terms of time delay, cost overrun and conflict and provide contract success. The model can also be used as a decision support system by public partner for performing an efficient and accurate risk allocation.

Keywords: Construction industry, construction projects, Multi-Agent System (MAS), Public Private Partnership (PPP), risk management.

1. INTRODUCTION

Growing population and urbanization create a need for infrastructure investments along with improvement of the existing ones. Upon considering the increased infrastructure requirements along with the economic growth targets, Public Private Partnership (PPP)

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projects has been identified as an important potential by experts in terms of maintaining sustainable performance of the construction industry.

Despite being a financial model developed for establishing the public investments, PPP models are considered as a contract type that determine the rights, responsibilities and privileges between the public and the private sectors. Therefore, contracts between the public and the private sectors are important for ensuring effectiveness and efficiency during the entire lifecycle of the project [1], [2] along with resolving risk allocation problems which has the potential to affect the long term and stable cooperation between stakeholders in PPP projects [3], [4].

Risk management is important in each construction project. However, it plays a more outstanding role in PPP projects, since they are implemented as long-term contracts where the risks are distributed between the public and the private sectors appropriately. The performance of PPP infrastructure projects depends upon the efficiency of the risk distribution strategies adopted between the public and the private sectors and how the risks are balanced on the contracts within this context. Therefore, considering the long-term impacts of risk allocation decisions, the associated risks should be assigned to the stakeholder that is able to manage the risk better via contract [5]. However, it is observed that the principle of assigning the risk to the stakeholder that would manage it better is not practiced in general due to the disagreements between the project stakeholders based on their risk management skills [6], [7]. Thus, risk allocation process in PPP projects is generally implemented based on subjective interpretation of the parties. To overcome this shortcoming, there is a significant need for risk allocation models that determine which stakeholder (public or private sector) should manage the potential risks in PPP projects based on the possible impacts of the risks on the parties and risk allocation attitudes of the parties. However, it is observed that parameters such as risk sharing attitudes, risk management capacities of the stakeholders, contract conditions, etc. are not often addressed by the previous risk management studies related to PPP projects.

Within this background, a multi agent system-based Risk Allocation Model for PPP projects (RAMP^3) was developed to simulate the risk assessment process for PPP projects. RAMP^3 allows establishing realistic risk assignments by exhibiting how the general risks regarding PPP projects should be shared between the parties based on the different objects, goals, utilities, motivation, and knowledge-skill levels of each parties. The multi agent-based risk sharing system of RAMP^3 ensures inclusion of the decisions regarding the risk assignment in the contract at the end of the negotiations carried for each individual risk between the parties regarding the assignment of the relevant risk in PPP projects. The advantages of RAMP^3 for the construction companies comprise; achieving contractual success in PPP projects and determining appropriate risk allocation strategies based on the assessment of potential time, cost, and disputes. Another important advantage of RAMP^3 is that it can be used as an auxiliary tool for early identification and effective management of potential risk factors in PPP projects.

2. MULTI AGENT SYSTEMS (MAS)

Multi Agent Systems (MAS) consist of multiple autonomous units called agents that interact with each other to increase utility or to achieve a common goal. An agent is a computer system capable of autonomous action in some environment. Multi agent systems are also considered as a fast-developing information technology, where several intelligent agents, representing the real-world parties, co-operate, negotiate, or compete to reach a common agreement, purpose or plan [8]. Achieving the common goal can be done either by cooperation where knowledge is shared among agents or by competition where knowledge is not shared. The following are the essential characteristics of agents that make them ideal for supporting cooperation, coordination, and negotiation:

- **Autonomy** - agents can operate without the direct intervention of humans or others and have control over their actions and internal state.
- **Reactive** - agents maintain an ongoing interaction with its environment and respond to the changes that occur in the environment.
- **Pro-activeness** - agents do not simply act in response to their environment, they attempt to achieve their goals.
- **Social ability -** agents can interact with other agents via agent communication language such as cooperate, coordinate, and negotiate with others.
- **Ability to learn -** agents can learn and update their information when interacting with the external environment [9].

2.1. MAS Use in Construction Management Literature

MAS can solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Therefore, in recent years, there is an increasing tendency in construction management literature to use MAS due to their ability to provide robustness and efficiency and to solve problems in which data, expertise, or control is distributed [8]. The construction industry requires multiple parties who should work together to execute a construction project (such as employer, designer, contractor, subcontractor etc.). Considering that those parties are mostly geographically diverse and have different perspectives and/or objectives about the project, it becomes crucial to use distributed problem-solving systems with multi agents to simulate the characteristic of construction projects [10]. Thus, multi-agent systems have considerable potential to address some of the fragmentation of the construction industry. In this context, many researchers in construction management area applied MAS in their research for solving distributed problems of the industry. General application of MAS methodology is used for solving construction engineering and management problems that involves a negotiation process between parties. Claim management, supply chain management, and risk management are some of the research fields that MAS is commonly used in construction management area.

2.2. MAS Use in Risk Management Literature

Although the studies related to risk management area generally aim to provide conceptual frameworks about risk allocation decisions, there should be more efforts for establishing decision support systems and developing risk management models by using information technologies. Thus, more systematic and realistic risk management models should be established. It is seen that the number of studies adopting MAS in risk management area for construction industry is quite limited [10]. Chengshuang and Guochang [11] created a MAS based risk management system for construction projects in terms of the analysis of risk characteristics and management process of construction projects. Li and Ren [12] discussed the general procedure, the principles of risk allocation between the public client and the private consortium in a PPP project. They suggest that Bayesian approach, which is considering the responding information from the opponent, is more suitable in dynamic decision making for risk allocation. Karakas et al. [13] also developed MAS that simulates the negotiation process between parties (mainly contractor and client) about risk allocation and sharing of cost overruns in construction projects. Taillandier et al. [14] proposed a multi-agent model coupled with a stochastic approach with the aim of evaluating risk impacts for each stakeholder and for the whole construction project. Proposed model test different risk mitigation strategies to measure their interest and then to support risk management decisions. The main reason for developing this model is that the risks affecting construction projects are varied throughout the different phases of the project and there is more than one interaction between the risks.

In addition, risk management models developed by using MAS frequently used as decision-making processes and focus on risk-cost sharing or resolution of disputes between parties [11], [12], [13], [14], [15], [16], [17]. RAMP^3 model developed within the scope of this study is a decision support system that can be used primarily by decision makers like the existing models in the literature. However, rather than deciding which stakeholder should manage cost increases due to risks, it offers a decision support system for determining risk allocation decisions depending on impact of each risk on the project's success criteria along with the risk attitudes of the parties. In this context, it is possible to simulate the risk sharing process among the project participants and to identify risks that should be assigned to the stakeholder that is able to manage the risk better by the contract between the public and the private sectors. Considering that risk allocation studies for PPP construction project with MAS adaptation is relatively limited, the multi agent-based risk allocation model developed within the scope of this study aims to fill an important gap in the literature. In existing studies related to risk management area, parameters such as risk sharing attitudes, risk management capacities, contract conditions, etc. are often not addressed. However, within the scope of effective risk management, more than one project participant with different utility functions should be identified and the communication rules between them must be determined [16]. In this context, RAMP^3 model can be used as a decision support system for determining the risk allocation strategies of the project parties by evaluating risk factors specific to PPP transport projects according to project parties' objectives, knowledge-ability levels along with the impact of risk factors such as time extension, cost increase and conflict.

3. DESIGN OF RAMP^3 MODEL

RAMP^3 consists of "agents" that are negotiating with each other to undertake or transfer risks depending on criteria such as contract, utility, risk attitudes and stakeholders' knowledge and management skills related to specific risk factor. RAMP^3 ensures the final risk sharing decisions as a result of the negotiation process depending on the risk response of the stakeholders and reflect risk sharing decisions to the contract. Therefore, RAMP^3 consist of stages such as i) identification of risks by agents, ii) assessment of each risk's importance and impact, iii) communication of agents to negotiate on risk allocation decision and iv) determination of strategies and utility functions to be used in negotiation process. Since the focus of this study is presenting negotiation process of agents (and steps it involves) through the designed RAMP^3 model, detailed information regarding the first two stages were excluded (However, Table 1. shows the overall findings related to identification of risk factors affecting PPP construction projects and their predicted weights).

Within the architectural structure of the RAMP^3, model constitutes four main agents representing concessionaire (private sector), public institution, contract, and risk factors. The architectural structure of the RAMP^3 is explained in detail below:

- **Risk factor agent:** This agent allows user to display information regarding all the risks and importance level of the risks that may affect the PPP project. Within this context, all risk factors affecting PPP projects through their life cycle were identified initially (Table 1). This agent delivers the relevant information to the agent representing public institution and the concessionaire to be used in the negotiation process.
- **Concessionaire agent:** The main purpose of this agent is to negotiate with the agent representing public institution to finalize the risk assignment result of the relevant risk. This agent obtains information related to the importance of each risk factor and calculates the impact of each risk factor. This agent negotiates with the agent representing public institution depending on criteria such as knowledge, organization, and management skills of the concessionaire. The agent also communicates with the agent representing the project contract to ensure that the risk allocation decision is concluded as a contract clause.
- **Public institution agent**: The main purpose of this agent is to negotiate with the agent representing concessionaire to finalize the risk assignment result of the relevant risk. This agent obtains information related to the importance of each risk factor and calculates the impact of each risk factor. This agent negotiates with the agent representing concessionaire depending on criteria such as knowledge, organization, and management skills of the public institution. The agent also communicates with the agent representing the project contract to ensure that the risk allocation decision is concluded as a contract clause.
- **Project contract agent**: This agent represents the terms of the project contract. User can display all the risk factors and risk allocation decisions related to the project. In addition, this agent coordinates with risk factors agent to find out if there are any risk factors not included in the contract draft. In addition, the contract intermediary provides the materialization of the associated issues if any, not included in the contract draft text but as a result of the information received from the risk factors intermediary. If any risk allocation decisions of the associated risk factors have not been discussed in the contract draft, this agent gives an alert to the user.

Figure 1 shows the overview diagram of the negotiation process in the RAMP^3. There is only information flow from risk factor agent to the agents representing public institution and concessionaire. The negotiation process only takes place between public institution agent and concessionaire agent. The process ends when the related risk allocation decision is made. The risk allocation decisions given as a result of the negotiation process is conveyed to the contract agent. Thus, the parties responsible for the risk factors are determined in the contract text. Within the RAMP^3 model, the risk factor agent is responsible for identification of the project-specific risks whereas public institution and concessionaire agents are responsible for initiating the negotiation process by estimating the time and cost increase in case of the occurrence of risk.

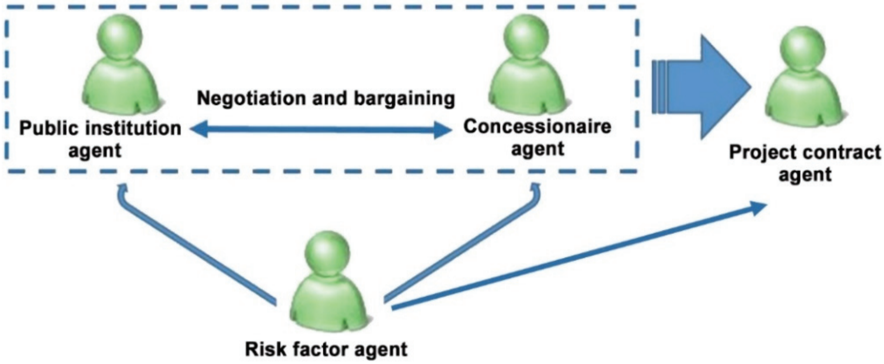

Figure 1 - The overview diagram of the negotiation process in the RAMP³ model

The architecture of the RAMP³ model was realized in Python programme. Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built-in data structures, combined with its object-oriented approach help programmers write clear, logical code for small and large-scale projects [18]. An empirical study found that scripting languages, such as Python, are more productive than conventional languages, such as C++ and Java, for programming problems involving string manipulation and determined that memory consumption was often better than Java and not much worse than C++ [19]. The fact that python is commonly preferred to C++ or Java in cases where prototypes of large software have to be produced and tested quickly was effective in selecting this program.

4. SYSTEM IMPLEMENTATION OF RAMP³ MODEL

The output of multi agent system-based platform is the reflection of risk allocation decisions specific to PPP projects to the contract as a result of the negotiation process between the public and private sector parties. Since negotiation process between agents within the RAMP³ model is one of the most important factors affecting the results produced by the system, sub-topics such as negotiation process, negotiation theories, concession protocols in negotiations, bargaining strategies, conflict deal and flowchart of negotiation process that will guide the communication and decision-making processes of the agents should be detailed.

4.1. Negotiation Process

One of the critical stages in successful risk mitigation and fairly distribution is the capturing of the dynamics in negotiation process. The basic elements of the negotiation are defined as the interest, social motivates of the participants and their interactions [20]. Through negotiation, parties try to find a settlement point, from several options, that is acceptable for both parties. Risk allocation in a multi-agent environment can also be considered as a form of negotiation [10]. Each negotiation has a start point (target), an end (agreement or disagreement) and a series of steps (offers) in between. To direct these steps, negotiators should be conscious of its characteristics and steps [17]. The factors influencing the decisions of the agents representing public institution and concessionaire are essential to understand their target values and minimum amounts that they can accept. Concessionaire agent's target is to compensate almost all his losses, while public institution agent wants to complete the project with minimum additional payments. Negotiation will take place only if there is possible agreement zone between the defined positions (Figure 2).

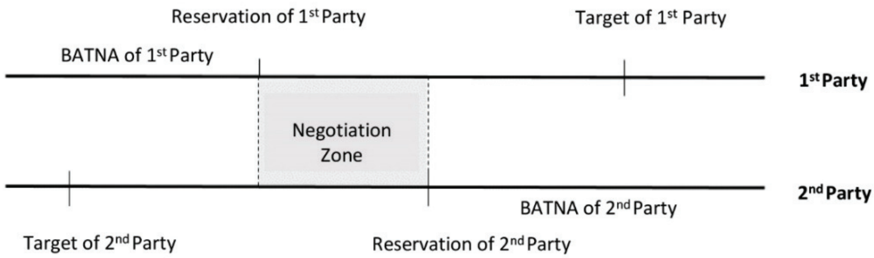

Figure 2 - Negotiation terms [17]

- **Target (Optimum) Value:** The highest amount that a party aimed to take from the negotiation is named as "target" and it will be the initial proposal of the parties. Calculation of initial offer is important, as the parties cannot suggest any more improvement during the negotiation process.
- **Reservation Value:** The minimum value that a party is willing to accept in negotiation is named as reservation value. Reservation value is closely related with Best Alternative to Negotiated Agreement (BATNA). BATNA defines what will happen in case of a conflict in negotiation, therefore parties need to know their BATNA to assess whether the incoming offer is acceptable or not. Defining reservation point before the negotiation is a key factor in successful negotiation. By determining reservation value, parties are protecting themselves from accepting an unfavorable option during negotiation.

  In RAMP^3 model, each agent calculates its reservation value considering risk weight of each risk factor and risk impact that can be expressed as the loss if the risk occurs. The reservation value (RV) proposed by each agent at the beginning of the negotiation process, is calculated by using Equation (1) and (2).

RV = Risk Weight x Risk Impact (1)

$$\text{Risk Impact} = \sqrt[3]{(x_1 y_1)(x_2 y_2)(x_3 y_3)} \tag{2}$$

where x_1, x_2, x_3 indicates risk weight considering time extension, cost increase and claim for the relevant risk respectively; y_1, y_2, y_3 the value of the loss to be incurred in terms of time extension, cost increase and claim respectively.

RAMP[3] was developed to determine the proper risk allocation decisions between the public and private parties for PPP projects. With this aim, all risk factors related to PPP projects were identified through a comprehensive literature review. As the result of comprehensive literature review, total number 99 risk factors were identified under 12 categories. Users can eliminate or add new project-specific risks by using risk factor agent in RAMP[3] model. Determined risk factors were conveyed to the risk factor agent within the RAMP[3] model. The predicted weight of each risk factor was calculated using Fuzzy Analytical Hierarchy Process (FAHP). For the details of FAHP calculations of determined risk factors, please see [29]. The predicted weight of each risk factor is presented to the model user within the RAMP[3] model. However, users can determine risk weight of each project specific risk factor. Table 1 shows Exogenous risk factors affecting PPP construction projects and their predicted weights as an example.

Table 1 - Exogenous risk factors affecting PPP construction projects [29]

	Risk Categories	**Risk Factors**	**Risk Weights**
Exogenous Risks	**1. Political Risks**	1. Political instability	0,202
		2. Lack of national strategies	0,243
		3. Termination of concessionaire by public institution	0,293
		4. Political opposition	0,262
	2. Legal Risks	5. Inadequate legal framework:	0,099
		6. Lack of law and regulations specific to PPP	0,118
		7. Changes in law and regulations	0,113
		8. Environmental and Social Impact Assessment	0,123
		9. Failure/delay in obtaining permit/approval	0,159
		10. Ownership assets	0,119
		11. Expropriation	0,151
		12. Uncompetitive tender	0,118
	3. Macro-Economic Risks	13. Importance for local economy	0,167
		14. Instability of national economy	0,097
		15. Fluctuation of the inflation rate	0,071
		16. Fluctuation of interest rate	0,140
		17. Currency risk	0,187
		18. Taxation risk	0,085
		19. Loan risk	0,159
		20. Fluctuation of the labor, material, equipment prices	0,095
	4. Socio-Cultural Risks	21. Socio-cultural differences in the host country	0,294
		22. Socio-cultural differences between JV partners	0,310
		23. Social opposition to the project	0,396
	5. Industry-Specific Risks	24. Demand changes	0,246
		25. Level of competition	0,234
		26. Market share of the project stakeholder	0,268
		27. Presence of supporting sectors	0,252
	6. Natural Risks	28. Force Majeure	0,272
		29. Unexpected weather conditions	0,224
		30. Unexpected geological conditions	0,251
		31. Unexpected site conditions (archeological finds etc.)	0,253

Table 1 - Exogenous risk factors affecting PPP construction projects (continue) [29]

	Risk Categories	Risk Factors	Risk Weights
Endogenous Risks	1. Project Management Competence Risks	1. Project time management	0,063
		2. Project cost management	0,060
		3. Project quality management	0,061
		4. Project human resource management	0,039
		5. Project communications management	0,058
		6. Project risk management	0,078
		7. Project procurement management	0,056
		8. Project stakeholder management	0,069
		9. Contract and dispute management	0,074
		10. Demand management	0,077
		11. Process and documentation management	0,063
		12. Occupational health and safety management	0,057
		13. Waste and energy management	0,071
		14. Innovation management	0,067
		15. Operational management	0,106
	2. Competency Related Risks	16. Organizational expertise and capabilities of the parties	0,070
		17. Tendering and pricing ability of the parties	0,090
		18. PPP experience of public institution	0,021
		19. PPP experience of private partners	0,149
		20. Skilled workforce	0,150
		21. Financial adequacy of the partners	0,110
		22. Financial adequacy of the subcontractors	0,082
		23. Technical competency	0,178
		24. Know-How based on new technology and innovation applications	0,151
	3. Organization and Coordination Risks	25. Improper partner selection	0,098
		26. Incompetent contractor selection	0,085
		27. Incompetent supplier selection	0,064
		28. Lack of cooperation and communication between stakeholders	0,078
		29. Project objective/purpose differences between stakeholders	0,076
		30. Improper risk allocation decisions	0,079
		31. Lack of commitment between stakeholders	0,079
		32. Know-how/working method differences between stakeholders	0,067
		33. Inadequate relationships with industry (trade unions)	0,076
		34. Inadequate relationships with employer (public)	0,086
		35. Inadequate relationships with stakeholders	0,074
		36. Inadequate relationships with NGOs	0,075
		37. Inadequate relationships with end user (society)	0,064

Table 1 - Exogenous risk factors affecting PPP construction projects (continue) [29]

	Risk Categories	Risk Factors	Risk Weights
Endogenous Risks	4. Financial Risks	38. Purchasing guarantees by public institution	0,070
		39. Financial attractiveness of the project	0,075
		40. Revenue (income) risk	0,071
		41. Payment mechanisms	0,065
		42. Investment costs	0,075
		43. Unit costs	0,068
		44. Finance issues related to cost increase	0,062
		45. Bankruptcy/insolvency of stakeholders	0,073
		46. Additional costs related to fast-track construction	0,069
		47. High costs (bidding costs, design and construction costs, operational costs)	0,068
		48. Residual value	0,041
		49. Instability of financial structure	0,067
		50. Lack of credibility of stakeholders	0,064
		51. Inability of debt service	0,063
		52. Wrong estimation of cost trade-offs	0,069
	5. Contractual Risks	53. Redundancy in contract variations	0,208
		54. Contract content	0,155
		55. Different interpretation of the agreement by the parties	0,199
		56. Insufficient plans and specifications	0,239
		57. Lack of a definitive dispute resolution process	0,199
	6. Design and Construction Risks	58. Delays, uncertainties and inconsistencies in design and construction phases	0,064
		59. Improper design (deficient and defective design)	0,103
		60. Excessive design variations	0,105
		61. Occupational accidents	0,108
		62. Improper technology use	0,082
		63. Delays in procurement	0,097
		64. Construction changes	0,101
		65. Lack of supportive facilities	0,068
		66. Lack of supportive infrastructural facilities	0,080
		67. Integration between design and construction phases	0,108
		68. Technical construction risks	0,083

- **First (Initial) Offer:** The first offer is the initial offer given by an agent. This value defines the highest utility for the agent. The concessionaire agent's first-offer value is always higher than its reservation value. For the public institution agent, its reservation value is always higher than its initial value. The initial offer value proposed by each agent at the beginning of the negotiation process, is calculated by using Equation (3) and (4).

$$FO_{Ca} = RV + (RV \times RA) \quad (3)$$

$$FO_{PIa} = RV - (RV \times RA) \quad (4)$$

where FO_{Ca} / FO_{PIa} = The First Offer given by concessionaire/public institution agent, RV= Reservation Value of concessionaire/public institution agent; RA = Risk Attitude of concessionaire/public institution agent. Risk attitude value shows the willingness of each agent for taking the risk over depending on their ability to manage that risk. The numerical values for risk attitude are 0.1 for very low; 0.3 for low; 0.5 for medium; 0.7 for high; 0.9 for too high.

- **Concession:** The range between the target point and reservation point is the concession range. The bargaining tactics should start with the target and make concessions to reach an agreement. Under reservation point, negotiator should not accept any offer and put an end to negotiation.
- **Negotiation zone:** The area between the reservation values of the negotiating parties is called as negotiation zone or bargaining range. The negotiation starts with the target offer from a party and takes places within the negotiation zone. This area will be positive or negative. If it is negative, then there will be no settlement unless one or both the parties change reservation points.
- **Utility:** The objectives of the parties are usually specified as "utility", or more explicitly "profit". The utility of a negotiator at his target point is highest, and utility decreases by coming closer to reservation point. Utility functions are the mathematical representations of the user preferences that are useful in development of automated systems. In RAMP[3] model, linear utility curves was used for simplicity [10], [21].

  Agents calculate the utility and then make their decision using utility values. The utility of given offers is calculated using the utility curves for each agent. All agents have a utility of 1 for their first offer and a utility of 0.6 for their reservation value. In between these values the utility curve is linear. Using its utility curve at each round, the agent calculates the utility from its previous offer and the utility from its opponent's offer. Zeuthen's strategy uses fully informed agents, so each agent can also access its opponent's reservation value. This information and the first offer received from the opposing agent are used to calculate the other agent's utility curve and its risk for that round. Then the opponent's risk is compared with the agent's own risk, and if the risk for the opponent is greater than the agent's own risk value, then a concession is made. The value of this concession is the minimum amount that will make the opposing agent's risk equal to or less than the agent's own risk. At each round, agents calculate their offers and either make a concession or offer the same amount that was offered in the previous round [10]. Figure 3 shows the general characteristics of utility curves in RAMP[3] model whereas Figure 4 shows the key negotiation features adopted in RAMP[3] model.

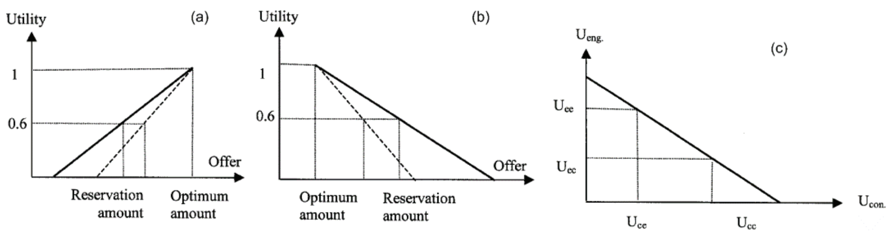

Figure 3 - Utility function of: (a) Concessionaire agent; (b) Public institution agent; (c) The function between the two agents' utilities [21]

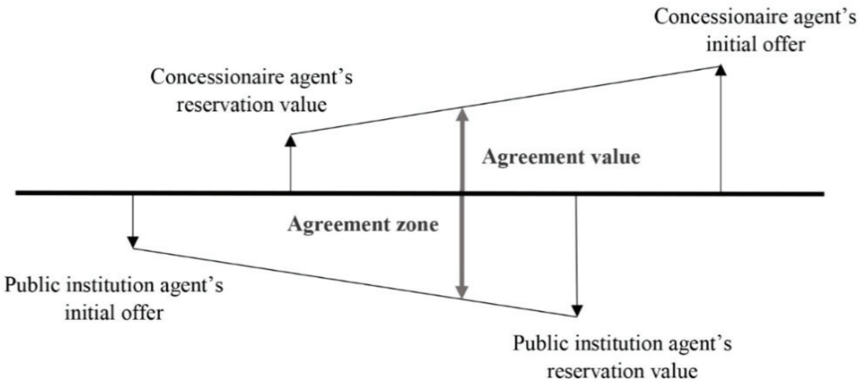

Figure 4 - The key negotiation features in RAMP[3] model (adopted from [21]

- **Agent's Willingness to Risk Conflict (Risk Value):** Zeuthen's strategy simulates the negotiation process by comparing gains and losses. It measures each agent's willingness to risk conflict. According to this strategy at each negotiation step, parties evaluates their willingness to take conflict risk, which is calculated by dividing -the loss due to accepting opponents offer- to -the loss due to going into conflict. Agents calculate the utility for various cases and then make their decision using these utility values. In each round an agent determines the loss of its utility due to accepting the opponent's offer and loss due to rejecting the offer and running into a conflict (conflict is assumed to have a utility of 0). The ratio of these items is the calculated risk for this agent [28]:

$$\text{Risk} = \frac{\text{Utility agent 1 loses by conceding and accepting agent 2's offer}}{\text{Utility agent 1 loses by not conceding and causing a conflict}} \tag{5}$$

Risk is the indication of how much an agent is willing to risk a conflict by sticking to its last offer. As risk grows, the agent has less to lose from a conflict and will be more willing to not concede and risk creating a conflict [28]. According to the negotiation protocol, in each round the concession for an agent is the minimum amount that will make the opponent's risk less than or equal to the agent's own risk. Using Equation (5), following risk formulas for each agent are obtained:

$$R_{Ca} = \frac{U^t_{CaCa} - U^t_{CaPIa}}{U^t_{CaCa} - 0} \; ; \; R_{PIa} = \frac{U^t_{PIaPIa} - U^t_{PIaCa}}{U^t_{PIaPIa} - 0} \tag{6}$$

where R_{Ca} / R_{PIa} = calculated risk for concessionaire/public institution agent for round t; U^t_{CaCa} / U^t_{PIaPIa} = utility of concessionaire/public institution agent due to its own offer in round t; U^t_{CaPIa} / U^t_{PIaCa} = utility of concessionaire/public institution agent due to opponent agent's offer in round t. The utility of conflict for each agent in the model is assumed to be 0. If the utility of an offer is assumed to be 0 for an agent, then the risk value should be taken as 1. At each round, agents calculate and compare the risk value of their own and counteragent's risk value. According to the negotiation protocol, if the risk value of the counteragent is greater than the risk value of the agent; counteragent will have fewer losses in case of conflict and will be less prone to reach agreement. Therefore, the agent having the less risk value will make next offer by making concession [10], [21], [22], [23]. In other words, each agent should continue to make concessions until its willingness to risk conflict (risk value) is greater than counteragent [27]. The value of the concession to be made by the agent is the value that makes the counteragent's risk value less than or equal to the agent's own risk value. Otherwise, the agent will repeat the offer value in the previous round. Agents will continue to compromise until the maximum risk of conflict within both parties reaches to "0" [10], [21], [22], [23].

4.2. Negotiation Theories

In literature, there are three main approaches used to model negotiation in a multi agent environment: game theory, economic theory, and behavior theory [21], [22], [23], [24]. Game theory based studies typically assume that agents are allowed to select the best strategy from the space of all possible strategies by considering all possible interactions. It turns out that the search space of strategies and interactions that needs to be considered has exponential growth, which means that the problem of finding an optimal strategy is in general computationally intractable [24]. Game theory seeks to get at the essentials of decision-making and the associated strategies in situations where two or more parties are interdependent, and where, therefore, the outcome of their conflict and competition must be the product of their joint requirements and the interaction of their separate choices [23]. Although game theory is known to propose an influential mechanism for studying and arranging strategic interaction among agents, its usage in negotiation has negative aspects. In game theory, it is assumed that agents can characterize their preferences by considering all possible outcomes and they have perfect computational rationality [25]. Economic theory seeks to develop dynamic models of process, involving offers and counteroffers and interdependent concession making. In contrast to the classical game theory, there is no concern for the discovery of once-and-for-all strategies, but rather an intention to examine how the bargainers should interact in terms of their expectations of each other. Economic models analyze the processes through which the demands of the participants converge over time toward some specific point on the contract curve. The key element is the development of a specific concession mechanism that permits the positions of the parties to converge in the course of offers and counteroffers [21], [23]. Behavior theory focuses on the complex human factors of negotiation. It attempts to analyze the negotiation processes in which negotiators influence each other's expectations, perceptions, assessments, and decisions during the search for an outcome, thereby affecting the outcome. Much attention is given to the nature of changing expectations and bargainers' tactics, and to the significance of uncertainties of information, perception, and evaluation—all matters that tend to be ignored by game theory and economic theory [21], [23]. Economic theory approach was used in RAMP[3] model since it seeks to develop a dynamic structure by considering the process of making concessions through proposals, counteroffers, and interconnected proposals. This theory examines how the bargainers act according to each other's demands, and according to this theory, each negotiator should only consider its own interests. However, the bargainers wishing to reach an agreement converge in the course of offers and counteroffers. The reason for choosing the economic theory approach is that game theory is insufficient to reflect the dynamic structure of the bargaining process, whereas behavioral theory is criticized for focusing on the modeling of intermediaries rather than modeling the bargaining process [21], [22], [23].

4.3. Concession Protocols in Negotiation

Concession protocol in negotiations is the base for directing the interaction of parties. These rules cover the number of parties involved in the negotiation, main stages (like accepting the offer or ending it), progresses throughout negotiation (like sending new offer), the acts of parties (like who will make the decision, who will send the message, etc.). In RAMP[3] model, there is a one-to-one interaction between agents to create an interactive negotiation process. Until reaching a settlement, negotiating parties need to make concession over their offers. In case, parties do not have willingness to concede, the negotiation will end with conflict (monotonic concession process) [23]. After the input variables are calculated, the model simulates negotiations using Zeuthen's (complete information) negotiation protocols. Zeuthen's strategy simulates the negotiation process by comparing gains and losses. According to the Zeuthen strategy adopted within the scope of the bargaining process, agents determine their offers for each counter using their utility curves. In each round an agent determines the loss of its utility due to accepting the opponent's offer and loss due to rejecting the offer and running into a conflict (conflict is assumed to have a utility of 0). The ratio of these items is the calculated risk for this agent [10]. Risk is the indication of how much an agent is willing to risk a conflict by sticking to its last offer. As risk grows, the agent has less to lose from a conflict and will be more willing to not concede and risk creating a conflict [28]. According to the Zeuthen's strategy, agents do not try to learn each other's utility curve since they are fully informed about each other's utility curve. Thus, the reserve value of counteragent can be calculated in each round of the negotiation process.

4.4. Bargaining Strategies

The bargaining strategy to be used by the parties is playing an important role in determination of how much compromise a party shall make from his target. In literature, the most widely used strategy is Zeuthen strategy [17]. Thus, RAMP[3] model adapts Zeuthen strategy as bargaining strategy. In Zeuthen bargaining strategy, parties determine the highest possibility of disagreement that they can accept and the party with the less risk acceptance level makes concession [26]. In negotiation process, parties have willingness to give as less concession as possible until reaching the agreement. According to Zeuthen bargaining strategy, an agent makes its decision of concession based on how much it has to lose by running into conflict at that time. If an agent has already made many concessions, it will have less to lose from a conflict, and will be less willing to concede. Thus, it has a high acceptability to risk conflict. Here, risk acceptability is measured by the comparison of an agent's loss caused by accepting the opponent's current offer and its loss caused by a conflict deal. At each step, each agent will compare its risk acceptability with that of its opponent. The agent with smaller risk acceptability will make the next concession, which will be sufficient to make its opponent's risk acceptability smaller than its own [27]. Since risk allocation decisions are mostly affected by the risk attitudes of the parties and the compromises to be made by the parties in the negotiation process are shaped by the risk attitudes of the parties, risk attitudes of the parties are included in the bargaining process of RAMP^3 model.

4.5. Conflict Deal

Generally, if neither agent concedes at the same step, then the negotiation ends with a conflict deal. This restriction is relaxed in RAMP^3 model. Negotiations will not necessarily fall into a conflict deal even if agents stand still for five encounters. If the bargaining cannot be resolved at the end of the relevant rounds, the relevant risk factor will be allocated to the public and private sectors together.

4.6. Negotiation Phases

Negotiation process consists three main stages namely: i) Preparation stage (calculation of input variables), ii) Bargaining stage (negotiations between parties) and iii) Closing stage. In preparation stage, public institution agent and concessionaire agent communicate with risk factor agent and determinate risk factors that are going to be allocated between parties on the current project basis as a situation assessment. In this stage, the input variables that are needed to start a negotiation (the reservation value of each agent and first-offer values) are calculated. After these values are calculated, the negotiations start by using negotiation protocols. In bargaining stage, utility determination, making first offer, evaluation of risks taken by agents to decide which should make a concession, determining concession amount and making counteroffer/offer take place, respectively. The entire negotiation process is carried out by the agents without interference of the user. Lastly, in closing stage agents make decision to accept or conflict. Table 2 summarize the general characteristics of negotiation process in RAMP^3 model.

Table 2 - Characteristics of negotiation process in RAMP^3 model

Bargaining strategies	Each agent tries to increase its own benefit in the incoming offer. The loss of the party is accepted as counterparty's profit.
Determination of bargaining values	Within the negotiation process, parties negotiate based on their reservation and optimum values.
Parties	In the context of the monotonous concession protocol, negotiations are only made between the public institution agent and the concessionaire agent.
Parties' approach	According to Zeuthen bargaining strategy, the parties make their offers in each encounter by making concessions. In this process, each agent analyzes its loss due to the counterparty's offer. The agent with smaller risk acceptability will make the next concession.
Impact of counterparty's strategies	According to Zeuthen bargaining strategy, parties do not try to learn the concession rate of the counterparty in each round of the bargaining process.

4.7. Flowchart of Negotiation Process

Negotiations take place only between two agents representing concessionaire and public institution. Each agent in the system is independent and carries out the negotiation process on its own. At the end of the negotiations, either a settlement is reached or, if a deadlock is identified, a conflict deal is declared. In RAMP^3 model, a negotiation process is carried out for each risk factor. At the end of negotiation process, the risk allocation decision for the related risk is made. All the negotiation processes mainly depend on reservation value and offer value. In the negotiation process, both agents' goal is to have the maximum utility. In the first step of negotiation process, both agents calculate their reservation value and first (initial) offer primarily. The first offer is the initial offer given by an agent. The reservation value can be described as the highest amount that public institution agent can accept as a result of bargaining and it is the lowest offer that the concessionaire agent can accept. During the negotiation process, public institution and concessionaire agents calculate their first offer and reservation values in the same way. Agents make concessions as much as the difference between their reserve value that have zero concession and their offer values which are their target points. To start the negotiation process, the agents must determine these points. During the negotiation process, the concessionaire agent does not accept offers lower than its own reservation value whereas the public institution agent does not accept offers above its reservation value. The explanations related to the calculation of input variables for each agent are given below.

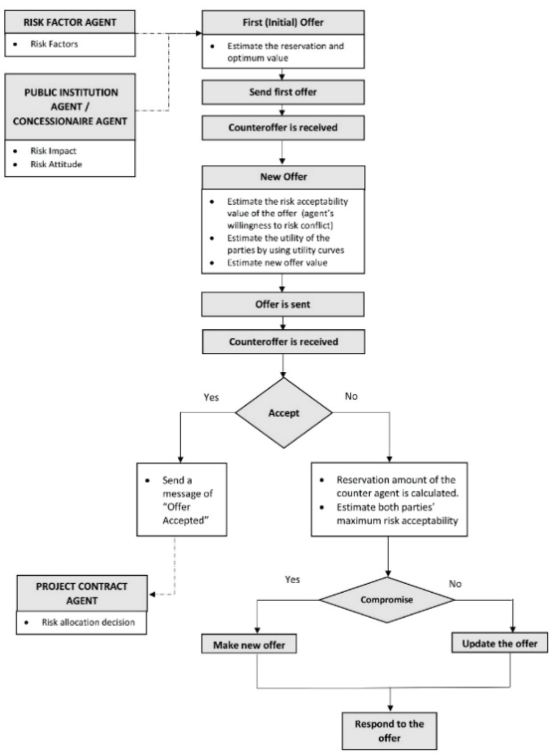

Figure 5 - Flowchart of negotiation process

Negotiation process starts when the message of the concessionaire agent's opening offer is delivered to public institution agent. The public institution agent replies this offer with its own opening offer. When a message is received, agent first decides what to do based on the message type. If the received message is of "Offer Accepted" type, this means that the counterparty has accepted the offer. In this case, agent concludes that an agreement has been made based on the last offer and ends the negotiation process. If the received message is of "Offer Rejected" type, this means that bargaining is dragged into a dilemma. However, considering the concession protocol the negotiation process should be continued without a deadlock. Therefore, agents should continue encounters by making concession over their past offers until they reach to a settlement. If the received message is of "Offer" type, this means that a new offer has been received and agent calculates its new offer amount based on the negotiation protocol. If there is no impasse in the offers, agent compares its own offer with the counterparty's offer. If it is indicated that that counterparty's offer provides more advantages from its own offer, agent would accept this offer and a message of "Offer Accepted" type is sent to the counterparty. The flowchart of the negotiation process for RAMP^3 model is presented in Figure 5.

5. TESTING AND VALIDATION

Validation of RAMP^3 model was performed in two stages: 1) Theoretically validation**:** conceptual model validation that checks if agents are modelled in consistency with accepted theories and 2) Operational validation: that ensures the correspondence between model and reality by determining that the model outputs behavior has sufficient accuracy for its intended purpose and use.

Four major attributes should be included in a negotiation protocol to argue that the multi agent-based model is theoretically valid. These major attributes are distributed model, efficiency, simplicity, and symmetry [16], [21].

- **Distributed Model:** This attribute ensures that there is no central decision-making unit in the model, and hence the freedom of each agent to make its own decisions and to negotiate according to its own priorities.
- **Efficiency:** The efficiency of the model is measured by the fact that the agents can generate results where the sum of earnings is the largest. Zeuthen strategy used within the model ensures that the model meets the efficiency attribute.
- **Simplicity:** Transactions should consume reasonable computing and communication resources. Since the bargaining process occur only between two agents representing concessionaire and public institution, the number of messages sent, and the communication resources used are limited.
- **Symmetry:** This attribute ensures that the model treats each agent equally.

Operational validation of the model was carried out with two real PPP projects. Testing of RAMP^3 model was carried out by conducting interviews with experts from both concessionaire and the public institution. During the operational validation of the model, one main risk group with the most sub-risk factors was selected (financial risk factors) instead of focusing 99 risk parameters belonging to 12 main risk groups. Participants were asked to enter the data required in the architectural structure of the RAMP³ model related to selected risk factors. Based on the data obtained, the proposed risk allocation decision of the related risks was determined after the negotiation process carried out by agents. As a next step, an expert with 16 years of experience in risk management in PPP projects was asked to interpret the risk allocation decisions independently generated by the model.

- **First case:** A mega tunnel project which was awarded to private sector using Built-Operate-Transfer (BOT) approach with a total investment of 1.245 billion USD was considered as the first case. The concessionaire won the tender in 2008 and signed the implementation agreement for the BOT model of the project with the public institution in 2011. The construction phase of the tunnel with a 55-month construction period started in 2013 and completed in 2016. The participants were as follows: 1) Concessionaire representative: a project manager with 12 years of experience in PPP project companies with civil engineering background, and 2) Public institution representative: one public representative from General Directorate of Highways. As a result of the evaluations, it is seen that the model accurately predicts the results by 87% (13 out of 15 criteria) which means model estimation results are in agreement with the expert's evaluation (Table 3).

Table 3 - Trial results of first case

Risk Factors	Risk allocation results according to RAMP³	Risk allocation results according to expert assessment
1. Purchasing guarantees by public institution	Concessionaire + Public institution	Concessionaire + Public institution
2. Financial attractiveness of the project	Concessionaire	Concessionaire + Public institution
3. Revenue (Income) risk	Concessionaire	Concessionaire
4. Payment mechanisms	Concessionaire + Public institution	Concessionaire + Public institution
5. Investment costs	Concessionaire	Concessionaire
6. Unit costs	Concessionaire	Concessionaire + Public institution
7. Finance issues related to cost increase	Concessionaire	Concessionaire
8. Bankruptcy/insolvency of stakeholders	Concessionaire	Concessionaire
9. Additional costs related to fast-track construction	Concessionaire	Concessionaire
10. High costs (bidding costs, design and construction costs, operational costs)	Concessionaire + Public institution	Concessionaire + Public institution

Table 3 - Trial results of first case (continue)

11. Residual value	Concessionaire	Concessionaire
12. Instability of financial structure	Concessionaire	Concessionaire
13. Lack of credibility of stakeholders	Concessionaire	Concessionaire
14. Inability of debt service	Concessionaire	Concessionaire
15. Wrong estimation of cost trade-offs	Concessionaire	Concessionaire

- **Second case:** An airport project which was awarded to private sector using BOT approach with a total investment of 38.7 billion USD was considered as the second case. The concessionaire won the tender and signed the implementation agreement for the BOT model of the project with the public institution in 2013. The first construction phase of the airport with a 42-month construction period will be finalized in 2018, whereas all construction phases are going to be completed by the first half of 2025. Operational validation of $RAMP^3$ in second case was carried out by conducting interviews with both concessionaire and public institution representatives. The participants were as follows: 1) Concessionaire representative: a project manager with 8 years of experience in PPP project companies with civil engineering background, and 2) Public institution representative: one public representative from General Directorate of State Airports Authority. As a result of the evaluations, it is seen that the model accurately predicts the results by 80% (12 out of 15 criteria) which means model estimation results are in agreement with the expert's evaluation (Table 4).

Table 4 - Trial results of second case

Risk Factors	**Risk allocation results according to $RAMP^3$**	**Risk allocation results according to expert assessment**
1. Purchasing guarantees by public institution	Concessionaire + Public institution	Concessionaire + Public institution
2. Financial attractiveness of the project	Concessionaire + Public institution	Concessionaire + Public institution
3. Revenue (Income) risk	Concessionaire + Public institution	Concessionaire
4. Payment mechanisms	Concessionaire	Concessionaire + Public institution
5. Investment costs	Concessionaire	Concessionaire
6. Unit costs	Concessionaire	Concessionaire + Public institution
7. Finance issues related to cost increase	Concessionaire	Concessionaire
8. Bankruptcy/insolvency of stakeholders	Concessionaire	Concessionaire

Table 4 - Trial results of second case (continue)

9. Additional costs related to fast-track construction	Concessionaire	Concessionaire
10. High costs (bidding costs, design and construction costs, operational costs)	Concessionaire	Concessionaire + Public institution
11. Residual value	Concessionaire	Concessionaire
12. Instability of financial structure	Concessionaire	Concessionaire
13. Lack of credibility of stakeholders	Concessionaire	Concessionaire
14. Inability of debt service	Concessionaire	Concessionaire
15. Wrong estimation of cost trade-offs	Concessionaire	Concessionaire

6. FINDINGS AND DISCUSSION

Results show that RAMP^3 is theoretically valid since i) it does not have any central decision-making unit, ii) it proceeds the negotiation process as each agent maximizes its own utility, iii) transactions consume reasonable computing and communication resources between two agents, iv) model treats intermediaries equally during the bargaining process. This means that RAMP^3 model meets the distributed model, efficiency, simplicity, and symmetry criteria, respectively. On the other hand, the results of operational validation of the model shows that the level of prediction of the model is high since model estimation results are in agreement with the expert's evaluation for two cases (above %80).

In addition, some lessons learnt from RAMP^3 implementation and recommendations for improving the model can be summarized as follows:

- Results shows that the rule of "allocating risk factor to both public and private sectors if the negotiations do not end in five encounters" prevents deadlocks and accelerates negotiation process.
- Results shows that in concession rounds, the higher risk value of an agent gets, agent's utility due to counter agent in that concession round lowers.
- In conjunction with that situation, the higher utility gets, offer value of an agent also gets higher.
- Preliminary findings show that it is mainly the reservation value that determines the settlement amount of the negotiation and risk factor is assigned to the party that has a higher risk acceptability in negotiation process.
- Developed RAMP^3 model should be tested on variable case studies and the sensitivity of the model should be analyzed in the light of the data obtained.
- This study presents the architectural structure of RAMP^3 with an aim of predicting the right party who can manage PPP project related risk factors based on each risk's importance and impact. Interactions of risk factors were neglected. Considering impact or significance of a risk factor can be affected by other risk factor(s), interrelated relationships should be taken account within MAS model.
- Inclusion of learning ability for agents would improve model's performance.

- The research opens to future evaluations after the integration of a project agent that will transfer information from the designer(s), subcontractor(s) or financiers to the project-specific model in order to improve the performance of the model.

7. CONCLUSION

In existing studies related to risk management area, parameters such as risk sharing attitudes, risk management capacities, contract conditions, etc. are often not addressed. However, within the scope of effective risk management, more than one project participant with different utility functions should be identified and the communication rules between them must be determined [16]. Considering that the performance of PPP infrastructure projects depends on the efficiency of the risk allocation strategies adopted between public and private sectors and how the risks between the parties are balanced by the contract [4], [5], risks should be assigned to the party that can better manage them. However, it is observed that this principle is generally not implemented due to the difference in perception among project stakeholders regarding risk management capabilities [6], [7]. Within this context, a multi agent system-based Risk Allocation Model (RAMP^3) that simulates the risk allocation process for PPP projects was developed to fill this gap in literature. Developed model enables users to determine risk allocation decisions by evaluating project parties' risk attitudes (varies according to their objectives, knowledge-ability levels) along with the impact of risk factors such as time extension, cost increase and conflict. Thus, final risk allocation results generated from this model can be reflected into contract clauses to ensure that risk factors are assigned to the party who can better manage the risks. Therefore, this study differentiates from other risk management studies that adapted MAS since the focus of those studies were the simulation of either cost-sharing process or risk-mitigation decisions under different scenarios regarding the risk-allocation principles.

The methodology of RAMP^3 involves i) identification of risks by agents, ii) assessment of each risk's importance and impact, iii) communication of agents to negotiate on risk allocation decision and iv) determination of strategies and utility functions to be used in negotiation process. The focus of study is presenting the steps of negotiation process of agents using economic theory and Zeuthen bargaining strategy. RAMP^3 developed within the scope of this study consists risk factor agent, concessionaire agent, public institution agent and project contract agent. Within the negotiation process made between the public institution agent and the concessionaire agent, parties negotiate based on their reservation and optimum values. In RAMP^3, each agent tries to increase its own benefit in the incoming offer using utility curves. According to bargaining strategy, each agent analyzes its loss due to the counterparty's offer and the agent with smaller risk acceptability makes the next concession. RAMP^3 enables users to evaluate risk factors specific to PPP projects according to project parties' objectives, knowledge-ability levels along with the impact of risk factors such as time extension, cost increase and conflict. RAMP^3 was validated on two real PPP projects. Preliminary findings show that the higher risk value of an agent gets, agent's utility due to counter agent in that concession round lowers. Results also show that risk is allocated to the party that has a higher risk acceptability in negotiation process.

Considering the importance of PPP projects for the construction sector, determination of the risk allocation decision in accordance with the competencies of the parties should be prior step within the framework of an effective risk management. Thus, RAMP^3 that has been developed as a decision support system for determining who should manage the potential risk in PPP transport projects creates sectoral contributions.

The multi agent system-based risk allocation model developed within the scope of this study focuses on the negotiation process between in PPP projects. This study can contribute to the development of other works whose focus is negotiation between parties with multiple perspectives, objectives, and different levels of knowledge. Similarly, the multi agent system-based risk allocation model developed for PPP projects can be subject to the future research related to PPP–typed energy, telecom or water and sewerage projects.

Notation

The following symbols are used in this paper:

FAHP = Fuzzy Analytical Hierarchy Process

MAS = Multi Agent System.

PPP = Public-Private-Partnership.

RAMP^3 = Risk Allocation Model for PPP Projects.

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References

[1] Ke, Y., Wang, S., Chan, A. P., Lam, P. T. I., Preferred Risk Allocation in China's Public–Private Partnership (PPP) Projects, International Journal of Project Management, 28(5), 482–492, 2010.

[2] Hwang, B. G., Zhao, X., Gay, M. J.S., Public Private Partnership Projects in Singapore: Factors, Critical Risks and Preferred Risk Allocation from the Perspective of Contractor, International Journal of Project Management, 31(3), 424-433, 2013.

[3] Gross, M. E., Aligning Public-Private Partnership Contracts with Public Objectives for Transportation Infrastructure, Doctoral Thesis, Virginia Polytechnic Institute and State University, 2010.

[4] Yun-na, W. U., Xin-liang, H. U., Ling-shuang, X. U., Ze-zhong, L., Research on Risk Allocation of Public-Private Partnership Projects Based on Rough Set Theory, Communications in Information Science and Management Engineering, 2(7), 15-20, 2012.

[5] Marques, R. C., Berg, S., Risks, Contracts, and Private-Sector Participation in Infrastructure, Journal of Construction Engineering and Management, 137(11), 925-932, 2011.

[6] Thomas, A. V., Kalidindi, S. N., Ananthanarayanan, K., Risk Perception Analysis of BOT Road Project Participants in India, Construction Management and Economics, 21(4), 393–407, 2003.

[7] Lam, K. C., Wang, D., Lee, T. K. P., Tsang, Y. T., Modelling Risk Allocation Decision in Construction Contracts, International Journal of Project Management, 25(5), 485–493, 2000.

[8] Ren, Z., Anumba, C. J., Multi-Agent Systems in Construction–State of The Art and Prospects, Automation in Construction, 13(3), 421-434, 2004.

[9] Zhu, L., Zhao, X., Chua, D. K. H. Agent-Based Debt Terms' Bargaining Model to Improve Negotiation Inefficiency in PPP Projects. Journal of Computing in Civil Engineering, 30(6), 04016014, 2016.

[10] Ke, Y., Wang, S., Chan, A., Cheung, E., Research Trends of PPP in Construction Journal, Journal of Construction Engineering and Management, 135(10), 1076–1086, 2009.

[11] Chengshuang, S., Guochang, Risk Management Framework of Multi-agent System for Construction Projects. Journal of Northeast Forestry University, 1-5, 2006.

[12] Li, B., Ren, Z., Bayesian Technique Framework for Allocating Demand Risk Between The Public and Private Sector in PPP Projects, 6th International Conference on Service Systems and Service Management, China, 2009.

[13] Karakas, K., Dikmen, I., Birgonul, M.T., Multiagent System to Simulate Risk-Allocation and Cost-Sharing Processes in Construction Projects, Journal of Computing in Civil Engineering, 27(3), 307-319, 2013.

[14] Taillandier, F., Taillandier, P., Tepeli, E., Breysse, D., Mehdizadeh, R., Khartabil, F., A Multi-Agent Model to Manage Risks in Construction Project (SMACC). Automation in Construction, 58, 1-18, 2015.

[15] Karakaş, K., Development of A Multi Agent System for Negotiation of Cost Overrun in International Construction Projects, Master of Science Thesis, Middle East Technical University, 2010.

[16] Dikmen, İ., Birgönül, M. T., Tanyer, A. M., Alparslan, F. N., Uluslararası İnşaat Projeleri İçin Çok Aracılı Bir Risk Modelleme Platformunun Geliştirilmesi, TÜBİTAK Project Report, Project No: 107M334, 2010.

[17] Dağkıran, G., A Multi Agent Risk Analysis and Sharing Platform for International Construction Projects Doctoral Thesis, Middle East Technical University, 2015.

[18] Python, https://www.python.org/ 29 July 2019.

[19] Prechelt, L. An empirical Comparison of C, C++, Java, Perl, Python, Rexx And Tcl. IEEE Computer, 33(10), 23-29, 2000.

[20] Sycara, K., Dai, T. Agent Reasoning in Negotiation. In: Kilgour D., Eden C. (eds) Handbook of Group Decision and Negotiation. Advances in Group Decision and Negotiation, vol 4. Springer, Dordrecht, 2010.

[21] Ren, Z., Anumba, C. J., Ugwu, O. O., Negotiation in a Multi-Agent System for Construction Claims Negotiation, Applied Artificial Intelligence, 16(5), 359-394, 2002.

[22] Ren, Z., Anumba, C. J., Ugwu, O. O., The Development of a Multi-Agent System for Construction Claims Negotiation, Advances in Engineering Software, 34(11), 683-696, 2003a.

[23] Ren, Z., Anumba, C. J., Ugwu, O. O., Multiagent System for Construction Claims Negotiatio, Journal of Computing in Civil Engineering, 17(3), 80-188, 2003b.

[24] Jennings, N. R., Faratin, P., Lomuscio, A. R., Parsons, S., Sierra, C., Wooldridge, M., Automated Negotiation: Prospects, Methods and Challenges, International Journal of Group Decision and Negotiation, 10(2), 199–215, 2001.

[25] Fidan, G., Dikmen, I., Birgonul, M. T., Using Multi Agent Systems in Construction Claim Negotiation, International Conference on Computing in Civil and Building Engineering and XVII Workshop on Intelligent Computing in Engineering, Nottingham-UK, 2010.

[26] Young, O.R., Bargaining: Formal Theories of Negotiation. University of Illinois Press, Urbana, 1975.

[27] Ren, Z., Anumba, C.J., Ugwu, O. O., Construction Claims Management: Towards an Agent-Based Approach, Engineering Construction and Architectural Management, 8(3), 185-197, 2001.

[28] Rosenschein, J. S., Zlotkin, G., Rules of Encounter: Designing Conventions for Automated Negotiation Among Computers, MIT Press, Cambridge, MA, 1994.

[29] Aladağ, H.. Multi-Agent Risk Allocation Model for Build-Operate-Transfer (BOT) Type Transportation Projects, Doctoral Dissertation, Yildiz Technical University, 2016.