DEVELOPMENT OF A MULTI AGENT SYSTEM FOR NEGOTIATION OF COST OVERRUN IN INTERNATIONAL CONSTRUCTION PROJECTS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

MAY 2010

APPROVAL OF THE THESIS:

DEVELOPMENT OF A MULTI AGENT SYSTEM FOR NEGOTIATION OF COST OVERRUN IN INTERNATIONAL CONSTRUCTION PROJECTS

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ABSTRACT

DEVELOPMENT OF A MULTI AGENT SYSTEM FOR NEGOTIATION OF COST OVERRUN IN INTERNATIONAL CONSTRUCTION PROJECTS

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May 2010, 144 pages

Multiagent systems (MAS) are systems consisting of several autonomous entities, called agents, which interact with each other to either further their own interests (competition) or in pursuit of a joint goal (cooperation). In systems composed of multiple autonomous agents, negotiation is a key form of interaction that enables groups of agents to arrive at a mutual agreement regarding some belief, goal or plan. The aim of this thesis is to develop a multiagent system that simulates the negotiation process between parties about sharing of cost overrun in international construction projects. The developed tool can be used to understand how the risks and associated costs are shared between parties under different scenarios related with the risk allocation clauses in the contract, objectives of parties and level of knowledge about actual sources of cost overrun. MAS can be utilized by decision-makers to predict potential outcomes of a negotiation process.

Keywords: Multi-Agent Systems, Negotiation Theory, Claim Negotiations

ÖZ

ULUSLARARASI PROJELERDEKİ MALİYET ARTIŞI İÇİN PAZARLIK AMAÇLI ÇOK ARACILI SİSTEM GELİŞTİRİLMESİ

Karakaş, Kıvanç
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Mayıs 2010, 144 sayfa

Çok aracılı sistemler (ÇAS), birbirleriyle kazançlarını arttırma (rekabet) veya ortak bir hedefe ulaşma (işbirliği) amacıyla etkileşime geçen, aracı denilen birden çok otonom birimden oluşur. Çoklu otonom aracılardan oluşan sistemlerde, bir fikir, amaç veya plan üzerine ortak bir anlaşmaya varılmasında pazarlık temel bir etkileşim yöntemidir. Bu tezin amacı; uluslararası projelerdeki maliyet artışının paylaşımı için yapılan pazarlık sürecini canlandıran çok aracılı bir sistem geliştirmektir. Geliştirilen program risklerin ve ilgili maliyetlerin, sözleşmedeki risk paylaşım maddeleri, tarafların hedefleri ve maliyet artışının nedenleriyle ilgili bilgi düzeyine göre, farklı senaryolar altında taraflar arasında nasıl paylaşıldığını anlamak amaçlı kullanılabilir. ÇAS karar mercileri tarafından, pazarlık sürecinin olası sonuçlarını tahmin etmek amacıyla kullanılabilir

Anahtar Kelimeler: Çok Aracılı Sistemler, Pazarlık Teorileri, Hak talebi pazarlığı

To My Mother
My Family
and Filiz

ACKNOWLEDGEMENTS

I want to express my thanks to my supervisor Assoc. Prof Dr. İrem Dikmen Toker for her wise guidance and trust in me throughout this study. She led me with her experience and always had a positive attitude which encouraged me to overcome difficulties.

I also express my gratefulness to my Co-Supervisor Prof. Dr. M.Talat Birgonul. His experiences both in academic and professional life help this study to come down to earth at the times of uncertainty.

I would like to offer my thanks to my manager Esen Kaçar, for her understanding and support during the process.

I want to thank Assist. Prof. Dr. Ali Murat Tanyer for his help and guidance during the study and also for his support in programming.

I want to thank Gülşah Fidan for assisting me in every step of this study; she has been my connection to school. I also want to express my thanks to Matineh Eybpoosh for sharing her study with me.

I would like to express my gratitude to my family. My father Mehmet Ali, my sisters İlknur and Duygu, my brothers in law and even my young nephews and niece; I always felt their loving support.

And Filiz; I owe her so much. She was always there for me in the most difficult times, both personally and professionally. When I fall down Filiz helped me to get up on my feet and move on. Her loving guidance and support was priceless, this thesis would not exist without her.

Finally I want to express my gratefulness and deepest longing to my mother, Yıldız. Even in her last days she tried to support me. Now she could not see the completion of this study but I know in my every step she was always with me, with her endless love.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ACL	Agent Communication Language
ADLIB	Agent-Based Support for the Collaborative Design of Light Industrial Buildings
AID	Agent identifier
AOP	Agent-Oriented Programming
ASCII	American Standard Code for Information Interchange
$C(CL)_i$	Claim amount “i” which is under the responsibility of the client agent
$C(S)_i$	Claim amount “i” which is under the shared responsibility
C_{min}	Minimum possible claim amount
C_{opt}	Optimum claim amount
C_{opt}	Optimum claim amount calculated by the contractor agent
DAI	Distributed Artificial Intelligence
DPS	Distributed Problem Solving
FH_F	First offer multiplier for high knowledge and favourable attitude
FH_R	Reservation amount multiplier for high knowledge and

	favourable attitude
F_i	Fuzziness on the i'th claim amount
FIDIC	International Federation of Consulting Engineers
FIPA	Foundation for Intelligent Physical Agents
FL_F	First offer multiplier for low knowledge and favourable attitude.
FL_R	Reservation amount multiplier for low knowledge and favourable attitude
GUI	Graphical User Interface
H	A specific hypothesis
IEEE	Institute of Electrical and Electronics Engineers
JADE	Java Agent Development Framework
LPGL	Lesser General Public License
MAS	Multi-Agent Systems
MASCOT	A Multi-Agent System Design for Construction Claims Negotiation
$Offer_{CT1}$	First offer given by the contractor
$Offer_i$	Offer value at round i
$P(E \mid H)$	The conditional probability of seeing the evidence E if the hypothesis H happens to be true
$P(E)$	The marginal probability of E. Probability of having the evidence E with using all possible hypotheses

$P(H \mid E)$	The posterior probability of H given E
$P(H)$	The probability of H before receiving a new evidence E
PRV	Contractor's predicted reservation value
R_{Cln}	Calculated risk for client agent for round t
R_{Ctr}	Calculated risk for contractor agent for round t
$Risk^t_i$	Risk of the agent i at step t
TP	Time penalty of the agent entered by the user
TP_i	Time penalty of the agent at the round i
TÜBİTAK	The Scientific and Technological Research Council of Turkey
$U(C)$	Utility of conflict
UH_F	First offer multiplier for high knowledge and unfavourable attitude
UH_R	Reservation amount multiplier for high knowledge and unfavourable attitude
UL_R	Reservation amount multiplier for low knowledge and unfavourable attitude
UL_R	First offer multiplier for low knowledge and unfavourable attitude.
$U^t_{Cln}(C)$	Utility of conflict for client agent
U^t_{ClnCln}	Utility of client agent due to its own offer in round t

U^{t}_{ClnCtr}	Utility of client agent due to contractor agent's offer in round t
$U^{t}_{Ctr(C)}$	Utility of conflict for contractor agent
U^{t}_{CtrCln}	Utility of contractor agent due to client agent's offer in round t
U^{t}_{CtrCtr}	Utility of contractor agent due to its own offer in round t
δ^{t}_{i}	Offer made by agent i at step t

CHAPTER 1

INTRODUCTION

Construction projects are vulnerable to several external and internal conditions that usually result in deviations from initially set project objectives. Majority of construction projects result in delays and cost overrun because of changes experienced throughout the project due to uncertainties regarding project scope, availability and cost of resources, country-related conditions etc. Cost overrun usually results in construction claims.

Construction claims are resolved in using different methods such as litigation, arbitration or mediation. But all of these methods are time consuming and lead to losses which are sometimes more significant than the amount of claim itself. Due to this reason a negotiation process is followed before taking any other course of action. This study aims to simulate this process using artificial intelligence. Goal is to prepare a software model that can be used to estimate results of claim negotiations and study the impact of variables that affects the negotiation process.

In this thesis following the introduction, second chapter represents a literature review. Artificial intelligence studies and multi agent systems, construction claim negotiations, and negotiation theories are discussed. Also other related studies in the field are presented. Then in the next chapter background of the software model is presented. International standards used in the multi agent systems and framework used for the software model is introduced. Also flowchart of the model and a comparison of the model with respect to previous studies are made. In the forth chapter developed software model is introduced. Model can use three different negotiation protocols; in this chapter determination of the input variables and calculation details for each protocol is given with examples. Then sensitivity analysis of the model is presented. Characteristics of the agents are also introduced with the interfaces developed for the software. Fifth chapter is devoted to evaluation of the model. First a theoretical evaluation of the model made. Then findings of the evaluation of the system with the professionals from the industry are presented. And finally a discussion about the study is made and references are given for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Multi-Agent Systems

2.1.1 Artificial Intelligence

The term Artificial Intelligence (AI) was first used in a conference at Dartmouth College in July 1956. Major AI textbooks define the field as "the study and design of intelligent agents” (Poole et al., 1998). Engineering computer programs and machines that have intelligence is under the scope of artificial intelligence. Understanding human intelligence with using computer programs is very similar to AI but AI may also include methods which are not biologically observable (McCarthy, 2007). While some systems use a “top down” approach which starts building the system from higher level functions, the others use a “bottom up” approach which starts form bottom level functions to neuron level and worked up to create higher level functions (Brunette et al., 2009). First approach is related to efforts of creating expert systems, an individual intelligent human like being, and second approach resulted in distributed artificial intelligence.

2.1.2 Distributed Artificial Intelligence (DAI)

Since the earliest development of artificial intelligence the term was usually referred to creation of an intelligent machine, one capable of performing complex tasks as well as a human being. The process was generally based on humanization or individualization of AI. Intelligence was considered as something pertaining to distinct individuals. Expert systems reflect that way of looking at computer. Computer programs that are used to replace human being in the areas which are extremely complicated and needs certain kind of experience and reasoning (Ferber, 1999). However intelligence is not an isolated entity that can be developed without social interactions. As stated by Smedslund (1966) interactions between individuals are a major factor for cognitive development. This shows us the concept of expert systems is not capable of creating an artificial intelligence not because of the technical difficulties but due to the very first idea of having an individual system without interactions with other programs and outside world. In DAI metaphor of intelligence is based upon social behavior and the emphasis is on actions and interactions. This way of creating artificial intelligence can be used to solve large and complex problems which involve physically distributed reasoning, knowledge and data managing. (Schobbens, 1994).

Need of a distributed intelligence not only arise from the technical reasons but also practical problems caused by the complexity of the question to be answered. By 1980's early hopes of replicate human level intelligence in a machine diminished as the magnitude and difficulty of that goal was seen. This led to the idea of decomposition of the central system into smaller pieces, individual modules based on different aspects of the human brain. We see subfields of artificial intelligence such as "knowledge representation", "learning", "planning", "qualitative reasoning", etc... (Brooks, 1991). In a complex system the knowledge and the expertise needed is possessed by different individuals who communicate within a group, exchange knowledge and collaborate in carrying out a common task. This creates group knowledge that is not equal to the sum of the individuals. Each kind of know-how is linked to a specific point of view, and these different ways of looking at things, which sometimes contradict each other, cannot necessarily be brought together to form a coherent whole. So carrying out a common task will require discussions, adjustments, perhaps even negotiations to resolve any conflict that may arise (Ferber, 1999).

2.1.3 Distributed Problem Solving (DPS)

In DPS agents work together to solve a particular problem which usually needs a collective effort to solve the problem. Each agent has different capabilities. Some have a high knowledge in a particular area, some have higher information or expertise or some have higher processing power. So usually it is not possible for an agent to accomplish own tasks alone. In a DPS an agent can accomplish tasks more efficiently and more accurate when working with other agents. (Durfee, 1999). DPS researches focuses on dividing the work involved in solving a particular problem among a number of modules or “nodes”. A central design is used in DPS modules. This approach helps to improve aspects like performance, stability, modularity or reliability. Cooperation is developed in these modules and this cooperation is used to reach a solution to the given problem. (Kraus et al., 1995). While each node tries to find a solution to a particular piece of the problem a central system provides sub-problem distribution, results synthesis, optimization of problem solver coherence and co-ordination (Wikipedia, 2010).

2.1.4 Multi-Agent Systems (MAS)

Main topic in the researches of MAS is creating intelligent behavior with using a collection of autonomous intelligent agents. In the context of MAS an agent is defined as “an entity that functions continuously and autonomously in an environment in which other processes take place and other agents exist”.

Autonomy means the actions and activities carried out by the agents do not require constant human guidance (Shoham, 1993). Often in MAS, knowledge is not homogeneous among agents and there is no mediator or some kind of global control. Goals and targets of the agents may also be different and real competition among the agents is possible (Kraus et al., 1995). Characteristics of a multi-agent system are defined by Sycara (1998) as follows;

1. Agents do not have complete information over the problem. Also each agent has different capabilities
2. System is not controlled globally
3. Information is not concentrated and data is distributed among different agents
4. There is no synchronization between different computations

MAS are showing an increasing trend since it is first appearance in 1980's. The reason for this growing interest is summarized in 6 terms by Sycara (1998);

1. MAS can be used for problems that are too large for a centralized system to solve. This may be due to resource limitations or in centralized systems there can be bottlenecks or possibility of failing at a critical item.
2. Systems that interact with changing business environment need periodic updates. Usually rewriting such a system is often too expensive if not impossible. Creating an agent community and incorporating these systems into the community is the only way of keeping these systems useful (Genesereth & Ketchpel, 1994).
3. Some of the problems can naturally be regarded as interacting autonomous agents. For example a air traffic control program each

plane may be regarded as individual agents (Cammarata et al., 1983) or a bargaining system for buying and selling of online goods.

4. MAS can provide solutions for efficient use of information sources that are spatially distributed. Some example to that kind of usage is sensor networks (Corkill & Lesser, 1983) and seismic monitoring (Mason & Johnson, 1989).
5. In some problems expertise is distributed. Examples of such problems include concurrent engineering (Lewis & Sycara, 1993), health care and manufacturing.
6. Enhance performance in terms of
    a. Computational efficiency: Parallel computations are possible.
    b. Reliability: Since if an agent fails another agent can take the responsibility.
    c. Extensibility: Number and capacity of agents working on a problem can be changed.
    d. Robustness: Uncertainty can be tolerated by the system since agents only exchange suitable information.
    e. Maintainability: As MAS systems are modular systems. It is easier to maintain a system composed of separate modules.
    f. Responsiveness: Modular architecture can handle anomalies locally and do not propagate them to whole system.
    g. Flexibility: Since every agent has different capabilities they can adept to different problem domains.
    h. Reuse: Agents can be reused in different projects.

2.2 Construction Claims

The American Institute of Architects, as quoted in Levin (1998), defines a claim as “a demand or assertion by one of the contracting parties seeking, as a matter of right, adjustment or interpretation of the contract terms, payment of money, extension of time, or other relief with respect to the terms of a contract”. A similar definition may also be obtained from (Arditi & Patel, 1989) "A request by a contractor for final compensation for additional work over and above the original agreed upon contract sum or damages supposedly resulting from events not included/envisaged in the initial contract”. Claims are items that cannot be included in the budget estimations prior to the construction. Ren (2002) in his PhD Thesis summarized the types of the claims that a contractor can make against the client as fallows;

- **Claims under the contract:** Some items that cause the loss are covered under the terms of the contract. Payment is made with the mechanisms described under the contract.
- **Claims for breach of contract:** These claims arise out of the damages that resulted due to parts’ violation of the contract terms.
- **Claims for the breach of Common Law in tort:** Damages that are result of violation of the common law.
- **Quasi-contractual claims:** Claim for the extra service or work done which are not covered under the contract conditions.
- **Ex gratia claims:** Sometimes claims arise due to the kindness of the client, also referred to as a sympathetic claim (Powell-Smith & Stephenson, 1993) .

Reasons of the claims stated by the Levin (1998) are;

- Project complexity
- Strict price structure that is not flexible enough to absorb additional costs
- Contract conditions that burden all the financial risks or exposure should on the contractor once a contract is let and price is determined.

2.2.1 Construction Dispute Resolution Mechanisms

Conflicts arise due to improperly managed claims that could not be settled during construction period. A variety of dispute resolution mechanisms are developed to resolve these conflicts (El-adaway, 2008). Even if there is many mechanisms, none of these them can still provide a real cost effective method to resolve disputes. Some of most widely used mechanisms are as fallows;

Litigation: Resolution of the conflict is done by the courts. Resolution is sound and definite but they usually result in a very long time. Due to this nature they are the most cost ineffective way of resolving a dispute.

Arbitration: This technique is used to solve conflicts outside the courts. It is a private court which takes both contract conditions and the laws into account to resolve the conflict. Most important disadvantage of arbitration is it is a post project completion process thus producing additional costs to the parties (Haselgrove-Spurin, 2004).

Mediation: Mediation is a negotiation process which is guided by a independent third party. Negotiations are done under the guidance of a mediator. A “mutually acceptable” solution is investigated with the help of the mediator. The mediator cannot impose a solution, unlike an arbitrator or judge, each party maintains control of the process. Solution can only be reached when both parties are agreed on the outcome (Haselgrove-Spurin, 2004). Mediation apart from its advantages is still in most cases a post project completion resolution mechanism that only provides a non binding recommendation. In some cases it can be used by some parties as a way to lengthen the dispute duration before resorting to any other binding mechanism (El-adaway, 2008).

2.3 Negotiation Theories

Efficiency of the interactions between the agents is the main concern of distributed artificial intelligence (DAI). Negotiation is one of the key techniques for inter-agent cooperation. Agents can be designed to make negotiations for their goals and reach mutually acceptable solutions (Kraus et al., 1995).

Negotiation is a time consuming and costly process. Reaching a solution via negotiation may increase overhead cost of coordination. (Kraus et al., 1995). Due to this reason some negotiation protocols are developed to simulate real life negotiations between parties. These negotiation protocols are also widely used in MAS to resolve conflicts.

2.3.1 Negotiation Protocols

A negotiation protocol is a mechanism that is used to resolve conflicts between agents (Kraus et al., 1995) . Protocol defines the boundaries of the agent behaviors during negotiations and defines the general scheme for the interactions. Messages between agents are coordinated by the protocol. It determines the rules that must be followed by the parties if they want to involve into negotiation. The protocol is public and open to everyone (Bartolini et al., 2001).

2.3.2 Roles in Negotiation

In construction claim negotiations there exists two main parties; contractor, client. These parties have their own interests and powers. They are not symmetrical and their roles are determined by the contract.

The client: Client may have different level of power depending on the negotiation conditions. If the claim negotiations take place after the completion of the construction then client has the power of elongating the negotiation process. Since the structure is delivered, the client feels no pressure of finishing the negotiation process early. But if on the case of an ongoing construction client may need to accelerate negotiation process since a delay in the delivery of the construction may cause a higher loss then the claim amount.

Client's previous experience on the work done also determines its strength during the negotiations. An inexperienced client may only depend on the contractor's declarations about what actually happened during the construction process. Therefore it may not determine the claim amount by itself and has to trust the contractor about claim amounts. Also without experience the reservation and concession amounts determined by the client may be inaccurate.

On the other hand client has the power of being employer and controlling the flow of money. If there is a possibility of having future relationships between contractor and client then client may use this possibility into his advantage. It may even turn down all the claims with its authority (as in the case when the client is government).

The contractor: Contractor agent has the power of issuing claim. Since his goal is to maximize his profit theoretically he should try to make claims whenever possible. But in practice this is not true since this kind of approach will damage the prestige of the contractor and will lead him to lose future projects. Also if the negotiations take place after the completion of the work contractor would have a tremendous disadvantage, since as the time passes he will lose money but client agent would not. On the other hand, if the claim is sound, the contractor has a tremendous asset in setting the pace and direction of the negotiations since he has a larger degree of freedom in making his proposal and accepting a settlement (Levin, 1998).

2.4 Multi-Agent System Studies in Construction Industry

2.4.1 Agent-Based Support for the Collaborative Design of Light Industrial Buildings (ADLIB)

Developed by Ugwu, Anumba and Thorpe (Ugwu et al., 2000), objective of the study is to develop a MAS system for the collaborative design of light industrial buildings. Every agent in the ADLIB project represents a specialist in the design team. Each expert has different capabilities and goals. ADLIB tries to automate the interactions and negotiations between these agents (Anumba et al., 2003). In the study negotiation mechanism is developed in three steps. First negotiation theories are investigated then problems in the industry has been analyzed and then negotiation model is developed.

Study showed that MAS can be used for increasing efficiency in construction collaborative design. Also MAS can be further developed to solve other construction problems. Problems in the procurement processes, knowledge, site and claims management can also be addressed. Evaluation of the ADLIB negotiation mechanism shows that the system is suitable, stable and effective in the given domain. (Anumba et al., 2003).

2.4.2 A Multi-Agent System Design for Construction Claims Negotiation (MASCOT)

This study is presented by Ren and Anumba. Objective of the study is development of a multi-agent system for construction claims negotiation. System integrates Zeuthen's bargaining model with a Bayesian learning mechanism. Negotiations take place between contractor and engineer agents with incomplete information and time constrains. Also participation of a client agent is possible in the case of a deadlock.

The success of the study is its ability to create a rational negotiation mechanism. Model tackles with incomplete information problem with adopting a learning mechanism. But most apparent drawback of the system is also this learning mechanism. The negotiation process shows that learning mechanism used in the study is not effective and suitable for the construction claim management domain.

2.4.3 An Agent-Based Framework for Supply Chain Coordination In Construction

Presented by Xuea, Lia, Shen and Wang (Xue et al., 2005) study focuses on the topics in the construction supply chain management. According to the study construction supply chain management is the coordination of decision making processes and parties that take part in the construction. Problems in this management issues are studied and an agent community is developed to solve these problems. Multi attribute negotiation and multi attribute utility theory are used in the model. Developed framework produces solutions for coordination of supply chains in construction.

CHAPTER 3

DEVOLOPING MAS WITH JAVA AGENT DEVELOPMENT FRAMEWORK

3.1 Introduction

In the study Java is used as the programming language for the development of the software model and Java Agent Development Framework (JADE) is used as the system framework. In this chapter, basics of JADE are shown together with some example code. Foundation for Intelligent Physical Agents (FIPA) which is the main standards used in the system is presented. Underlying software architecture and the flow scheme of the model is also explained.

3.2 Foundation for Intelligent Physical Agents (FIPA)

FIPA is an IEEE (Institute of Electrical and Electronics Engineers) Computer Society standards organization that promotes agent-based technology and the interoperability of its standards with other technologies. It is originally founded on 1996 as a Swiss non-profit organisation. In 2005, it is joined to IEEE computer society. FIPA standards are developed by different companies and organizations. They try to facilitate the end-to-end interworking for heterogeneous and interacting agents and agent-based systems. Today a total of 54 companies are member of the FIPA.

Standards enable communication between different agents from several designers, several vendors and several organizations. They are the enabling factor for openness and heterogeneity. FIPA has the following set of standards (FIPA Specifications, 2005);

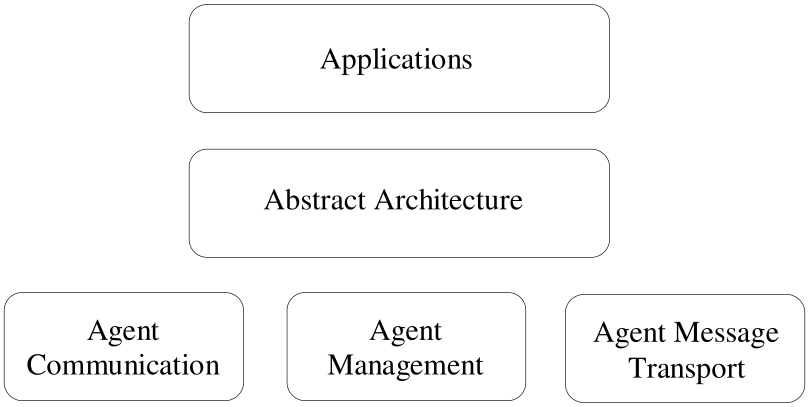


Figure 3-1 FIPA Specifications

FIPA Application specifications: These specifications give information on where the FIPA agents can be deployed. Ontology and service description specifications for a particular domain are represented.

FIPA Abstract Architecture specifications: Abstract entities that are required to build agent services and an agent environment.

FIPA Agent Communication specifications: Agent Communication Language (ACL) messages, message exchange interaction protocols, speech act theory-based communicative acts and content language representations.

FIPA Agent Management specifications: Management of agents inside and outside of the platforms.

FIPA Agent Message Transport specifications: Message transport and representation among different network transport protocols.

Among these categories agent communication is the core category.

3.2.1 Agent Communication Language (ACL)

Agent communication language is developed to ensure interoperability between agents. FIPA ACL is grounded in Speech Act Theory (Searle, 1969). In Speech Act Theory messages represents performatives which means communicative acts or actions. For example the sentence "may I borrow your phone?" has a performative of "request" or sentence "my name is Deniz" has a performative of "inform". FIPA standardized these performatives with 22 communicative acts.

Table 3-1 FIPA communicative acts (FIPA Specifications SC00037)

Element	**Description**
Accept proposal	The action of accepting a previously submitted proposal to perform an action.
Agree	The action of agreeing to perform a requested action made by another agent. Agent will carry it out.
Cancel	Agent wants to cancel a previous request.
Cfp	Agent issues a call for proposals. It contains the actions to be carried out and any other terms of the agreement.
Confirm	The sender confirms to the receiver the truth of the content. The sender initially believed that the receiver was unsure about it.
Disconfirm	The sender confirms to the receiver the falsity of the content.
Failure	Tell the other agent that a previously requested action failed.
Inform	Tell another agent something. The sender must believe in the truth of the statement. Most used performative.
Inform if	Used as content of request to ask another agent to tell us is a statement is true or false.
Inform ref	Like inform if but asks for the value of the expression.
Not understood	Sent when the agent did not understand the message.
Propagate	Asks another agent so forward this same propagate message to others.

Table 3-1 (continued)

Propose	Used as a response to a cfp. Agent proposes a deal.
Proxy	The sender wants the receiver to select target agents denoted by a given description and to send an embedded message to them.
Query if	The action of asking another agent whether or not a given proposition is true.
Query ref	The action of asking another agent for the object referred to by an referential expression.
Refuse	The action of refusing to perform a given action, and explaining the reason for the refusal.
Reject proposal	The action of rejecting a proposal to perform some action during a negotiation.
Request	The sender requests the receiver to perform some action. Usually to request the receiver to perform another communicative act.
Request when	The sender wants the receiver to perform some action when some given proposition becomes true.
Request whenever	The sender wants the receiver to perform some action as soon as some proposition becomes true and thereafter each time the proposition becomes true again.
Subscribe	The act of requesting a persistent intention to notify the sender of the value of a reference, and to notify again whenever the object identified by the reference changes.

According to FIPA standards for an agent to be fully compliant it should be able to receive any FIPA-ACL communicative act message and at very least reply with a “not-understood” message if the message could not processed.

Every FIPA-ACL message contains a set of one or more message parameters as given in FIPA specifications SC00061. Precisely which parameters are needed for effective agent communication will vary according to the situation; the only parameter that is mandatory in all ACL messages is the performative, although it is expected that most ACL messages will also contain sender, receiver and content parameters. Also user defined parameters may be added with adding “X-” prefix to the non-FIPA standard parameter’s name.

Table 3-2 ACL Message Parameters (FIPA Specifications SC00061)

Element	**Description**
performative	Denotes the type of the communicative act of the ACL message
sender	Denotes the identity of the sender of the message, i.e. the name of the agent of the communicative act.
receiver	Denotes the identity of the intended recipients of the message.
reply-to	This element indicates that subsequent messages in this conversation thread are to be directed to the agent named in the reply-to element, instead of to the agent named in the sender element.
content	Denotes the content of the message; equivalently denotes the object of the action.
language	Denotes the language in which the content element is expressed.
encoding	Denotes the specific encoding of the content language expression.
ontology	Denotes the ontology(s) used to give a meaning to the symbols in the content expression.
protocol	Denotes the interaction protocol that the sending agent is employing with this ACL message.
conversation-id	Introduces an expression (a conversation identifier) which is used to identify the ongoing sequence of communicative acts that together form a conversation.
reply-with	Introduces an expression that will be used by the responding agent to identify this message.
in-reply-to	Denotes an expression that references an earlier action to which this message is a reply.
reply-by	Denotes a time and/or date expression which indicates the latest time by which the sending agent would like to have received a reply.

3.3 Java Agent Development Framework (JADE)

3.3.1 Agent-Oriented Programming (AOP)

Agent-Oriented programming is a branch of distributed artificial intelligence. A program which is produced using AOP is a collection of components called Agents. Agents are autonomous, proactive and can interact with other agents. They can carry out long and complex tasks without any human guidance. Since they are proactive they can start performing an action by their selves and can take initiative. Agents can also interact with other agents using a communication protocol and can reach their goal with coordination and negotiation. Agents can communicate with any other agent and may receive any messages. (Bellifemine et al., 2007).

3.3.2 Overview of the Framework

JADE (Java Agent DEvelopment Framework) is a software framework fully implemented in Java language. It is an open source free software which is distributed under LPGL (Lesser General Public License) by Telecom Italia. It simplifies the application of multi-agent systems through a set of graphical tools and a middle-ware that complies with the FIPA specifications. This gives the program interoperability property. This means that JADE agents can interoperate with other agents, provided that they comply with the same standard. It also supports the debugging and deployment phases. It is designed to support for scalability so it can work with small to large projects. It can also be distributed between different hosts even between different operation systems. Usage with mobile devices which supports Java environment is also possible.

3.3.3 Architectural Model

Architectural model of the JADE platform can be shown in Figure 3-2 given below:

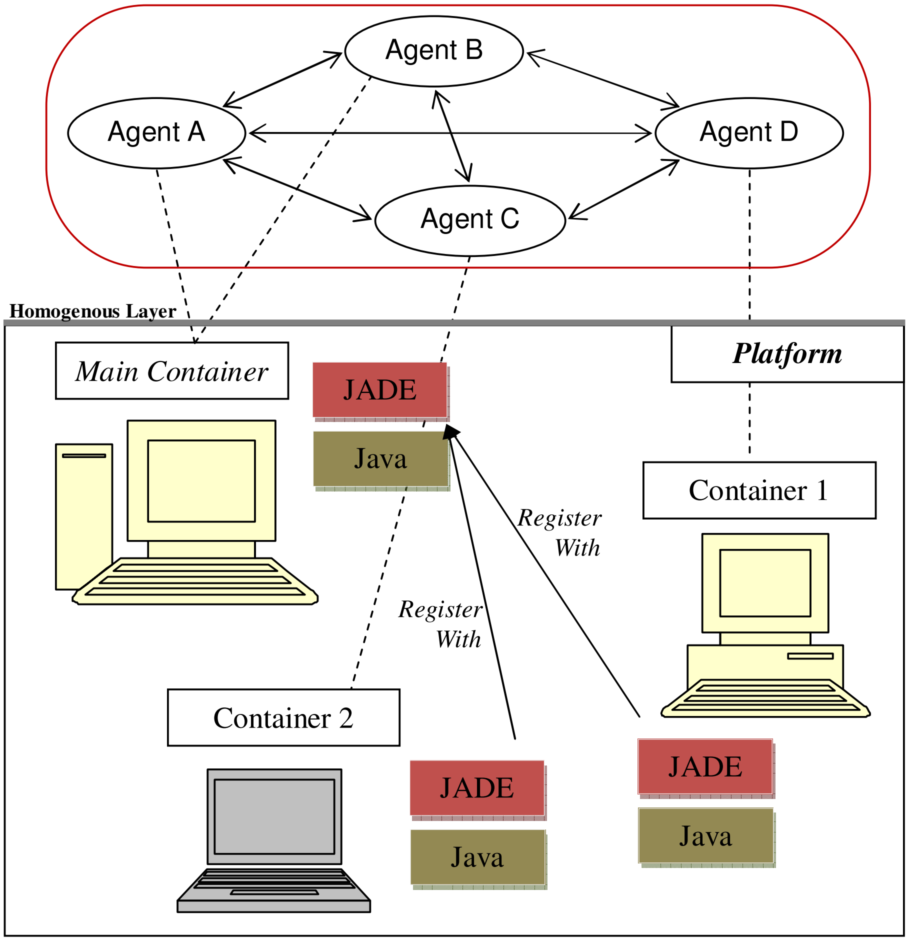


Figure 3-2 Architectural model of the JADE platform

Platform: The set of active containers. It provides a homogenous layer that hides the complex underlying operations. There may also exist more than one platform on a network.

Container: Each running instance of the JADE runtime. It can contain several agents. Each container may be deployed on different hosts. At each platform there exists a single special main container and all other containers registers to this main container as soon as they start. They can be connected via wireless and wireline network. Address of the main container should be known by each of the containers. Normally one host deploys one container but it is also possible to run multiple containers on one single host.

3.3.4 Agent Class

Agents are created by extending the jade.core.Agent class and redefining the setup() method. Each Agent instance is defined by an AID (Agent identifier) composed of a unique name plus some addresses. Names are in the form;

<local-name>@<platform-name>

Complete name of the agent must be globally unique. To call an agent within a single JADE platform, referring only to its local name is sufficient. Full name is only needed for inter-platform communication.

Main part of an agent resides in its setup() method. This is the part where initial behaviours are executed. Termination of an agent is done by calling its doDelete() method. On termination agent's takeDown() method is invoked, that can be used for cleanup operations. Below is an example code for an agent which displays a "Contractor Agent is ready" message after initialisation. Agent then immediately terminates and displays "Contractor Agent is terminated." message.

```
1  public class ContractorAgent extends Agent {
2    protected void setup(){
3      System.out.println("Contractor Agent is ready.");
4      doDelete();
5    }
6  Protected void takeDown(){
7    System.out.println("Contractor Agent is terminated.");
8  }
```

If we inspect the given code more closely;

Line 1: Creates the “Contractor Agent” by extending jade.core.Agent class

Line 2: Overrides the setup method of the agent class

Line 3: Displays the first message

Line 4: Calls doDelete() method which will terminate the agent. Calling this method also triggers the takeDown method

Line 6: Overrides the takeDown method of the agent class

Line 7: Displays the second method

3.3.5 Behaviour Class

Agents carry out their tasks with behaviours. Behaviours are created by extending jade.core.behaviours.Behaviour class. To make an agent execute a task first we create an instance of the corresponding Behaviour subclass then we call the addBehaviour() method of the Agent class to add this behaviour to the pool of behaviours of this agent. It is possible for an agent to execute multiple behaviours at once.

Each behaviour must implement following methods;

- public void action() : This is the part where the main processes run
- public void done() : This part tells whether the behaviour is finished or not

An agent lifecycle starts from its setup method and ends with takedown method. In between multiple behaviours may be created and terminated.

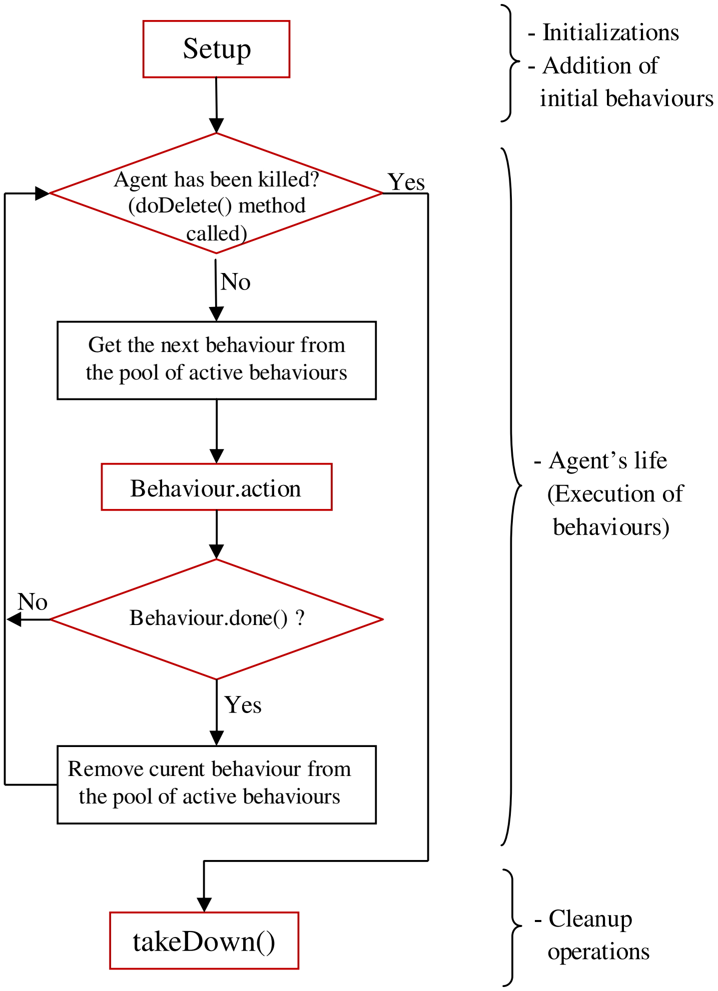


Figure 3-3 The agent execution model (Bellifemine et al., 2007)

JADE can execute several behaviours concurrently. But these behaviours action methods run one by one. Platform waits until one behaviour's action() method to finish and then moves onto the next active behaviour as shown on Figure 3-3. This does not mean that previous behaviour is killed but its action method is ended. Platform runs through all active behaviours for that agent and returns back to first active one again and executes its action method once more. This goes like that until this behaviour is killed. For a behaviour to be killed, behaviour's done() method should return "true". When there is no active behaviours left for the agent, that agent goes to sleep to preserve CPU. When a behaviour becomes active again this agent wakes up again.

There are 3 primary behaviour types are available with JADE;

One Shot Behaviours: These behaviours' action method runs only once. They are designed to complete in one execution phase. Their done() method is already implemented in their class definition and always returns "true".

Cyclic Behaviours: These behaviours are simply the opposite of one shot behaviours. They are designed to run until their agent terminates. At each run their action() method executes the same operation. Their done() method is implemented as "false".

Generic Behaviours: These behaviours termination is controlled from their action method. They embed a status At each run of the action() method, depending on the state of the behaviour a different operation is executed. When a given condition is met their done() method returns true and the behaviour is ended.

3.3.6 Agent Communication

Agent communication is handled with accordance with FIPA specifications. Messaging process is asynchronous and message format is determined by ACL specifications. Asynchronous messaging means that every agent has a mailbox (message queue) and JADE runtime posts messages from other agents to this mailbox. Whenever a message is posted in the mailbox receiver agent is notified. Picking up the message from the mailbox is a design choice of the agent programmer.

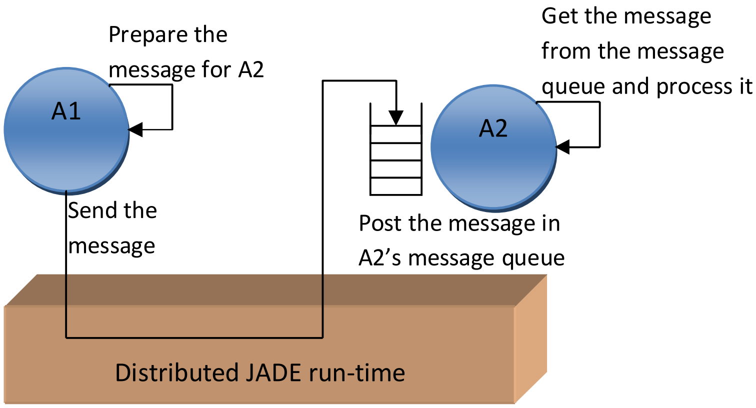


Figure 3-4 JADE asynchronous message passing paradigm
(Bellifemine, Caire, & Greenwood, 2007)

Each message has the fields defined in Table 3-2 ACL Message Parameters (FIPA Specifications SC00061). All messages exchanged with the instances of jade.lang.acl.ACLMessage class. This class provides methods to get and set all the parameters defined by the ACL specifications. Messages are sent with using “send” method of the agent class. Below is an example of how to create an ACL message and send it with using a one shot behaviour. In the example Contractor agent sends its first offer to the client agent.

```
1  private class SendFirstOffer extends OneShotBehaviour{
2    public void action() {
3      ACLMessage cfp = new ACLMessage(ACLMessage.CFP);
4      cfp.addReceiver(new AID("Client", AID.ISLOCALNAME));
5      cfp.setConversationId("Claim");
6      cfp.setContent(Double.toString(ContractorFirstOffer));
7      myAgent.send(cfp);
8    }
9  }
```

Line 1: Creates the “SendFirstOffer” behaviour by extending jade.core.behaviours.OneShotBehaviour class. A new one shot behaviour is added to the set of active behaviours for that agent.

Line 2: Overrides the action() method of the behaviour class

Line 3: An instance of ACL class is created with CFP performative; name of the new message is “cfp”. While creating a new ACL message, performative is always defined since it is the only mandatory information that should be included according to FIPA specifications. All other information is optional.

Line 4: Adds Client agent as the receiver of the message

Line 5: Sets conversation id as “Claim”. This information is used by the client agent to filter incoming messages and only process the ones which are about claim negotiation process.

Line 6: Sets the content of the message. Message content is the first offer value of the contractor which is a numeric value. But since ACL message content should be a string variable, it is first cast into a string.

Line 7: Sends the message with using send method of the agent class. Message will be delivered to the receiver agent’s inbox by the JADE run-time.

Agents receive the incoming messages by using “receive” method of the agent class. But a behaviour which will receive the messages does not know when a new message will be received and have to check the message queue continuously. This is a very CPU consuming process so JADE defines another method in behaviour class, “block()” method. This method blocks the execution of the behaviour until a new message is received. When a behaviour is blocked it is taken from the pool of active behaviours of the agent and put into a blocked state. When a new message reaches to the agent all blocked behaviours are activated and have a chance to receive the incoming message.

```
1  public void action(){
2    ACLMessage FirstOffer = myAgent.receive();
3    if (FirstOffer != null){
4      //Process the message
5    }
6    else {
7      block();
8    }
9  }
```

Line 1: Overrides the action() method of the behaviour class.

Line 2: A new ACL message is created with the name “FirstOffer” and its content is filled with the information from “receive()” method.

Line 3: Checks if the message object is empty (i.e. a message is received) or not.

Line 4: Message is processed

Line 7: If the message object is empty which means no message is received, block() method blocks the behaviour

3.4 Flowchart of the Model

A simplified version of the program’s flowchart is introduced to have insight about the program architecture. Since the calculation details of these procedures will be presented in the 4th Chapter, here only a basic workflow is displayed. For the following figures; blue boxes represent an operation or method and red boxes represent behaviours.

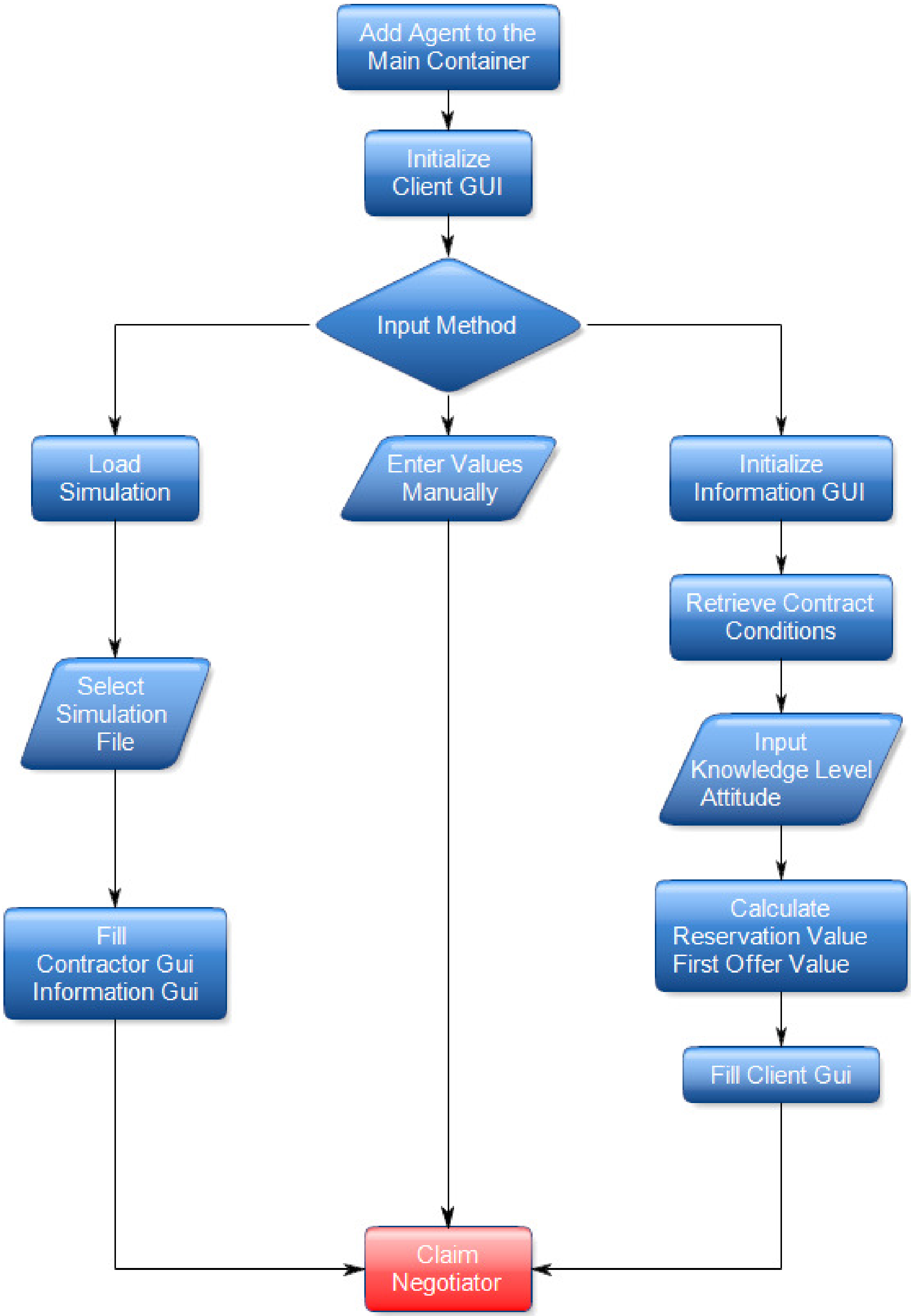


Figure 3-5 Workflow for determination of Client Agent's First Offer and Reservation Values

For the client agent, with the start of the JADE framework, agent is added to the Main Container. Then the Client Graphical User Interface (GUI) is displayed. Here user has three choices, he/she may enter the reservation and first offer values manually, load a previous simulation or initialize Information GUI. If the Information GUI is selected user input two variables knowledge level of the client and client agent's attitude against the contractor and program calculates first offer and reservation values with using this information. Then the control is transferred to Claim negotiator behaviour which waits in a blocked state until an offer received from the Contractor Agent.

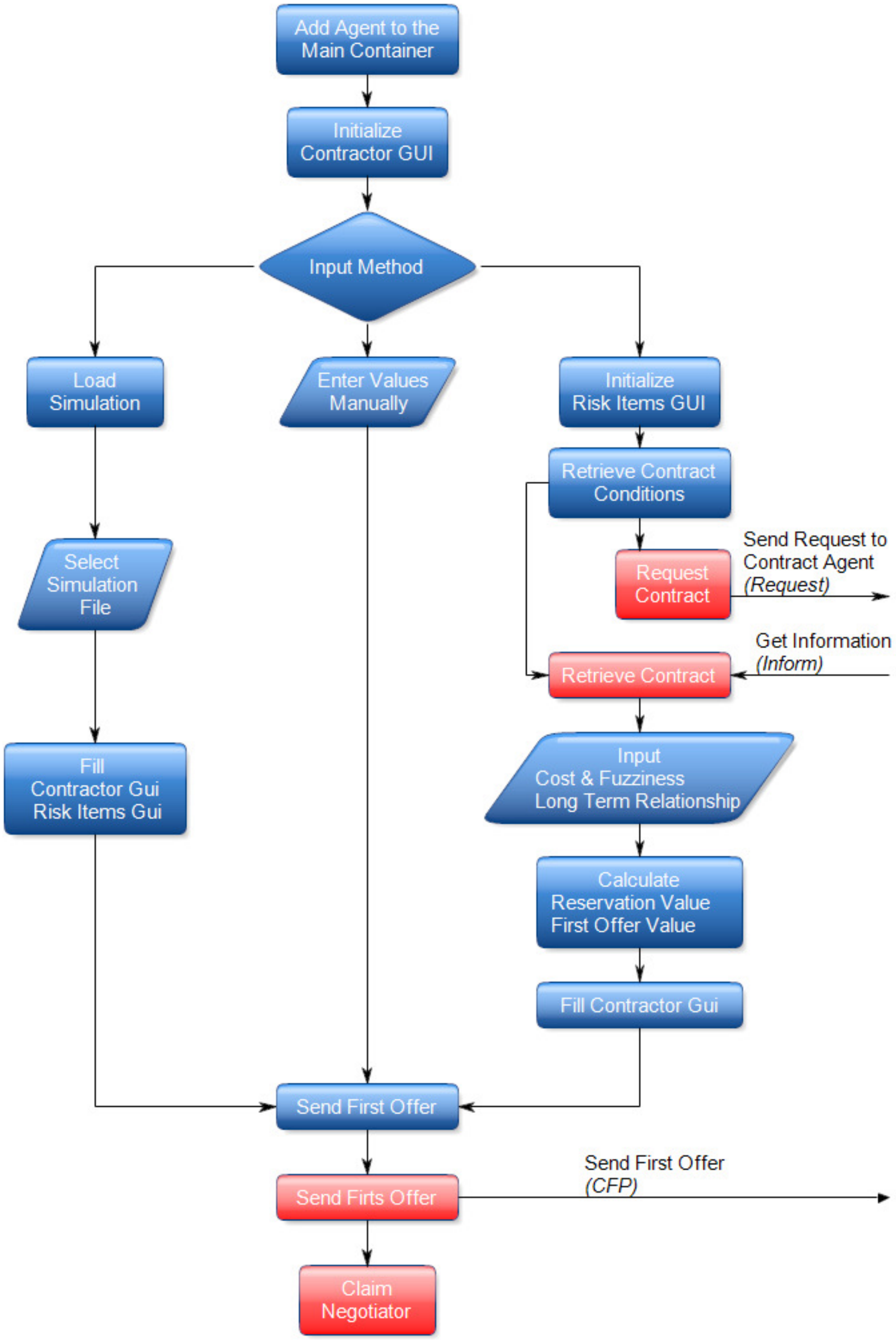


Figure 3-6 Workflow for determination of Contractor Agent's First Offer and Reservation Values

Contractor Agent is added with the initialization of JADE framework and Contractor GUI is displayed. Just like Client agent user has three choices, enter the reservation and first offer values manually, load a previous simulation or initialize Risk Items GUI. If the Risk Items GUI is selected user inputs cost and fuzziness values for each risk item. Risk items are retrieved from the Contractor Agent. An ACL message with "Request" performative is sent to the Contract Agent. Contract Agent replies with a message with "Inform" performative, content of this message contains the risk items and their responsible party assignments. In this GUI user also inputs if there is a possibility of having a long term relationship with Client Agent. Then program calculates the first offer and reservation values and transfer control to Send First Offer method. This method adds Send First Offer behaviour to the pool of active behaviours. This behaviour is a one shot behaviour and only executes once to send the first offer than terminates. Send First Offer behaviour also adds Claim Negotiator behaviour which waits in a blocked state for the Client agent's reply.

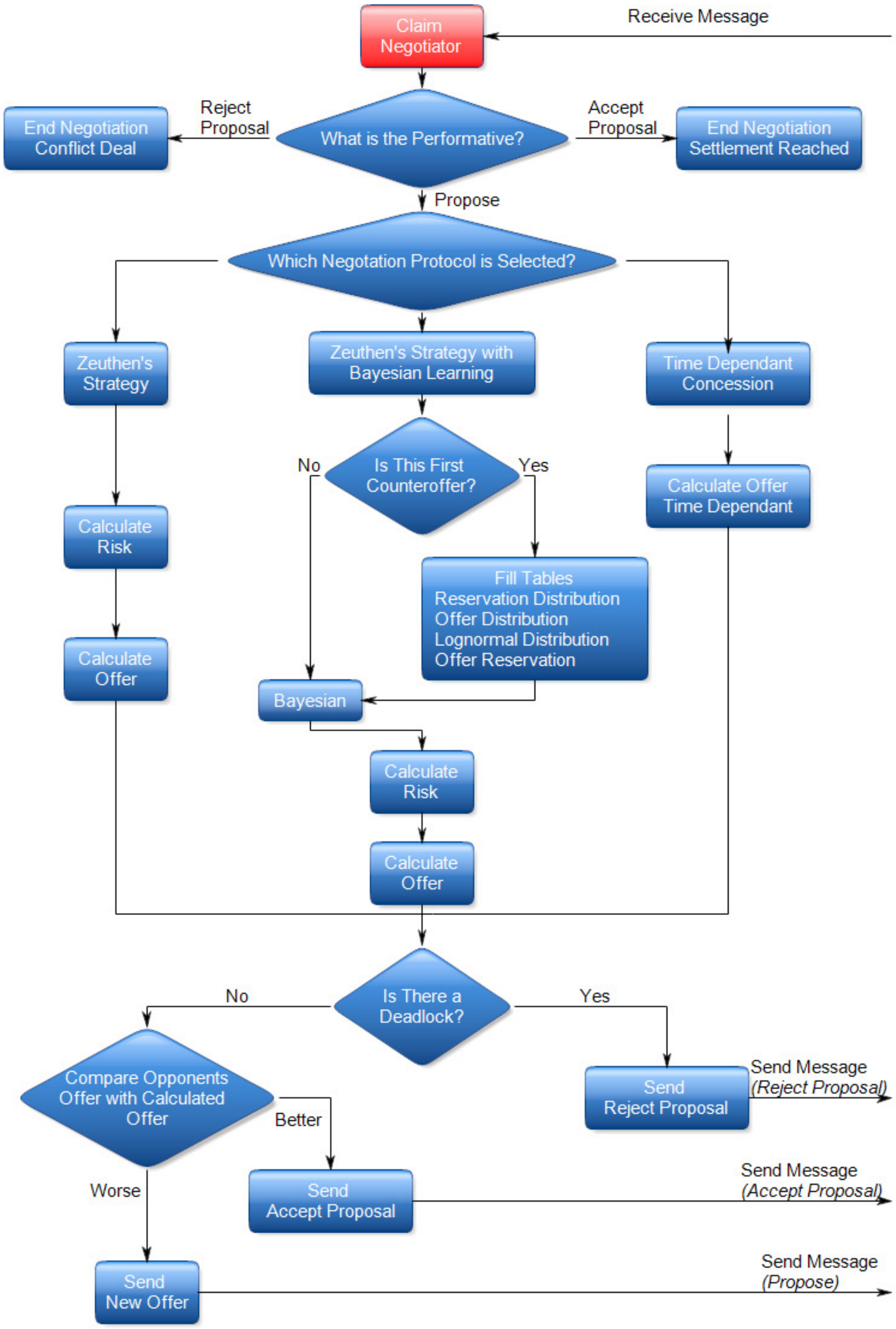


Figure 3-7 Negotiation workflow for Contractor and Client Agents

Same negotiation protocols are used for both of the agents so workflows of the agents are very similar to each other and represented with one flowchart. When an offer is received from the other party Claim Negotiator behaviour is activated. Behaviour responds differently depending on the ACL performative of the received message. If the message has “Accept Proposal” performative this means opponent has accepted the offer, so negotiations ends successfully with a settlement value. If the “Reject Proposal” performative is received than agent understands opponent has ended the negotiation with a conflict deal, so agent ends the negotiations with a conflict deal. For both of these cases the Claim Negotiator behaviour is removed from the pool of active behaviours. But if the performative is “Propose” this means a new offer is received. So behaviour carries out the offer calculation and evaluation process. This behaviour can follow three different paths according to selected negotiation protocol. Each protocol follows a different path to calculate the new offer. Than agent checks if there is a deadlock by checking each agents previous offers. If there is a repetition in both agents’ offers than a deadlock is identified and an ACL message with “Reject Proposal” performative is sent to end the negotiation. If there is no deadlock, calculated offer is compared with opponent agent’s offer. For example for the Contractor Agent if the calculated offer on this turn is lower than the opponent’s offer than agent accepts the client agent’s offer. In this case a message with “Accept Proposal” performative is sent. If the agent is not satisfied with the opponent’s offer than new offer is sent with a message which contains new offer value as the content and “Propose” as the FIPA performative.

3.5 Advantages of the Developed MAS with Compared to Previous Studies

Developed model has the following advantages and extra features with respect to the similar studies done in the field;

- Model can calculate the main input variables of the negotiation process. First offer and reservation values can be determined by the model depending on the contract conditions and negotiation environment.
- A separate contract agent is available to represent the contract conditions. This agent can also use the conditions defined in FIDIC contract conditions.
- More than one negotiation protocol can be used in the model. 3 negotiation protocols are available for each agent to use. This also gives the user to make comparison between different negotiation protocols.
- Asymmetric negotiation is possible; each agent may use different negotiation protocol to determine its negotiation strategy.
- Model is fully compatible with FIPA specifications. Extending the model for future studies or adding agents developed by other researcher is possible.

CHAPTER 4

A MULTI-AGENT MODEL FOR CONSTRUCTION CLAIM NEGOTIATION

4.1 Introduction

This study focuses on the claim negotiation process in the construction industry. A multi-agent system is designed for this purpose. To be able to simulate real life negotiation process 2 agents that represent the contractor and client sides of the negotiation has been created. Also a contract agent which represents the role of a legal adviser about the contract conditions is added to the model. Negotiation process is modeled using a game theoric approach and input values for the process was created using fuzzy logic. JADE was used to create the software system and whole process is carried out with using international standards for the multi-agent systems. Sensitivity analyses are done for the items that affect the negotiation process. This chapter is devoted to introduce the details of calculation of the input parameters and work process of negotiation protocols and agents created in the software.

4.2 Calculation of Input Variables

Three different negotiation protocols are used in the study. All of these protocols are dependent on same two input variables, Reservation value and First offer of the agent. Model can calculate these values with using some input variables about the claim environment. So before going to the details of these strategies determination of these two variables will be discussed.

4.2.1 Reservation Amount

Reservation value is the amount that defines the limits of offer values for an agent. For the contractor agent reservation value is the lowest acceptable amount that can be accepted, any offer lower than this value is not acceptable even if rejecting the offer would mean a deadlock. On the other hand for the client agent reservation amount sets the limit for highest value for an offer. Offers higher than this value would be rejected regardless of the outcomes.

Determination of the reservation value has different calculation processes due to the individual characteristics of each agent. These processes for Contractor and Client agents are as follows.

4.2.1.1 Contractor Agent

Contractor agent determines its reservation amount depending on the responsibility distribution of the risk items, fuzziness attached to each item and possibility of a future relationship with the client.

Risk items are the items that cause the increase in the cost of the construction. These items are listed in the FIDIC contract conditions with the definition of the responsible party for each item. Responsibilities of each item are assigned to the one of the three sources; Contractor agent, Client agent or Shared due to source. Some example of these items with their related responsible party assignments with respect to FIDIC can be given as;

"Adverse change in availability of material (Contractor's responsibility), Delay in progress payments (Client's responsibility), Accidents (Shared Responsibility), etc." Up to 10 risk items can be defined in the model.

List of the Risk items with their responsible party assignments are retrieved from the Contract agent. User inputs the share of each risk item on the total claim amount. Total of these values must add up to 100 since these values are not the real claim amount instead they are the percentages which shows the participation of each item on the total cost increase.

There is always a certain level of uncertainty on each value entered for the risk items. Even if the user inputs a single value for the share of each risk item these values are not always exact. Each value has some degree of fuzziness related to it. For example calculating a certain claim amount for an item like "loss of productivity" would be difficult and calculated amount would have a high degree of fuzziness, on the other hand claim amount due to an item like "increase in material costs" would have a lower uncertainty on it and thus have a lower fuzziness level. So in order to reflect this situation, user also enters a fuzziness level for each one of the risk items. Fuzziness levels can be selected as "low", "medium" or "high". Each level corresponds to a percentage definition like 5% for low and 15% for high fuzziness. These definitions also can be changed by the user. By using these values model calculates a range for each claim amount. For example, a claim amount of 35 with a high fuzziness (i.e. 15% percentage) definition would represent a linear distribution of;

$$35 \times \left(1 - \frac{15}{100}\right) \leftrightarrow 35 \times \left(1 + \frac{15}{100}\right)$$

$$29.75 \leftrightarrow 40.25$$

So this claim amount may vary between 29.75 and 40.25 with equal probability.

Possibility of having a future relationship with the client is also an important aspect that affects the behaviour of the contractor agent. If there is a chance of taking another job from the client in the future this will lead to a less aggressive stance for the contractor. On the other hand if there is no possibility of having a future project then contractor would try to maximize its benefit from this encounter. To be able to model this situation user also enters if there will be a long term objective with the client or not.

With using these information model first calculates Minimum Claim Amount and Optimum Claim Amount. Minimum Claim Amount represents the amount which contractor agent would under no circumstances fall below. This amount is represented by the items which are assigned to client agent's responsibility. As these claim amounts define a range with their fuzziness definitions, lower limit of this range is used in the calculation of Minimum Claim Amount.

$$C_{min} = \sum_{1}^{i} C(CL)_i \times \left(1 - \frac{F_i}{100}\right) \quad for\ i = 1,2 \ldots,10$$

Where,

C_{min} : Minimum possible claim amount.

$C(CL)_i$: Claim amount “i” which is under the responsibility of the client agent. Only the items that are assigned to client agent are used.

F_i : Fuzziness on the i’th claim amount. Percentage definitions of the fuzzy level definitions are used.

Optimum Claim Amount represents the total claim amount that is arisen due to client agent’s responsibilities and shared responsibilities. No fuzziness is taken into account while computing the Optimum Claim Amount.

$$C_{opt} = \sum_{1}^{i} \left(C(CL)_i + C(S)_i \right) \quad for\ i = 1,2 \ldots,10$$

Where,

C_{opt} : Optimum claim amount.

$C(CL)_i$: Claim amount “i” which is under the responsibility of the client agent. Only the items that are assigned to client agent are used.

$C(S)_i$: Claim amount “i” which is under the shared responsibility.

Reservation amount is calculated differently depending on the possibility of a future relationship with the client.

If there is a long term objective with the client then;

$$\text{Reservation Amount} = C_{min}$$

If there is no long term objective with the client then the reservation amount falls between C_{min} and C_{opt} . Model takes these two values and also takes a coefficient from the user as input and determines the reservation amount with the following formula;

$$Reservation\ Amount = C_{opt} - \left[\left(C_{opt} - C_{min}\right) \times \frac{LT}{100}\right]$$

Where,

LT: Long term effect multiplier.

4.2.1.2 Client Agent

Client agent's reservation value depends on the Client's knowledge level about the work done and Client's attitude against the contractor. These two variables are used to create a 2x2 matrix and each item in the matrix represents a multiplier for the calculation of the reservation amount.

Table 4-1 Multiplier definitions for Client Agent's Reservation Amount

Knowledge Level Attitude	High	Low
Favorable	FH_R	FL_R
Unfavorable	UH_R	UL_R

These multipliers are taken by user input. Calculation of reservation amount for each case is done differently.

1. High Knowledge

   If the knowledge level of the client about the work is high then it is accepted that the client have information about the real increase in the cost of work done. This knowledge can be either gathered by the previous experience of the client or a consultant engineer representing the client in the field. So share of claim amounts entered by the contractor agent is also exposed to the client agent, client agent can read the total increase in the cost. This is done by direct share of the information in the code, not by an agent communication process (i.e. ACL messaging). This is due to the fact that client agent does not asks for the information instead it knows it by itself.

With this information provided client agent calculates its reservation amount with the following formula;

$$\textit{Reservation Amount} = \begin{Bmatrix} C_{opt} \times FH_R, & \text{if the attitude is favorable} \\ C_{opt} \times UH_R, & \text{if the attitude is unfavorable} \end{Bmatrix}$$

Where,

C_{opt} : Optimum claim amount calculated by the contractor agent. Only client and shared items are taken into consideration.

FH_R: Reservation amount multiplier for high knowledge and favourable attitude.

UH_R: Reservation amount multiplier for high knowledge and unfavourable attitude.

2. Low Knowledge

If the client agent has low knowledge then it has no access to real claim amounts. So it takes its stance depending on the first offer given by the contractor. Calculations are done with the following formula;

$$\textit{Reservation Amount} = \begin{Bmatrix} \text{Offer}_{CT1} \times FL_R, & \text{if the attitude is favorable} \\ \text{Offer}_{CT1} \times UL_R, & \text{if the attitude is unfavorable} \end{Bmatrix}$$

Where,

Offer_{CT1}: First offer given by the contractor

FL_R: Reservation amount multiplier for low knowledge and favourable attitude.

UL_R: Reservation amount multiplier for low knowledge and unfavourable attitude.

4.2.2 First Offer Value

First offer is the initial offer given by an agent. This value defines the highest utility for the agent. Calculation of the fist offer is different for client and contractor agent.

4.2.2.1 Contractor Agent

Contractor agent's first offer value is always higher than its reservation value. Calculation of this value just like the reservation amount depends on the responsibility distribution of risk items and fuzziness attached to each item. Definitions for these terms are identical with those explained in the reservation amount calculation steps. These item descriptions and values entered by the user used for both the calculation of reservation amount and first offer value.

First offer value is the summation of cost items which the client is responsible for and items with a shared responsibility. Claim amounts associated to these items define a range with their fuzziness definitions. While calculating the first offer upper limit of this range is used. Possibility of a long term objective with the client has no effect on the calculation process. Calculation of the first offer value for the contractor agent done with the following formula;

$$First\ Offer = \sum_{1}^{i}\left[\left(C(CL)_i \times \left(1 + \frac{F_i}{100}\right)\right) + \left(C(S)_i \times \left(1 + \frac{F_i}{100}\right)\right)\right]$$

$for\ i = 1,2 \ldots,10$

Where,

$C(CL)_i$: Claim amount "i" which is under the responsibility of the client agent. Only the items that are assigned to client agent are used.

$C(S)_i$: Claim amount "i" which is under the shared responsibility.

F_i : Fuzziness on the i'th claim amount. Percentage definitions of the fuzzy level definitions are used.

4.2.2.2 Client Agent

First offer of the client agent is calculated similar to its reservation value. It depends on the client's knowledge level about the construction and its attitude against the contractor. These variables form a 2x2 matrix and each item in the matrix represents a multiplier for the calculation of the first offer value.

Table 4-2 Multiplier definitions for Client Agent's First Offer Value

Knowledge Level / Attitude	High	Low
Favorable	FH_F	FL_F
Unfavorable	UH_F	UL_F

These values are taken as user input. Calculations for each case are carried out differently

1. High Knowledge

Just like reservation amount calculations high knowledge of the client agent gives it direct access to real claim amounts entered by the contractor agent. Client agent calculates its first offer as follows;

$$First\ Offer = \begin{Bmatrix} \mathrm{C_{opt}} \times \mathrm{FH_F}, & \text{if the attitude is favorable} \\ \mathrm{C_{opt}} \times \mathrm{UH_F}, & \text{if the attitude is unfavorable} \end{Bmatrix}$$

Where,

C_{opt}: Optimum claim amount calculated by the contractor agent. Only client and shared items are taken into consideration.

FH_F: First offer multiplier for high knowledge and favourable attitude.

UH_F: First offer multiplier for high knowledge and unfavourable attitude.

2. Low Knowledge

If the client agent has low knowledge about the construction process it has no access to real claim amounts. So first offer is calculated depending on the offer received from the contractor agent

$$First\ Offer = \begin{Bmatrix} \mathrm{Offer_{CT1}} \times \mathrm{FL_F}, & \text{if the attitude is favorable} \\ \mathrm{Offer_{CT1}} \times \mathrm{UL_F}, & \text{if the attitude is unfavorable} \end{Bmatrix}$$

Where,

$Offer_{CT1}$: First offer given by the contractor

FL_F: First offer multiplier for low knowledge and favourable attitude.

UL_R: First offer multiplier for low knowledge and unfavourable attitude.

4.2.3 Sensitivity Analysis

Negotiation process depends mainly on the reservation and first offer values. Calculation of these values depends on some variables as described in the previous section. To be able to have a better understanding of impact of each variable on the calculation of these values, sensitivity analysis has been performed. These analyses done up to the limit conditions and extreme cases are used to represent model behaviour in a wide range.

4.2.3.1 Analysis of distribution of risk items

Each risk item has a responsible party assignment; Contractor, Client or Shared these items can be entered by the user or can be retrieved from the FIDIC conditions. User also enters the share of each risk item on the total claim value. This information determines the distribution of the responsible party assignments on the total claim amount. As can be seen from the calculation steps of reservation and first offer amounts this distribution has a great effect on the values. To be able to observe these effects, three different extreme cases are observed with using constant fuzziness definitions;

1. No shared contribution (changing contractor and client contributions)

   To observe the impact of increasing client contribution on the reservation and first offer values, shared responsibility is ignored and risk items are distributed between contractor and client parties. Fuzziness is taken constant as 10% and cases with or without long term objective with the client is observed. Long term effect multiplier is taken as 50%.

Table 4-3 Effect of increasing client contribution with decreasing contractor contribution

Client Responsibility %	**Reservation (Long Term)**	**First Offer (Long Term)**	**Reservation (No Long Term)**	**First Offer (No Long Term)**	***Claim Optimum***
100	90	110	95	110	100
95	85.5	104.5	90.25	104.5	95
90	81	99	85.5	99	90
85	76.5	93.5	80.75	93.5	85
80	72	88	76	88	80
75	67.5	82.5	71.25	82.5	75
70	63	77	66.5	77	70
65	58.5	71.5	61.75	71.5	65
60	54	66	57	66	60
55	49.5	60.5	52.25	60.5	55
50	45	55	47.5	55	50
45	40.5	49.5	42.75	49.5	45
40	36	44	38	44	40
35	31.5	38.5	33.25	38.5	35
30	27	33	28.5	33	30
25	22.5	27.5	23.75	27.5	25
20	18	22	19	22	20
15	13.5	16.5	14.25	16.5	15
10	9	11	9.5	11	10
5	4.5	5.5	4.75	5.5	5
0	0	0	0	0	0

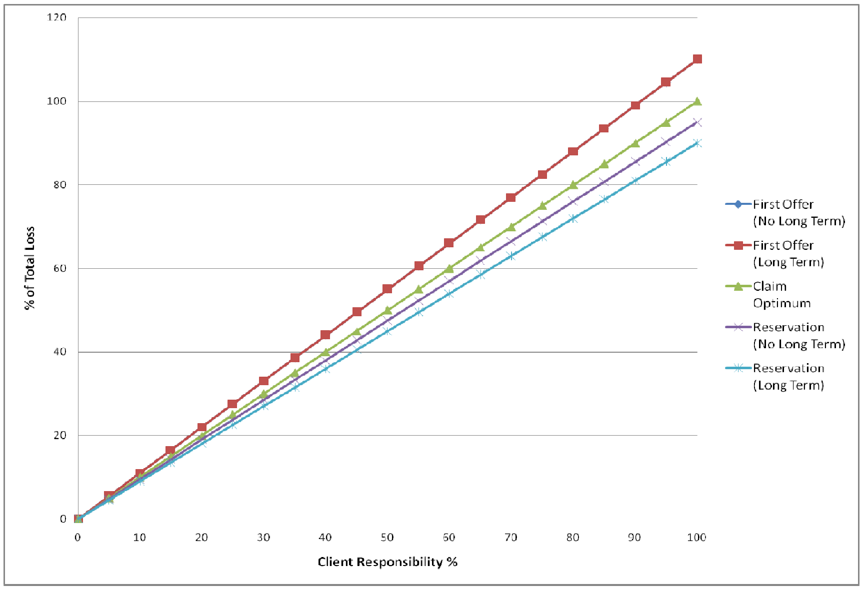


Figure 4-1 Effect of increasing client contribution with decreasing contractor contribution

In the above table and figure optimum claim amount is the sum of client and shared risk items with no fuzziness attached. From the values it can be seen that as the contribution of client agent increases first offer and reservation values increases. Reservation value is always lower when there is a possibility of long term objective with the client compared with the case when there is no long term objective. First offer value is not affected from the long term objective with the client but it is always higher than the optimum value. It can be also seen that even if all the loss is under the client responsibility still the reservation value is lower than 100%. This is due to the fuzziness attached to each risk item.

2. No client contribution (changing contractor and shared contributions)

   To observe the impact of increasing shared contribution on the reservation and first offer values, client responsibility is ignored and risk items are distributed between contractor items and shared items. Fuzziness is taken constant as 10% and cases with or without long term objective with the client is observed. Long term effect multiplier is taken as 50%.

Table 4-4 Effect of increasing shared contribution with decreasing contractor contribution

Shared Responsibility %	**Reservation (Long Term)**	**First Offer (Long Term)**	**Reservation (No Long Term)**	**First Offer (No Long Term)**	***Claim Optimum***
100	0	110	50	110	100
95	0	104.5	47.5	104.5	95
90	0	99	45	99	90
85	0	93.5	42.5	93.5	85
80	0	88	40	88	80
75	0	82.5	37.5	82.5	75
70	0	77	35	77	70
65	0	71.5	32.5	71.5	65
60	0	66	30	66	60
55	0	60.5	27.5	60.5	55
50	0	55	25	55	50
45	0	49.5	22.5	49.5	45
40	0	44	20	44	40
35	0	38.5	17.5	38.5	35
30	0	33	15	33	30
25	0	27.5	12.5	27.5	25
20	0	22	10	22	20
15	0	16.5	7.5	16.5	15
10	0	11	5	11	10
5	0	5.5	2.5	5.5	5
0	0	0	0	0	0

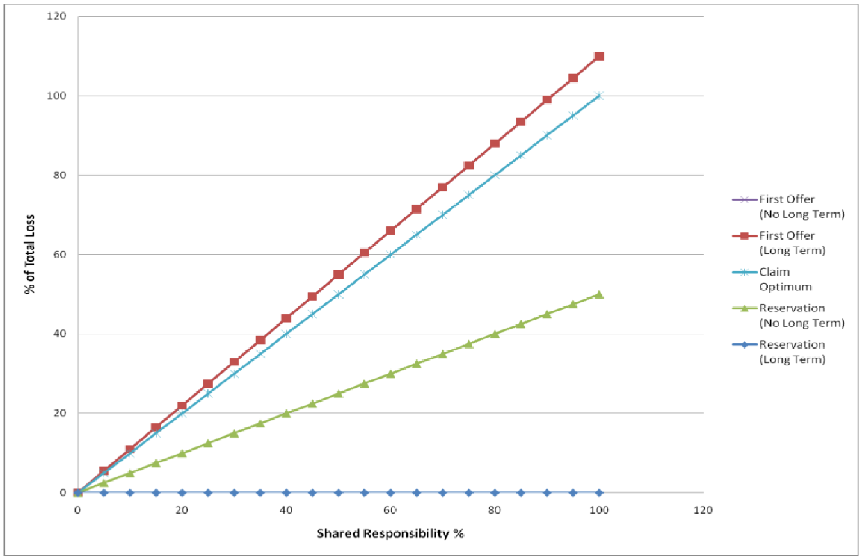


Figure 4-2 Effect of increasing shared contribution with decreasing contractor contribution

As can be observed from the results first offer values shows the same trend with the first case where there is no shared contribution. This is due to the fact that in the calculation of the first offer value items that are under the client responsibility and the items that have a shared responsibility has the same contribution to the first offer value. Most important change in the results is in the reservation amount values. There is a significant drop in the reservation values when there is no long term relationship with the client and values even drops to zero when there is a possibility of a long term relationship. This shows that when there is a long term relationship with the client and client has no full responsibility on any of the risk items then contractor agent is ready to compensate all of the loss itself due to its intention to take another job from the client. And for the case when there is no long relationship with the client the reservation value is only affected from the long term effect multiplier which is entered by the user.

3. No contractor contribution (changing client and shared contributions)

   In this analysis, case that contractor has no responsibility in any of the items is used. Risk items are distributed between client items and shared items. Fuzziness is taken constant as 10% and cases with or without long term objective with the client is observed. Long term effect multiplier is taken as 50%.

Table 4-5 Effect of increasing client contribution with decreasing shared contribution

Client Responsibility %	**Reservation (Long Term)**	**First Offer (Long Term)**	**Reservation (No Long Term)**	**First Offer (No Long Term)**	***Claim Optimum***
0	0	110	50	110	100
5	4.5	110	52.25	110	100
10	9	110	54.5	110	100
15	13.5	110	56.75	110	100
20	18	110	59	110	100
25	22.5	110	61.25	110	100
30	27	110	63.5	110	100
35	31.5	110	65.75	110	100
40	36	110	68	110	100
45	40.5	110	70.25	110	100
50	45	110	72.5	110	100
55	49.5	110	74.75	110	100
60	54	110	77	110	100
65	58.5	110	79.25	110	100
70	63	110	81.5	110	100
75	67.5	110	83.75	110	100
80	72	110	86	110	100
85	76.5	110	88.25	110	100
90	81	110	90.5	110	100
95	85.5	110	92.75	110	100
100	90	110	95	110	100

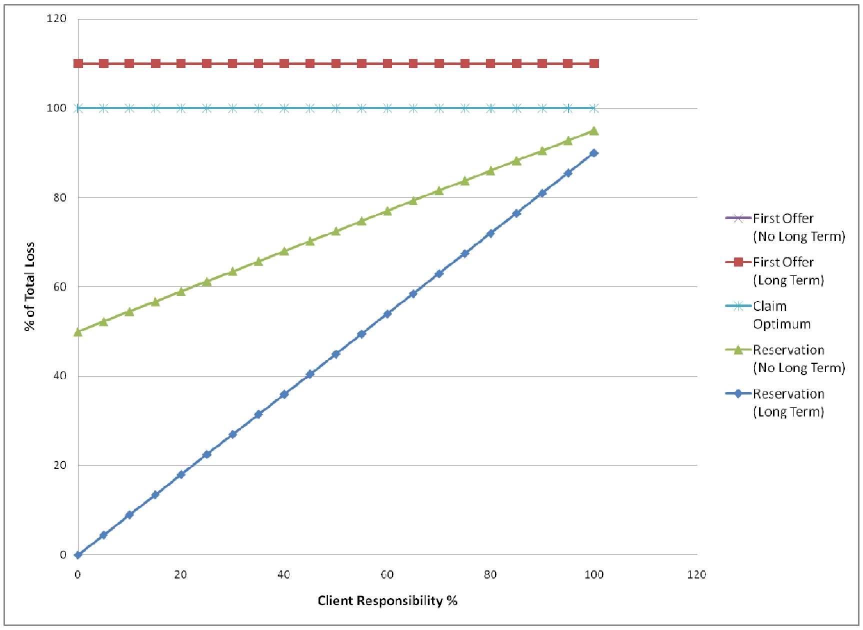


Figure 4-3 Effect of increasing client contribution with decreasing shared contribution

Above data shows that first offer value has no relationship with the composition of client and shared responsibilities as long as their summation is constant. It can also be seen that major factor that affects the reservation value is the contribution of client items. As the share of client items increases in the total loss the reservation value is increases. This is a result of the fact that under no circumstances contractor agent wants to compensate the losses due to the items that falls under client's responsibility. On the other hand, contractor agent accepts to cover some or all of the losses due to shared sources depending on the possibility of a long term relationship.

4.2.3.2 Analysis of effect of fuzziness definitions

For each risk item user inputs a claim amount and selects a fuzziness level for these amounts. In the program user can select the fuzziness level as “low”, “medium” or “high”. Model assigns separate values for each fuzzy level definition like 5% for low, 10% for medium and 15% for high which can also be modified by the user. These definitions have an important effect on the model since these values define a range for each claim item and these ranges are used for the calculation of the reservation and first offer values. To be able to observe the effect of these fuzzy level definitions fuzzy level definitions are changed while keeping the responsible party assignments and long term effect multiplier as constant. Responsible party assignments are used as 40% Contractor, 30% Client and 30% Shared. Long term effect multiplier is taken as 50%.

Table 4-6 Effect of increasing fuzziness level

Fuzziness %	**Reservation (Long Term)**	**First Offer (Long Term)**	**Reservation (No Long Term)**	**First Offer (No Long Term)**	***Claim Optimum***
0	30	60	45	60	60
5	28.5	63	44.25	63	60
10	27	66	43.5	66	60
15	25.5	69	42.75	69	60
20	24	72	42	72	60
25	22.5	75	41.25	75	60
30	21	78	40.5	78	60
35	19.5	81	39.75	81	60
40	18	84	39	84	60
45	16.5	87	38.25	87	60
50	15	90	37.5	90	60
55	13.5	93	36.75	93	60
60	12	96	36	96	60
65	10.5	99	35.25	99	60
70	9	102	34.5	102	60
75	7.5	105	33.75	105	60
80	6	108	33	108	60
85	4.5	111	32.25	111	60
90	3	114	31.5	114	60
95	1.5	117	30.75	117	60
100	0	120	30	120	60

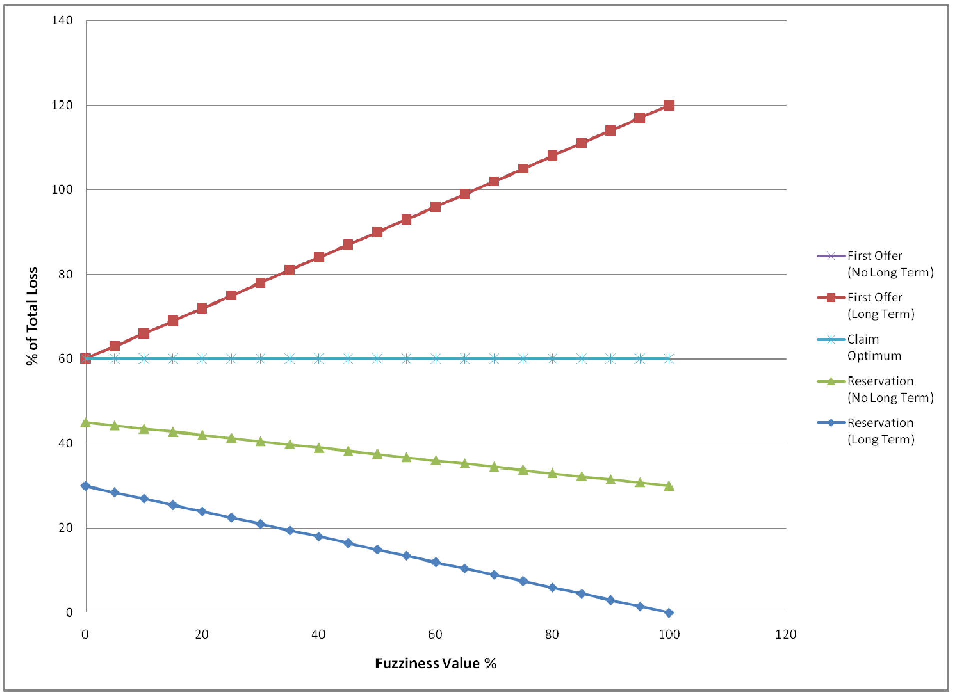


Figure 4-4 Effect of increasing fuzziness level

Data shows us the effect of increasing fuzziness. Greater fuzziness levels leads agent to give higher first offer values since agent uses the upper limit of the defined range for the claim amounts. On the other hand, reservation values drops due to the higher level of uncertainty. Agent tries to avoid a deadlock and uses the lower limit of the reservation values.

4.2.3.3 Analysis of effect of long term objective

Possibility of a long term objective with the client agent leads contractor agent to use possible minimum claim amount as its reservation value. But if there is no intention of having a future relationship with the client then the contractor agent's reservation value falls between minimum claim amount and optimum claim amount. In this case long term effect multiplier determines the exact value of the reservation value. This value is input by the user. While calculating the effect of long term effect multiplier other variables are taken as constant. Responsible party assignments are used as 40% Contractor, 30% Client and 30% Shared and fuzziness is taken as 50%.

Table 4-7 Effect of increasing long term effect multiplier

Long Term Multiplier %	Reservation (Long Term)	First Offer (Long Term)	Reservation (No Long Term)	First Offer (No Long Term)	*Claim Optimum*
0	15	90	60	90	60
5	15	90	57.75	90	60
10	15	90	55.5	90	60
15	15	90	53.25	90	60
20	15	90	51	90	60
25	15	90	48.75	90	60
30	15	90	46.5	90	60
35	15	90	44.25	90	60
40	15	90	42	90	60
45	15	90	39.75	90	60
50	15	90	37.5	90	60
55	15	90	35.25	90	60
60	15	90	33	90	60
65	15	90	30.75	90	60
70	15	90	28.5	90	60
75	15	90	26.25	90	60
80	15	90	24	90	60
85	15	90	21.75	90	60
90	15	90	19.5	90	60
95	15	90	17.25	90	60
100	15	90	15	90	60

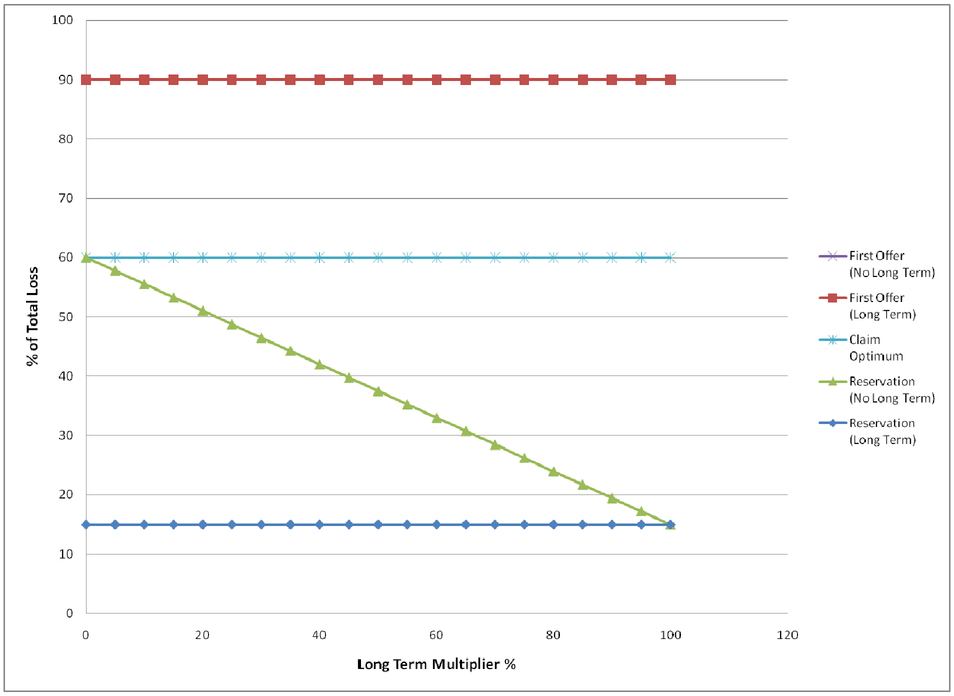


Figure 4-5 Effect of increasing long term effect multiplier

As can be seen from above results, increasing long term effect multiplier only affects the reservation value for the case when there is no long term relationship with the client. Increasing long term effect multiplier value leads reservation amount to drop towards the amount of reservation value where there is a long term relationship.

4.3 Negotiation Protocols

In this study three different negotiation protocols are used. For each simulation each agent is free to select the protocol that it will use during the process independently. This approach gives the model the ability of simulating unsymmetrical negotiations which agents may have different beliefs and may be under different conditions. In the model the three negotiation protocols used are;

- Zeuthen's strategy (Complete information)
- Zeuthen's strategy with Bayesian Learning (Incomplete information)
- Time dependant concession

4.3.1 Zeuthen's strategy

Zeuthen's strategy models the negotiation process by comparing the gains and losses. It measures each agent's willingness to risk conflict. Agents' calculates the utilities for various cases and then makes its decision with using these utility values. At each round an agent determines the loss of its utility due to accepting opponents offer and loss due to rejecting the offer and running into a conflict(conflict has an utility of 0). Ratio of these items is the calculated risk for this agent (Rosenschein & Zlotkin, 1994).

$$Risk_i^t = \left\{\begin{matrix} 1, & \text{if } \mathrm{Utility}_t(\delta_i^t) = 0 \\ \dfrac{\mathrm{Utility}_i(\delta_i^t) - \mathrm{Utility}_t(\delta_j^t)}{\mathrm{Utility}_t(\delta_j^t)}, & \text{otherwise} \end{matrix}\right\}$$

Where,

t: Negotiation step

i: Agent that makes the decision

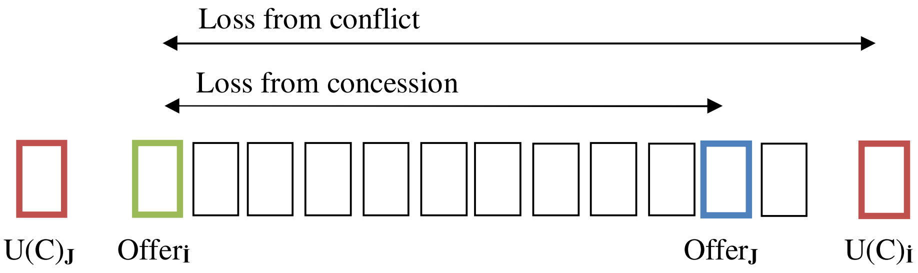
j: Opponent agent

δ^{t}_{i}: Offer made by agent i at step t

Or if we use words;

$$Risk_i^t = \frac{\text{Utility agent 1 loses by conceding and accepting agent 2's offer}}{\text{Utility agent 1 loses by not conceding and causing a conflict}}$$

Risk is the indication of how much an agent willing to risk a conflict by sticking to his last offer. As risk grows, agent has less to lose from a conflict, and will be more willing to not concede, and risk reaching a conflict (Rosenschein & Zlotkin, 1994).



As can be seen from the drawing as the utility for an offer approaches to utility of conflict U(C), ratio between concession and conflict which is defined as the risk increases. In this negotiation protocol at each round the concession for an agent is the minimum amount that will make the opponents risk smaller or equal to agents own risk. Agent with smaller risk will make the concession at each round.

Model used in this study also uses a cost of time for each round. As the rounds progresses this cost increases. This is included in the model to reflect the time dependent behaviour of claim negotiations. So at each round concession made by the agents is not only calculated by the risk evaluation of the agents but also cost of time taken into consideration. This leads agents to make a greater concession. At each round with using these inputs agents calculates its offer and either makes a concession or offers the same amount that it offered on previous round. There is no decision regret in the model so agents do not give values which will reduce their risk. For example contractor agent starting from its first offer at each round will reduce or give the same amount as its offer and never return back to its previous values.

Risk formula for each agent can be expressed as follows;

$$R_{Ctr} = \frac{\mathrm{U}^{t}_{\mathrm{CtrCtr}} - \mathrm{U}^{t}_{\mathrm{CtrCln}}}{\mathrm{U}^{t}_{\mathrm{CtrCtr}} - \mathrm{U}_{\mathrm{Ctr}}(\mathrm{C})}; \quad R_{Cln} = \frac{\mathrm{U}^{t}_{\mathrm{ClnCln}} - \mathrm{U}^{t}_{\mathrm{ClnCtr}}}{\mathrm{U}^{t}_{\mathrm{ClnCln}} - \mathrm{U}_{\mathrm{Cln}}(\mathrm{C})}$$

Where,

R_{Ctr} : Calculated risk for contractor agent for round t.

R_{Cln} : Calculated risk for client agent for round t.

U^{t}_{CtrCtr} : Utility of contractor agent due to its own offer in round t.

U^{t}_{ClnCln} : Utility of client agent due to its own offer in round t.

U^{t}_{CtrCln} : Utility of contractor agent due to client agent’s offer in round t.

U^{t}_{ClnCtr} : Utility of client agent due to contractor agent’s offer in round t.

$U^{t}_{Ctr}(C)$: Utility of conflict for contractor agent.

$U^{t}_{Cln}(C)$: Utility of conflict for client agent.

Utility of conflict for each agent in the model is 0. Utility for given offers are calculated with using the utility curves for each agent. Utility curves for the agents are linear and only dependant on the first offer and reservation values. So for each agent utility curves are defined as;

Utility for First Offer Value: 1

Utility for First Reservation Value: 0.6

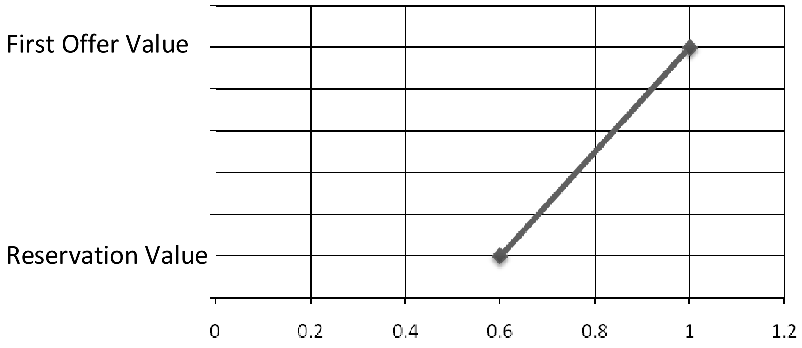


Figure 4-6 Utility curve for contractor agent

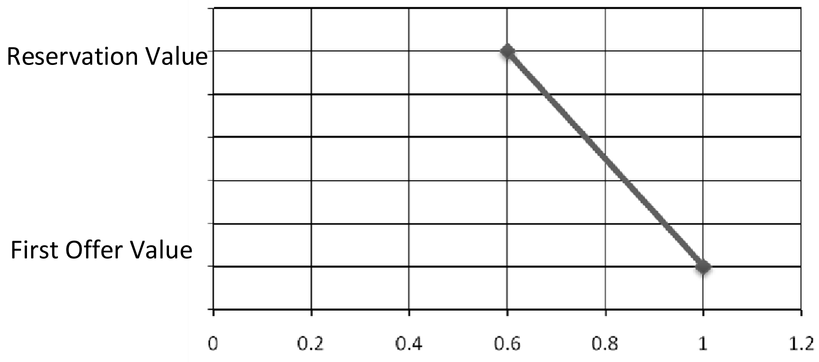


Figure 4-7 Utility curve for client agent

With using its utility curve at each round agent calculates the utility due to its previous offer and utility due to its opponent offer. Zeuthen strategy uses fully informed agents, so each agent can also access to its opponent's reservation value. This information and first offer received from the opponent agent used to calculate other agent’s utility curve and its risk for that round. Then opponent’s risk is compared with agent’s own risk and if risk for the opponent is greater than the agent’s own risk value, a concession is made. Value of this concession is the minimum amount that will make the opponent agents risk equal or smaller than the agent’s own risk. While making the calculations for concession a time penalty is also considered.

4.3.1.1 Example Negotiation

As an example negotiation a typical case is selected with the following conditions.

Contractor Agent		
	Value	**Utility**
Reservation Value	65	0.6
First Offer Value	95	1
Utility Conflict		0
Time Penalty (%)	3	

Client Agent		
	Value	**Utility**
Reservation Value	85	0.6
First Offer Value	60	1
Utility Conflict		0
Time Penalty (%)	3	

As stated earlier utility values are hard-coded into the model so user cannot change them but all remaining values can be changed by user input.

Round 1

In this first round simply first offer values are passed between the agents, first contractor agents gives its offer then client agent replies back with its starting offer;

Round1	Offer
Contractor	95
Client	60

Round 2

Contractor Agent

After receiving client agents offer contractor agent calculates utilities that are needed for risk calculations;

U_{CtrCtr} : Utility of contractor agent due to its own offer

Since contractor agent's last offer was its first offer value it has a utility of 1 for the contractor agent.

U_{CtrCln} : Utility of contractor agent due to client agent's offer in round t.

Client agent's offer from the first round was 60; utility of this value for the contractor agent is calculated with linear interpolation between first offer and reservation values. Result is 0.53 as can be seen from below graph.

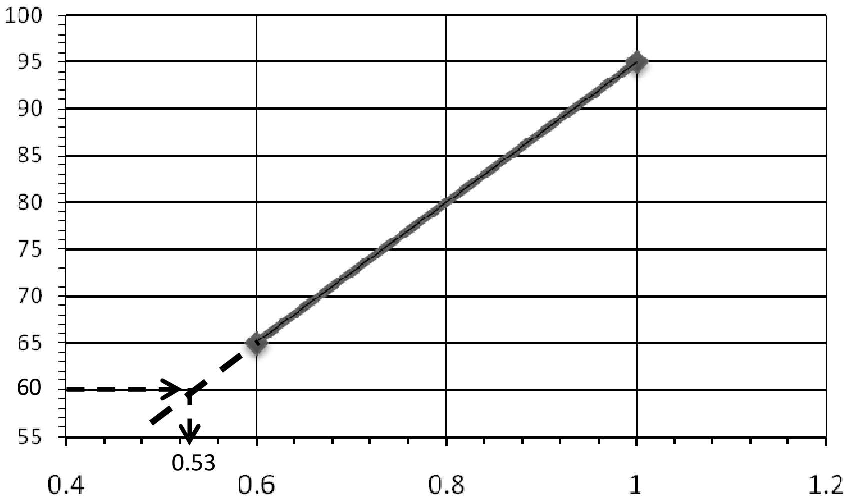


Figure 4-8 Linear interpolation for contractor agent's utility

Contractor agent also calculates the utilities for client agent since this information will be used for calculation of the client agent's risk perception.

U_{ClnCln} : Utility of client agent due to its own offer

Client agent's last offer was its first offer value so it has a utility of 1.

U_{ClnCtr} : Utility of client agent due to contractor agent's offer in round t.

Contractor agent's last offer was 95. A linear interpolation between client agent's first offer and reservation values is made to find associated utility for this value. Result is 0.44.

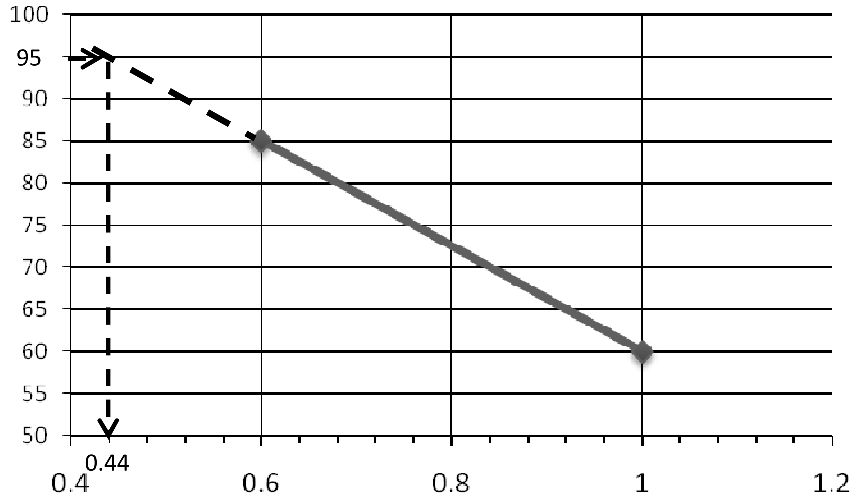


Figure 4-9 Linear interpolation for client agent's utility

So risk for each agent is;

$$R_{Ctr} = \frac{U^t_{CtrCtr} - U^t_{CtrCln}}{U^t_{CtrCtr} - U_{Ctr}(C)}; \quad R_{Cln} = \frac{U^t_{ClnCln} - U^t_{ClnCtr}}{U^t_{ClnCln} - U_{Cln}(C)}$$

$$R_{Ctr} = \frac{1 - 0.53}{1 - 0}; \quad R_{Cln} = \frac{1 - 0.44}{1 - 0}$$

$$R_{Ctr} = 0.447; \quad R_{Cln} = 0.560$$

Since the risk for contractor is smaller than client agent's risk even before a time penalty is applied we can say that a concession will be made.

Next step is calculation of minimum sufficient concession to make client agent's risk equal to contractor agent's risk. To be able to calculate this value first we need to equate client agent's risk formula to contractor agent's calculated risk value;

$$R_{Cln} = \frac{U^{t}_{ClnCln} - U^{t}_{ClnCtr}}{U^{t}_{ClnCln} - U_{Cln}(C)}$$

$$0.447 = \frac{1 - U^{t}_{ClnCtr}}{1 - 0}$$

$$U_{ClnCtr} = 0.533$$

So we know that client agent's utility due to contractor agent's offer should be 0.533. Now we need to calculate corresponding utility for the contractor agent so that we can apply the time penalty and find the offer value. If we formulate the utility curves for client and contractor agents, starting from the general formula of a line we reach the following equations;

$$y = ax + b$$

$$U_{Ctr} = 0.0133x - 0.267$$

$$U_{Cln} = -0.0160x + 1.96$$

Solving these two equations together we reach the following equation;

$$U_{Ctr} = 0.0133\left(\frac{1.96 - U_{Cln}}{0.0160}\right) - 0.267$$

$$U_{Ctr} = 1.3623 - 0.8313 \times U_{Cln}$$

Inserting the utility that we found earlier for the client agent, we find the utility value for the contractor agent that will bring client agent's utility to desired amount.

$$U_{Ctr} = 1.3623 - 0.8313 \times 0.5333$$

$U_{Ctr} = 0.9225$

So now we can convert this utility value to an offer value. But before doing this we should apply the time penalty;

$U_{Ctr}' = U_{Ctr} - \mathrm{TP}_{\mathrm{Ctr}}$

$U_{Ctr}' = 0.9225 - 0.03$

$U_{Ctr}' = 0.8923$

Then making linear interpolation for this utility value we reach the offer as 86.92.

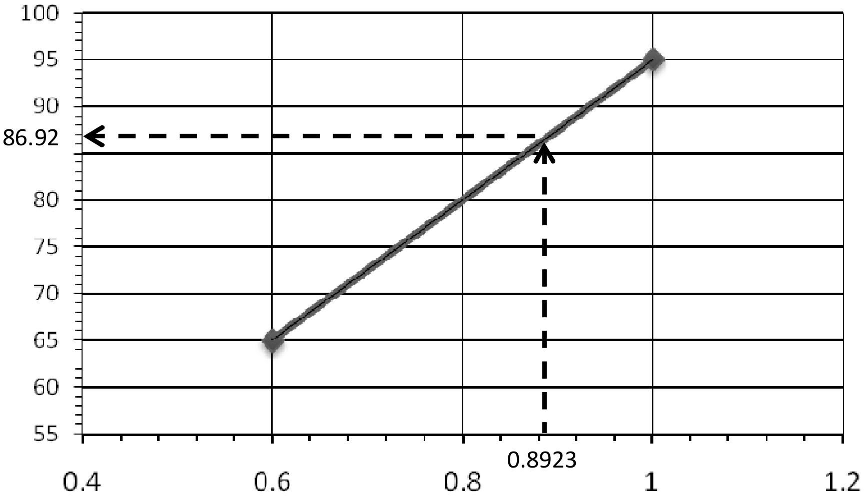


Figure 4-10 Reaching contractor agent’s offer value from calculated utility

Client Agent

Upon reaching the new offer from the contractor agent with the same procedures explained above client agent also calculates its new offer.

U_{CtrCtr}:	0.89	U^t_{CtrCln}:	0.53
U^t_{ClnCln}:	1	U_{ClnCtr}:	0.57

$R_{Ctr} = 0.402; \quad R_{Cln} = 0.431$

As the risk for the client agent is higher than contractor agent there may be no concession. But we should still have to apply time penalty and reach the final decision afterwards;

$\mathrm{U}_{\mathrm{CtrCln}} = 0.508$

$U_{Cln} = 1.031$

$U_{Cln}' = 1.001$

So when we make the linear interpolation we reach the offer value as 59.97. But since this value lower than the previous offer client agent sticks to its previous offer and gives an offer value of 60.

Round2	**Offer**
Contractor	86.92
Client	60

Remaining Rounds

Remaining rounds follows the same procedures. All of the negotiation process can be summarized as follows;

Table 4-8 Example negotiation process for Zeuthen's Strategy

	Contractor	**Client**	**R_{Ctr}**	**R_{Cln}**
Round1	95.00	60.00		
Round2	86.92		0.467	0.560
		60.00	0.402	0.431
Round3	80.64		0.402	0.431
		64.36	0.340	0.330
Round4	73.22		0.268	0.280
		70.74	0.166	0.152
Round5	64.15		0.047	0.048

Even if in the table 5th round is presented actually negotiations lasted for 4 rounds and at the 5th round upon calculating its offer lower than clients offer contractor agent ended the negotiation process and accepted client agent's offer. So the settlement amount of the negotiation is 70.74.

4.3.1.2 Sensitivity Analysis

To be able to have a better understanding of protocol's behaviour sensitivity analysis are carried out. In these analysis effects of three inputs "Time Penalty, Reservation Value and First Offer Value" has been observed, since these variables are the main factors affecting the model.

Effect of Time Penalty

User can input time penalty for each agent separately to the model. In this analysis while keeping client agent's time penalty constant, increasing values are applied to the contractor agent's time penalty. Input values for the analysis are as follows;

Contractor Agent		
	Value	**Utility**
Reservation Value	65	0.6
First Offer Value	90	1
Utility Conflict		0
Time Penalty (%)	Variable	

Client Agent		
	Value	**Utility**
Reservation Value	85	0.6
First Offer Value	60	1
Utility Conflict		0
Time Penalty (%)	1	

Table 4-9 Effect of increasing time penalty to the settlement values (Zeuthen Strategy)

Time Penalty of the Contractor	Settlement Value
0.0	81.62
0.5	77.81
1.0	75.61
1.5	73.06
2.0	71.88
2.5	70.83
3.0	71.11
3.5	69.75
4.0	68.50
4.5	68.71
5.0	68.81
5.5	68.79
6.0	68.64
6.5	67.67
7.0	66.19

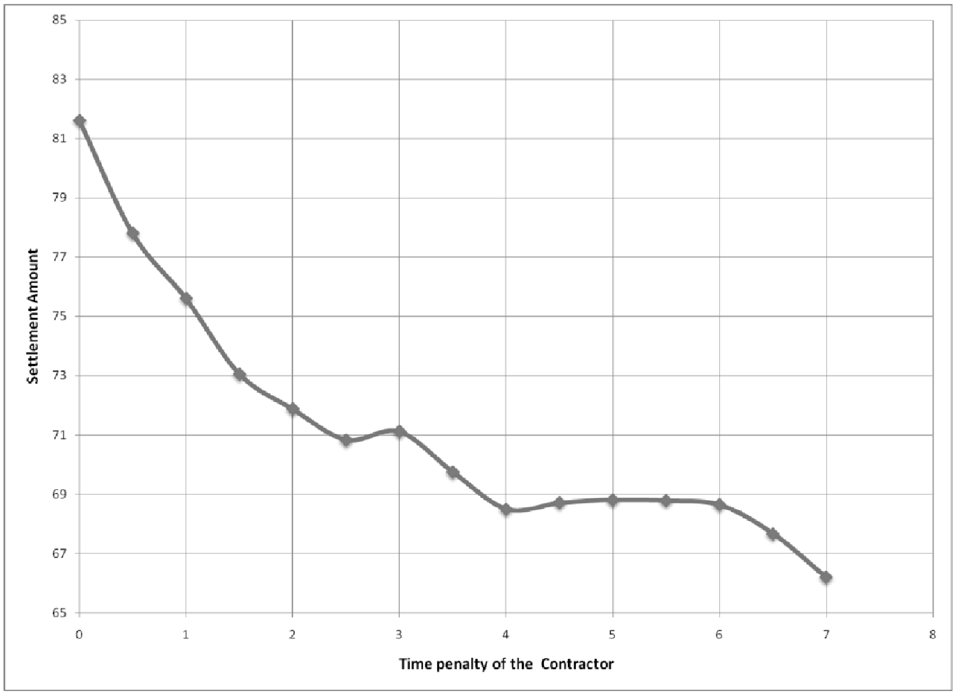


Figure 4-11 Effect of increasing time penalty to the settlement values (Zeuthen Strategy)

As can be seen from the graph as the time penalty of the contractor agent increases, settlement value (the amount that will be compensated by the client) drops. This means that increasing time penalty forces contractor agent to accept lower settlement amounts. If we also look at the offer values given at each round we can see this observe this process more closely.

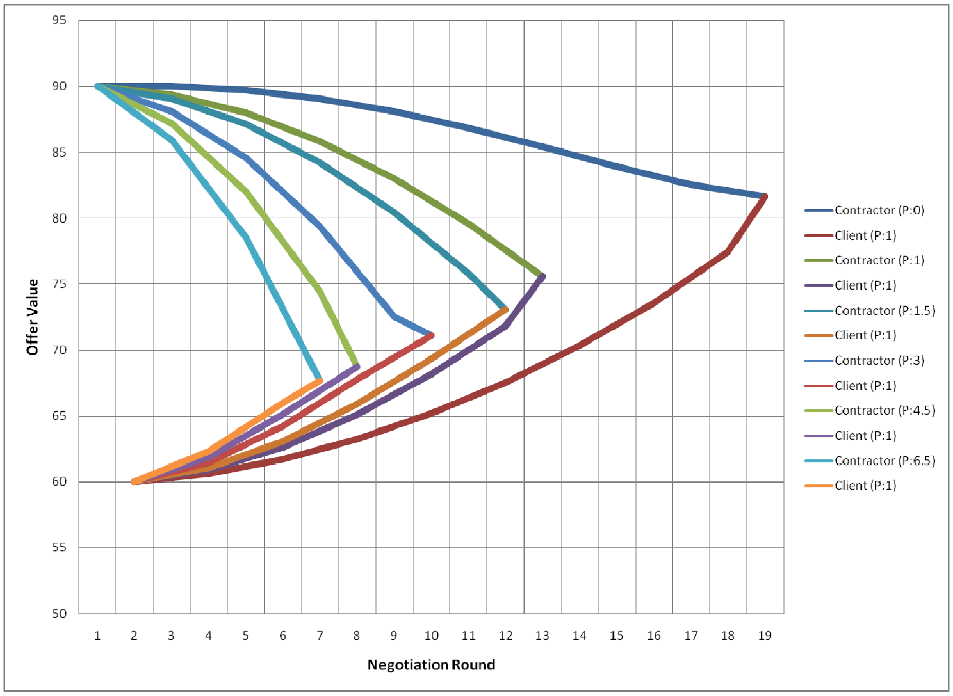


Figure 4-12 Effect of increasing time penalty to the offer values (Zeuthen Strategy)

This graph shows 6 different negotiation processes with different time penalties for the contractor agent. From the graph it can be observed that as the time penalty increases contractor agent makes greater concessions at each round. Also greater time penalty results in shorter negotiation processes, for example while negotiation with contractor agent's time penalty as 1 lasts for 13 rounds with the same conditions if we increase the contractor's time penalty to 4.5 negotiations ends at 8th round. This is meaningful since higher time penalty implies that contractor agent has limited time and wants to end negotiations as soon as possible.

Effect of Reservation Amount

Effect of the reservation amount on the negotiation process is inspected by changing the contractor agent's reservation value while keeping all other variables constant. Variable values used in the process are as follows;

Contractor Agent		
	Value	**Utility**
Reservation Value	Variable	0.6
First Offer Value	90	1
Utility Conflict		0
Time Penalty (%)	1	

Client Agent		
	Value	**Utility**
Reservation Value	85	0.6
First Offer Value	60	1
Utility Conflict		0
Time Penalty (%)	1	

Table 4-10 Effect of increasing reservation amount on the settlement values (Zeuthen Strategy)

$\mathbf{Ctr_{Reservation}}$	**Settlement Value**
65	69.36
66	71.54
67	73.74
68	74.97
69	75.71
70	76.53
71	77.72
72	79.24
73	80.93
74	82.78
75	84.61
76	85.00
77	85.00
78	85.00
79	85.00

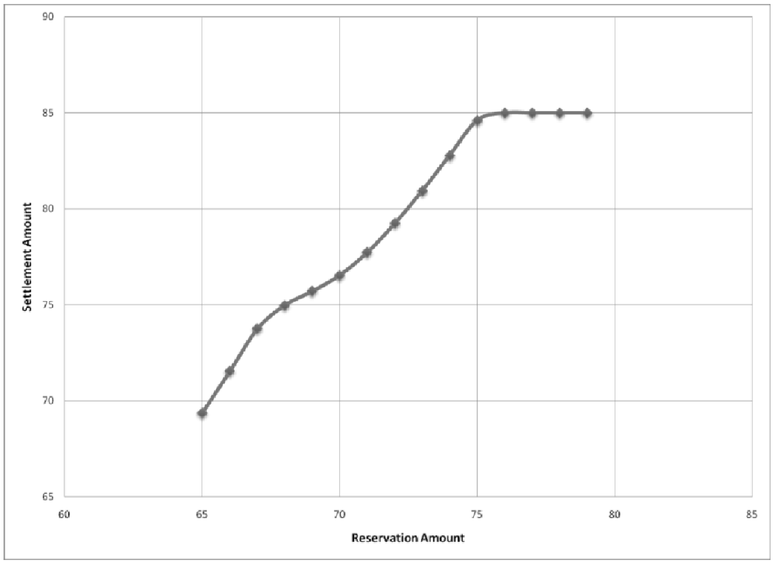


Figure 4-13 Effect of increasing reservation amount on the settlement values (Zeuthen Strategy)

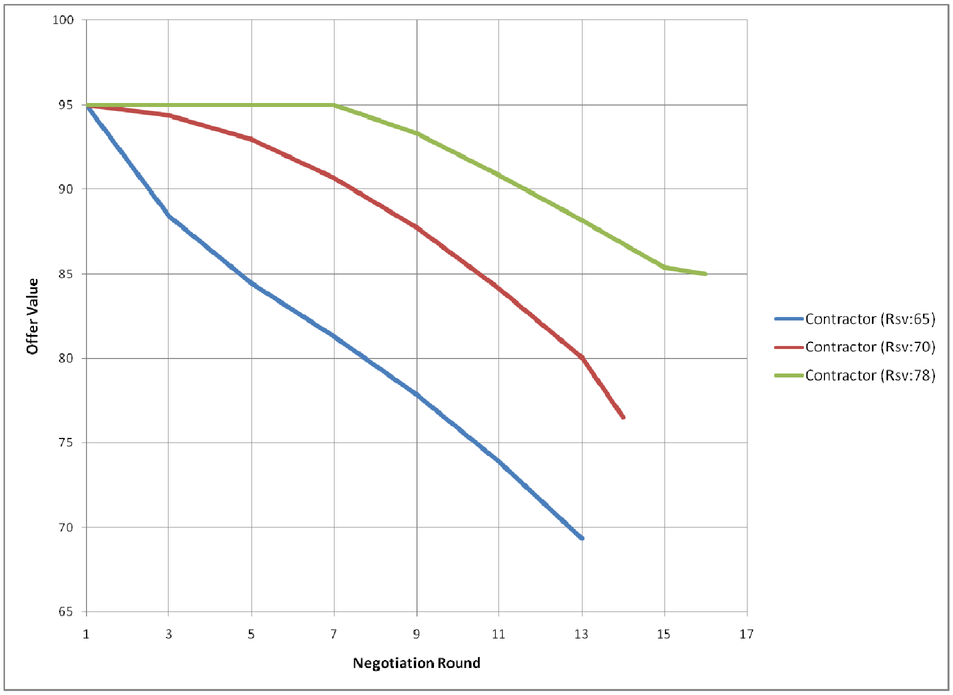


Figure 4-14 Effect of increasing reservation amount to the offer values (Zeuthen Strategy)

Analysis shows us as the reservation amount of the contractor agent increases the settlement amount increases. This is due to the reason that increasing reservation value left smaller space for contractor agent to negotiate and as can be seen from Figure 4-14 contractor agent is not willing to make concession for the first few rounds if the reservation value is high. It should be keep in mind that in this model agents first goal is to prevent a deadlock (since a deadlock has an utility of zero), so as contractor agents keeps its offers high client agent makes concessions since it has more space for concession and wants negotiations to end as soon as possible. But it can also be seen that as reservation amount for the contractor agent goes higher length of the negotiations also increases. This is again due to the smaller concession values given by the contractor agent.

Effect of First Offer Value

Another important variable in the protocol is the first offer value. Sensitivity analysis is done by changing contractor agents first offer value while keeping all other values as fixed.

Contractor Agent		
	Value	**Utility**
Reservation Value	65	0.6
First Offer Value	Variable	1
Utility Conflict		0
Time Penalty (%)	1	

Client Agent		
	Value	**Utility**
Reservation Value	85	0.6
First Offer Value	60	1
Utility Conflict		0
Time Penalty (%)	1	

Table 4-11 Effect of changing first offer value to the settlement amount (Zeuthen Strategy)

$\mathbf{Ctr_{First\ Offer}}$	**Settlement Value**
95	69.36
94	69.29
93	69.4
92	69.53
91	69.65
90	69.78
89	69.91
88	70.04
87	70.18
86	70.37
85	70.63
84	70.89
83	71.14
82	70.83
81	70.42

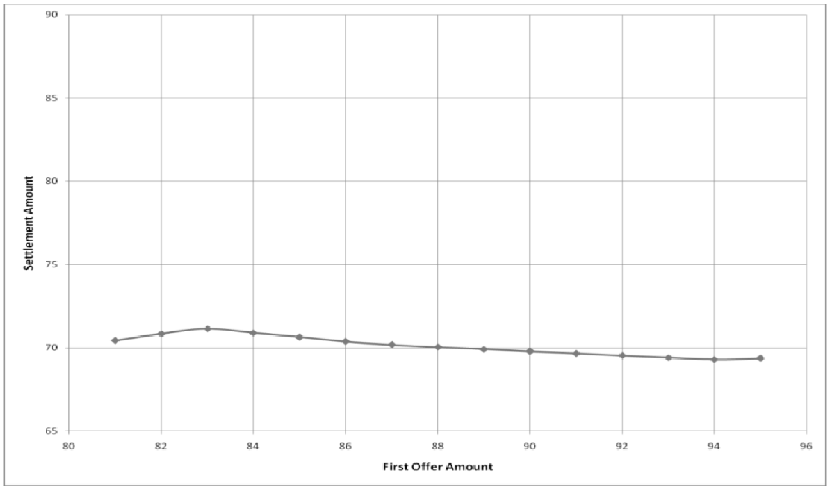


Figure 4-15 Effect of changing first offer value to the settlement amount (Zeuthen Strategy)

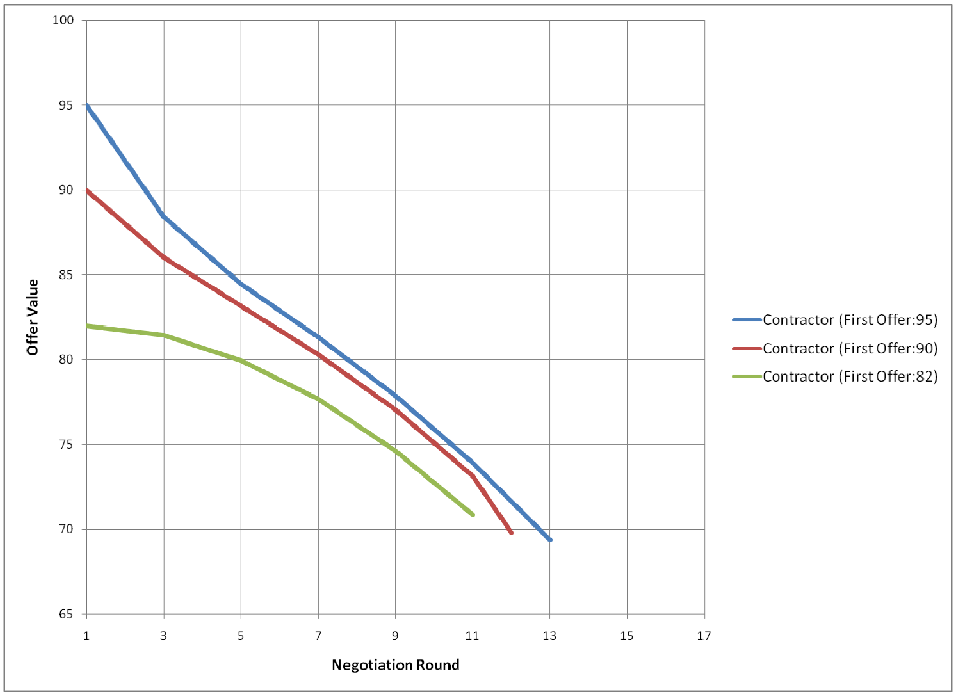


Figure 4-16 Effect of changing first offer value to offer values (Zeuthen Strategy)

Results show that there is not an apparent relationship between the first offer value and the reservation amount. Even if the reservation value changes settlement amount does not shows a significant change. Reason for this can be understood from Figure 4-16. Higher first offer value gives contractor agent a greater space to negotiate and it gives higher concession values. This keeps model in balance and results in similar settlement values. Only significant effect is on the negotiation duration. As first offer values gets apart from the reservation amount, negotiation process elongates.

4.3.2 Zeuthen’s Strategy with Bayesian Learning

Most important drawback of the Zeuthen’s Strategy is its complete information assumption. Every agent in the model is fully informed about other agent’s utility function. Model calculates utility functions based on two variables; first offer value and reservation value. While first offer value is open information for all of the agents Zeuthen strategy also assumes that every agent has access to other agent’s reservation value thus can calculate utility function for the opponent agent. However in the real claim negotiation environment this is not always possible. This protocol uses Zeuthen’s Strategy with incomplete information assumption. Each agent has no information about opponent’s reservation value and tries to estimate it with using Bayesian Learning mechanism. This protocol is added to the model on the work done by Ren (2003).

All of the negotiation features of the strategy is the same as Zeuthen’s Strategy except that agents has no access to other agent’s reservation value and at each offer estimates the reservation amount of the opponent based on its prior knowledge about the agent. For this purpose, model uses Bayesian Learning Mechanism. This mechanism uses Bayesian Theorem which takes its name from its creator Thomas Bayes. In its simplest setting involving only discrete distributions, Bayesian theorem relates the conditional and marginal probabilities of events A and B, where B has a non-vanishing probability. Bayesian theorem adjusts probabilities given new evidence in the following way (Bayesian Inference, 2010);

$$P(H|E) = \frac{P(E|H)\,P(H)}{P(E)}$$

$$P(E) = \sum P(E|H_i)\,P(H_i)$$

Where,

H: A specific hypothesis. This can be also be a null hypothesis

P(H): The probability of H before receiving a new evidence E.

P(E | H): The conditional probability of seeing the evidence E if the hypothesis H happens to be true. It is also called a likelihood function when it is considered as a function of H for fixed E.

P(E): The marginal probability of E. Probability of having the evidence E with using all possible hypotheses. Calculation is carried out by summing the product of all probabilities of a set of mutually exclusive hypotheses and corresponding conditional probabilities.

P(H | E): The posterior probability of H given E

To observe how this theorem is applied into negotiation process we can follow the workflow on an example.

4.3.2.1 Example Negotiation

To be able to work with Bayesian Learning mechanism three more variable should be introduced to the model;

- Other Agents Possible Reservation Value
- Negotiation Habit
- Uncertainty about estimate

Uncertainty about the estimate is input by the user via a drop down menu. It represents users confidence about other two variables; Variation of other agent's offer from its real reservation value and Other Agents Possible Reservation Value. It can take three different values "High", "Medium" or "Low".

Negotiation Habit represents variation of opponent agent's offer from its real reservation value. In the user input screen of the model this variable is defined as "Contractor/Client agent's reservation value is usually higher/lower than its reservation value by %". So for example for the contractor agent an input of 20 means; agent believes that its opponent's first offer value would be 20% lower than its real reservation amount. This gives us a probability distribution of possible offers given the reservation value. For the contractor agent this is illustrated in the following figure;

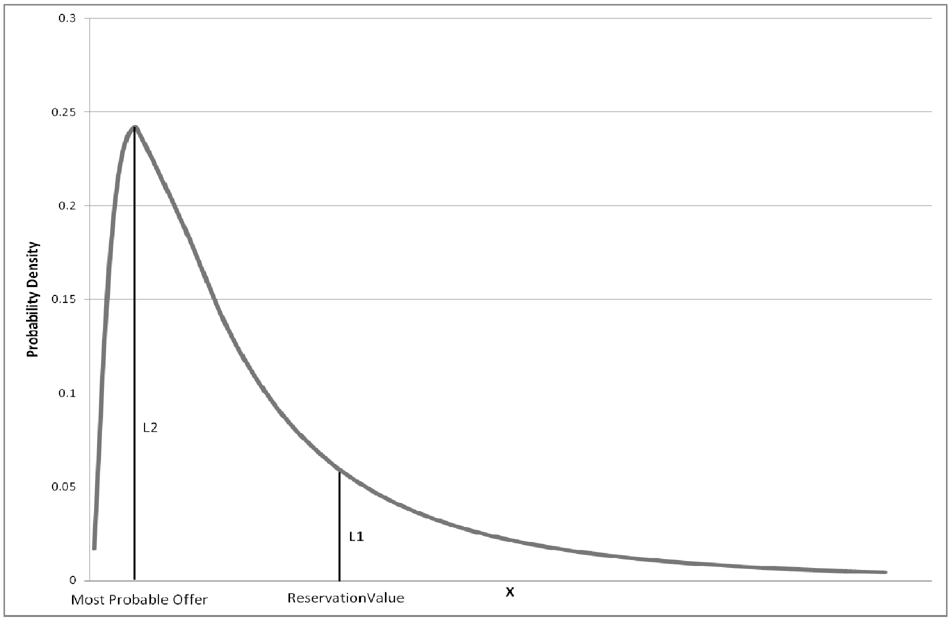


Figure 4-17 Relationship between agent's reservation value and possible offers

Lognormal distribution is used to represent relationship between reservation value and the most probable offer value because client agent will not make too low offers since contractor agent will not accept these. In the model input of negotiation habit represents the ratio L2/L1.

Uncertainty on the negotiation habit affects the lognormal distribution curve. To represent uncertainty three different lognormal distributions with different σ and μ values are selected.

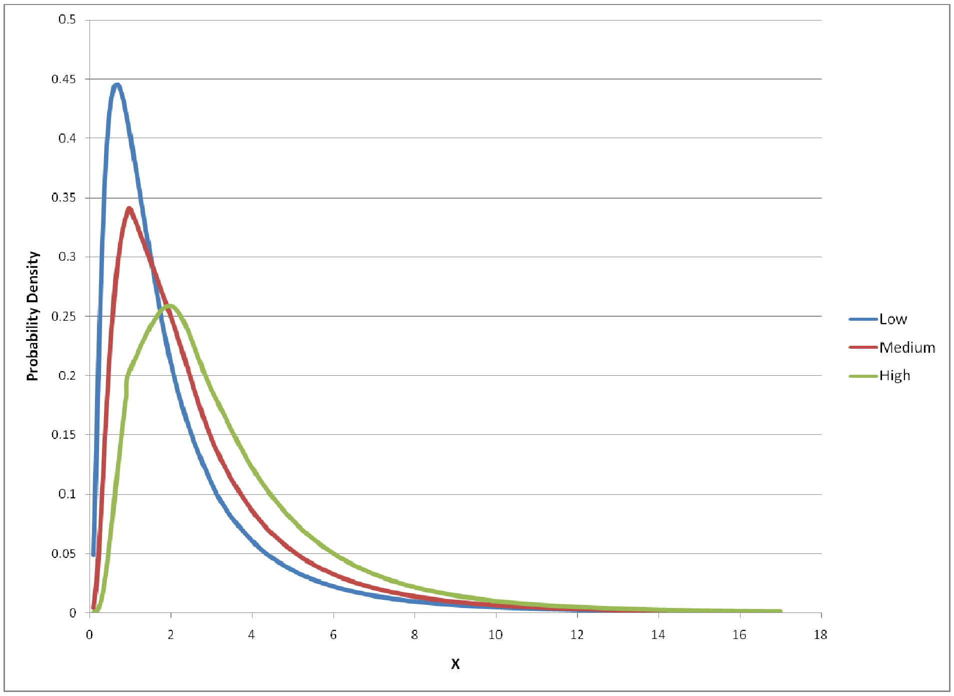


Figure 4-18 Offer probability distributions for different uncertainty levels

From these three curves 7 values are selected for each uncertainty level for simplicity.

Table 4-12 Offer probability distributions for different uncertainty levels

Low	Medium	High
0.380	0.298	0.182
0.445	0.340	0.259
0.421	0.249	0.188
0.402	0.147	0.122
0.210	0.086	0.078
0.109	0.052	0.050
0.061	0.033	0.033

Other Agents Possible Reservation Value is input by the user as a single value. This is user's belief about opponent's reservation value. Model converts this value into a group of possible reservation values with their related probabilities. These probabilities are determined based on normal distribution. Three different distributions are defined depending on the uncertainty about the estimate. As uncertainty about the estimate gets higher a higher standard deviation is applied to form probabilities. 11 values are selected from the distribution for simplicity.

Table 4-13 Probability distributions for reservation values

Uncertainty		
Low	**Medium**	**High**
0.026	0.059	0.074
0.050	0.075	0.083
0.083	0.091	0.091
0.120	0.105	0.097
0.148	0.114	0.101
0.160	0.117	0.103
0.148	0.114	0.101
0.120	0.105	0.097
0.083	0.091	0.091
0.050	0.075	0.083
0.026	0.059	0.074

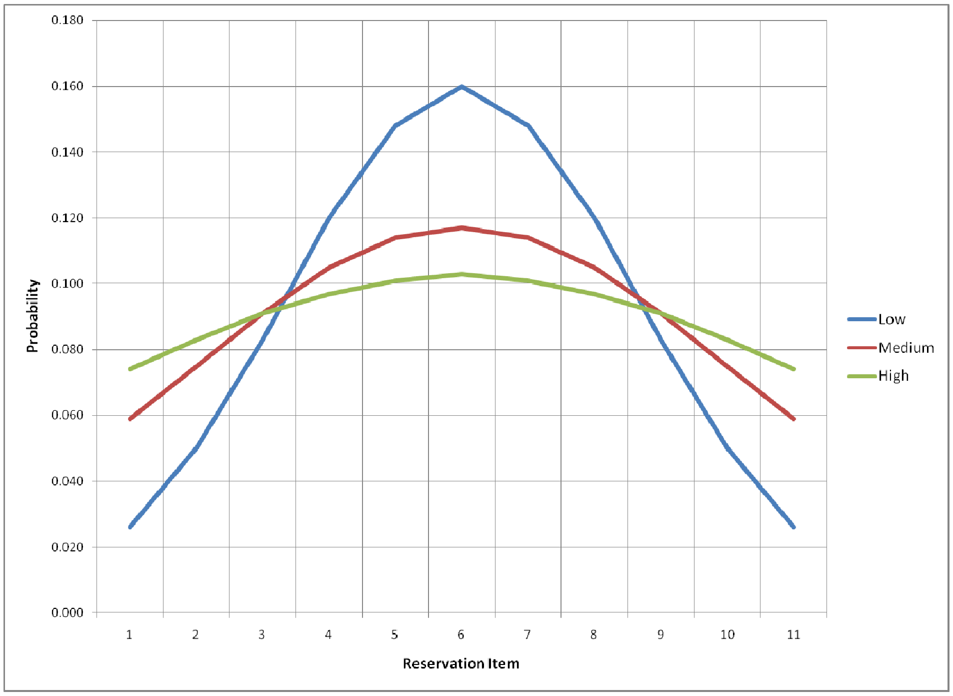


Figure 4-19 Probability distributions for reservation values

For the example case following values will be used;

Contractor Agent	
First Offer Value	90
Reservation Value	75
Client’s predicted reservation value	85
Uncertainty About Estimate	Low
Client’s offer is usually lower than its reservation value by (%)	20
Time Penalty (%)	1

Client Agent	
First Offer Value	60
Reservation Value	90
Contractor’s predicted reservation value	70
Uncertainty about estimate	Low
Contractor’s offer is usually lower than its reservation value by (%)	20
Time Penalty (%)	1

Before starting the negotiation we should prepare two tables which are needed for Bayesian Learning mechanism. First table is for opponent agent’s possible reservation values which we refer as Reservation Distribution Table. This table contains the P(H) values that are explained in the Bayesian Theorem. Distribution of reservation values are defined with using normal distribution. Predicted reservation value is used as the mean value of the distribution and opponent negotiation habits gives us the upper and lower limits for the distribution. Uncertainty about the estimate gives us the shape of the distribution. For simplicity 11 values from this distribution is selected for the model.

Contractor Agent constructs this table for client agent’s possible reservation values as follows;

$$\text{Upper Limit} = \text{PRV}_{\text{Client}} \times \left(1 + 3 \times \frac{\text{NH}_{\text{Client}}}{100}\right)$$

$$\text{Lower Limit} = \text{PRV}_{\text{Client}} \times \left(1 - 3 \times \frac{\text{NH}_{\text{Client}}}{100}\right)$$

Where,

$\text{PRV}_{\text{Client}}$: Predicted reservation value of the client

$\text{NH}_{\text{Client}}$: Negotiation habit of the client

So if we use the values from our example, distribute the numbers to 11 items between our limits and also add probabilities for “low” uncertainty we reach the following table.

Table 4-14 Initial probabilities of the possible reservation amounts

Reservation Value	Probability P(H)
34.0	0.026
44.2	0.050
54.4	0.083
64.6	0.120
74.8	0.148
85.0	0.160
95.2	0.148
105.4	0.120
115.6	0.083
125.8	0.050
136.0	0.026

Notice how the predicted reservation value entered by the user (85) is placed in the median with the highest probability assignment.

Second table that we should construct is for P(E|H) variable in Bayesian theorem. This is the probability of a reservation value given the offer value. In the table for each offer value probability of having a particular reservation value is stored. For example let's construct one line of this table for our first reservation value of 34;

1. A offer value distribution is formed using the same step interval that we used for reservation values;

Table 4-15 Distribution of possible offer values

Possible offer values
…
3.4
13.6
23.8
34.0
44.2
54.4
64.6
74.8
85.0
95.2
105.4
115.6
125.8
136.0
146.2
156.4
166.6
176.8
187.0
197.2
…

2. Negotiation habit of the opponent is 20% with “low” uncertainty which means that most probably client agent would offer a value 20% lower than its real reservation value. So from “offer probability distribution” table (Table3-10) probability values for “low” uncertainty is taken and highest probability is assigned to the value which is 20% lower than the reservation value.

$$34 \times \left(1 - \frac{20}{100}\right) - 27.2$$

27.2 is much nearer to offer value 23.8 so highest probability of 0.445 is assigned to this offer, rest of the probabilities are also placed in order.

Table 4-16 Offer reservation relationship for reservation value of 34

Reservation **Offer**	**34**
3.4	
13.6	0.380
23.8	0.445
34.0	0.421
44.2	0.402
54.4	0.210
64.6	0.109
74.8	0.061
85.0	

3. With the same workflow the entire table is filled.

Table 4-17 Offer reservation relationship

Reservation Offer	34	44.2	54.4	64.6	74.8	85	95.2	105.4	115.6	125.8	136
3.4											
13.6	0.3802										
23.8	0.4447	0.3802									
34	0.421	0.4447	0.3802								
44.2	0.402	0.421	0.4447	0.3802							
54.4	0.21	0.402	0.421	0.4447	0.3802	0.3802					
64.6	0.109	0.21	0.402	0.421	0.4447	0.4447	0.3802				
74.8	0.061	0.109	0.21	0.402	0.421	0.421	0.4447	0.3802			
85		0.061	0.109	0.21	0.402	0.402	0.421	0.4447	0.3802		
95.2			0.061	0.109	0.21	0.21	0.402	0.421	0.4447	0.3802	0.3802
105.4				0.061	0.109	0.109	0.21	0.402	0.421	0.4447	0.4447
115.6					0.061	0.061	0.109	0.21	0.402	0.421	0.421
125.8							0.061	0.109	0.21	0.402	0.402
136								0.061	0.109	0.21	0.21
146.2									0.061	0.109	0.109
156.4										0.061	0.061
166.6											

Now as we have created necessary tables we can inspect the negotiation rounds.

Round 1

In this first round simply first offer values are exchanged between the agents, first contractor agents gives its offer then client agent replies back with its starting offer;

Round1	Offer
Contractor	90
Client	60

Round 2

Contractor Agent

Having received an offer of 60 contractor agent updated its belief about client agent's reservation value. We can review Bayesian theorem again and explain its terms in the claim negotiations concept;

$$P(H|E) = \frac{P(E|H)\,P(H)}{P(E)}$$

$$P(E) = \sum P(E|H_i)\,P(H_i)$$

Where,
H: Reservation value

P(H): The prior probability of the reservation value that was inferred before new offer, E. These are the probabilities given in the Table 4-18.

P(E | H): The conditional probability of seeing reservation vale E if the client gives offer H.

P(E): The marginal probability of given offer, the a priori probability of witnessing the new offer under all possible hypotheses. It can be calculated as the sum of the product of all probabilities of any complete set of mutually exclusive hypotheses and corresponding conditional probabilities.

P(H | E): The posterior probability of reservation value H given the offer E

First the probability for each reservation amount is assigned from Table 4-16. As the received offer is 60 and this value is not in the table among the offer values linear interpolation is made to find respective probabilities. These probabilities are the P(E | H) in the Bayesian theorem which is the conditional probability of seeing reservation value E given the offer is H.

Table 4-19 Conditional probabilities of reservation values for given offer amount

Reservation	**P(E | H)**
34.000	0.155
44.200	0.297
54.400	0.411
64.600	0.432
74.800	0.416
85.000	0.416
95.200	0.209
105.400	0.000
115.600	0.000
125.800	0.000
136.000	0.000

Next step is the determination of the P(E | H) x P(H) values and P(E) summation;

Table 4-20 P(E | H) x P(H) values and P(E) summation for 2nd round

Reservation	**P(H)**	**P(E | H)**	**P(E | H) x P(H)**
34.000	0.026	0.155	0.004
44.200	0.050	0.297	0.015
54.400	0.083	0.411	0.034
64.600	0.120	0.432	0.052
74.800	0.148	0.416	0.062
85.000	0.160	0.416	0.066
95.200	0.148	0.209	0.031
105.400	0.120	0.000	0.000
115.600	0.083	0.000	0.000
125.800	0.050	0.000	0.000
136.000	0.026	0.000	0.000
		P(E) = Σ =0.264	

According the formula new probability values for the reservation values are division of P(E | H) x P(H) by P(E) value. Then we can calculate the new predicted reservation value by multiplying these new probability values with the reservation values and summing the results.

Table 4-21 Updated reservation values for 2nd round

Reservation	**P(H | E) = P(H)’**	**Reservation x P(H)’**
34.000	0.015	0.518
44.200	0.056	2.486
54.400	0.129	7.032
64.600	0.196	12.694
74.800	0.233	17.453
85.000	0.252	21.440
95.200	0.117	11.156
105.400	0.000	0.000
115.600	0.000	0.000
125.800	0.000	0.000
136.000	0.000	0.000
	Updated Reservation = Σ = 72.779	

With the calculations; not only the new prediction for the reservation value of client agent is found but also P(H) probabilities of the reservation amounts is updated. Next step of the offer calculation process is carried out with the same techniques explained in the Zeuthen’s Strategy section. New offer of the contractor agent is found as 85.18.

Client Agent

Same procedures are repeated for the client agent also and offer values for the second round is concluded as follows;

Round2	Offer
Contractor	85.18
Client	66.85

Round 3

Contractor Agent

At the third round calculations are the same with one exception. This time while calculating P(E | H) values the values calculated in previous round is also taken into account.

$$P(H|E_1,E_2) = \frac{P(E_1,E_2|H)\ P(H)'}{P(E_1,E_2)}$$

$$P(E_1,E_2) = \sum P(E_1,E_2|H_i)\ P(H_i)$$

$$P(E_1,E_2|H_i) = P(E_1|H_i) \times P(E_2|H_i)$$

$P(E_1, E_2 \mid H)$ values would be;

Table 4-22 $P(E_1, E_2 \mid H)$ values

$P(E_1 \mid H)$	$P(E_2 \mid H)$	$P(E_1, E_2 \mid H)$
0.155	0.098	0.015
0.297	0.188	0.056
0.411	0.360	0.148
0.432	0.417	0.180
0.416	0.439	0.183
0.416	0.439	0.183
0.209	0.394	0.082
0.000	0.084	0.000
0.000	0.000	0.000
0.000	0.000	0.000
0.000	0.000	0.000

Rest of the estimation process will be carried out with the same procedure used in the round 2.

Table 4-23 $P(E_1, E_2 \mid H) \times P(H)$ values and $P(E_1, E_2)$ summation for 3rd round

Reservation	**P(H)**	**$P(E_1, E_2 \mid H)$**	**$P(E_1, E_2 \mid H) \times P(H)$**
34.000	0.015	0.015	0.000
44.200	0.056	0.056	0.003
54.400	0.129	0.148	0.019
64.600	0.196	0.180	0.035
74.800	0.233	0.183	0.043
85.000	0.252	0.183	0.046
95.200	0.117	0.082	0.010
105.400	0.000	0.000	0.000
115.600	0.000	0.000	0.000
125.800	0.000	0.000	0.000
136.000	0.000	0.000	0.000
		$P(E_1, E_2) = \Sigma = 0.156$	

Table 4-24 Updated reservation values for 3rd round

Reservation	**$P(H \mid E_1, E_2) = P(H)'$**	**Reservation x P(H)'**
34.000	0.001	0.050
44.200	0.020	0.887
54.400	0.122	6.650
64.600	0.226	14.628
74.800	0.273	20.415
85.000	0.295	25.080
95.200	0.062	5.882
105.400	0.000	0.000
115.600	0.000	0.000
125.800	0.000	0.000
136.000	0.000	0.000
	Updated Reservation = Σ = 73.592	

Rest of the calculation is carried out using Zeuthen's strategy

Remaining Rounds

Remaining rounds follows the same procedures. All of the negotiation process can be summarized as follows;

Table 4-25 Example negotiation process for Zeuthen's Strategy with Bayesian Learning

	Contractor	**Client**	**PRV_{Client}**
Round1	90.00	60.00	-
Round2	85.18	66.85	72.78
Round3	81.32	71.71	73.59
Round4	79.65	75.35	75.56
Round5	**78.21**	-	77.14

In the table PRV_{Client} is the predicted reservation value of the client agent. Negotiation is ended at a settlement amount of 78.21.

4.3.3 Time Dependant Concession

Time dependant concession mechanism calculates the concession amounts depending on only the time penalty. At each round agent calculates the distance between their current offers and makes concession depending on this difference and time penalty for that round.

$$\mathrm{Offer}_{i+1} = \begin{cases} \mathrm{Offer}_i - \left[|(\mathrm{Reservation} - \mathrm{Offer}_i)| \times \dfrac{\mathrm{TP}_i}{100} \right], & \mathrm{Contractor} \\ \mathrm{Offer}_i + \left[|(\mathrm{Reservation} - \mathrm{Offer}_i)| \times \dfrac{\mathrm{TP}_i}{100} \right], & \mathrm{Client} \end{cases}$$

$$\mathrm{TP}_{i+1} = \mathrm{TP}_i + \mathrm{TP}$$

Where,

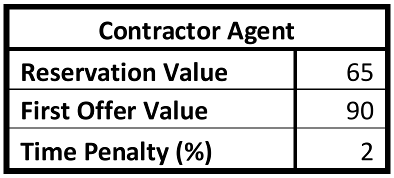
Offer_i : Offer value at round i.

Reservation: Reservation value of the agent

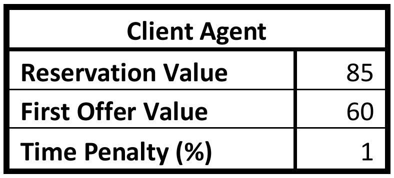
TP: Time penalty of the agent entered by the user

TP_i : Time penalty of the agent at the round i

4.3.3.1 Example Negotiation



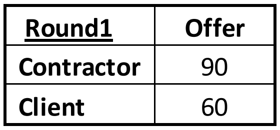
Contractor Agent	
Reservation Value	65
First Offer Value	90
Time Penalty (%)	2



Client Agent	
Reservation Value	85
First Offer Value	60
Time Penalty (%)	1

Round 1

At the first round each agent gives its first offer value.



Round1	Offer
Contractor	90
Client	60

Round 2

Contractor Agent

Upon receiving client agent’s offer contractor agent calculates its offer with the concession formula.

$$\text{Offer}_2 = \text{Offer}_1 - \left[|(\text{Reservation} - \text{Offer}_1)| \times \frac{\text{TP}_1}{100} \right]$$

$$\text{Offer}_2 = 90 - \left[|65 - 90| \times \frac{2}{100} \right]$$

$$\text{Offer}_2 = 89.5$$

Client Agent

Client agent also follows the same procedure with the contractor agent and calculates its offer value.

$$\text{Offer}_2 = \text{Offer}_1 + \left[|(\text{Reservation} - \text{Offer}_1)| \times \frac{\text{TP}_1}{100} \right]$$

$$\text{Offer}_2 = 60 + \left[|85 - 60| \times \frac{1}{100} \right]$$

$$\text{Offer}_2 = 60.25$$

Round2	**Offer**
Contractor	89.5
Client	60.25

Round 3

Contractor Agent

Same calculation steps are repeated at the round 3. Only time penalty is increased.

$$\text{TP}_2 = \text{TP}_1 + \text{TP}$$

$$4 = 2 + 2$$

$$\mathrm{Offer}_2 = \mathrm{Offer}_1 - \left[|(\mathrm{Reservation} - \mathrm{Offer}_1)| \times \frac{\mathrm{TP}_2}{100} \right]$$

$$\mathrm{Offer}_2 = 89.5 - \left[|65 - 89.5| \times \frac{4}{100} \right]$$

$$\mathrm{Offer}_2 = 88.52$$

Remaining Rounds

Same calculation steps followed for the rest of the negotiation process. All of the negotiation process can be summarized as follows;

Table 4-26 Example negotiation process for Time Dependant Concession

	Contractor	**Client**
Round1	90.00	60.00
Round2	89.50	60.25
Round3	88.52	60.74
Round4	87.11	61.47
Round5	85.34	62.41
Round6	83.31	63.54
Round7	81.11	64.83
Round8	78.85	66.24
Round9	76.64	67.74
Round10	74.54	69.30
Round11	72.63	70.87
Round12	70.95	70.95

4.3.3.2 Sensitivity Analysis

Negotiation protocol has three input variables "Time Penalty, Reservation Value and First Offer Value" so each of these variables are observed independently in the sensitivity analysis.

Effect of Time Penalty

Time penalty of each agent can be inputted separately to the model. In this analysis while keeping other variables constant time penalty of the contractor is increased to observe negotiation behaviour. Input values for the analysis are as follows;

Contractor Agent	
	Value
Reservation Value	65
First Offer Value	90
Time Penalty (%)	Variable

Client Agent	
	Value
Reservation Value	85
First Offer Value	60
Time Penalty (%)	1

Table 4-27 Effect of increasing time penalty to the settlement values (Time Dependent Concession)

Time Loss	**Settlement Value**	**Time Loss**	**Settlement Value**
0.5	77.96	8.0	66.24
1.0	74.63	8.5	66.07
1.5	72.42	9.0	65.82
2.0	70.95	9.5	65.61
2.5	70.50	10.0	65.45
3.0	69.30	10.5	65.33
3.5	69.19	11.0	65.23
4.0	68.11	11.5	65.15
4.5	67.74	12.0	65.10
5.0	67.74	12.5	65.06
5.5	67.29	13.0	65.03
6.0	66.74	13.5	65.01
6.5	66.30	14.0	65.00
7.0	66.24	14.5	65.00
7.5	66.24	15.0	65.00

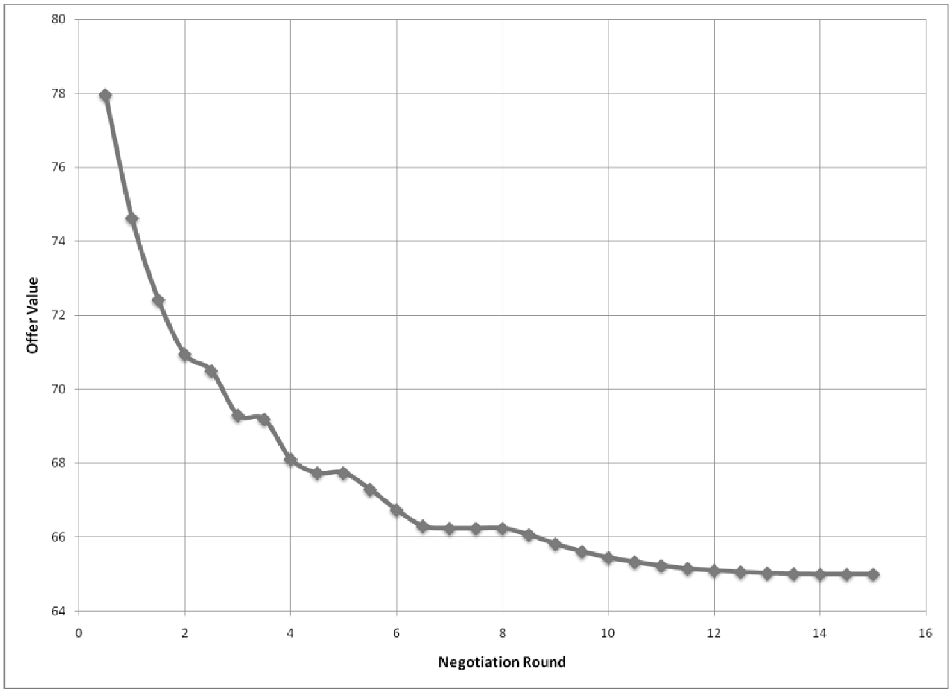


Figure 4-20 Effect of increasing time penalty to the settlement values (Time Dependent Concession)

As can be seen from the data increasing time penalty of the contractor agent results in lower settlement values. This is expected since higher time penalty means higher concession amounts.

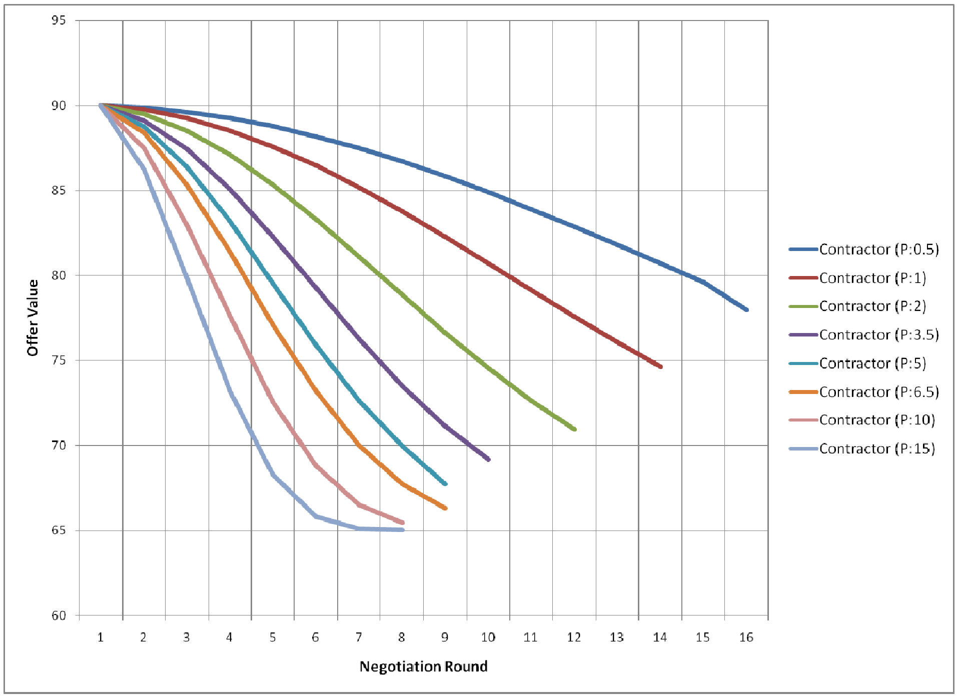


Figure 4-21 Effect of increasing time penalty to the offer values (Time Dependent Concession)

When we inspect the given offers by the contractor for different time penalties we can also see that higher time penalty results in shorter negotiation durations. This is also expected since contractor agent wants to end the negotiation sooner due to pressure of high time penalty.

Effect of Reservation Amount

Effect of the reservation amount is observed by changing the reservation value of the contractor agent while keeping other variables constant. Input variables are as follows;

Contractor Agent	
	Value
Reservation Value	Variable
First Offer Value	90
Time Penalty (%)	1

Client Agent	
	Value
Reservation Value	85
First Offer Value	60
Time Penalty (%)	1

Table 4-28 Effect of increasing reservation amount on the settlement values (Time Dependent Concession)

$\text{Ctr}_{\text{Reservation}}$	**Settlement Value**
65	74.63
66	75.25
67	75.37
68	75.37
69	75.96
70	76.63
71	76.72
72	77.07
73	77.79
74	77.96
75	78.55
76	79.09
77	79.55
78	80.09
79	80.77
80	81.3

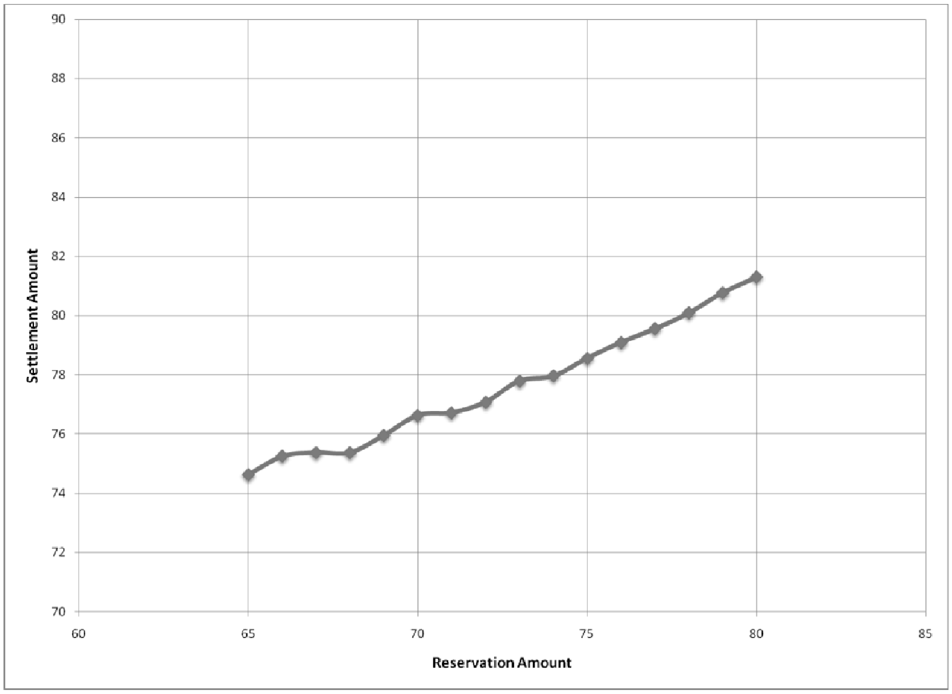


Figure 4-22 Effect of increasing reservation amount on the settlement values (Time Dependent Concession)

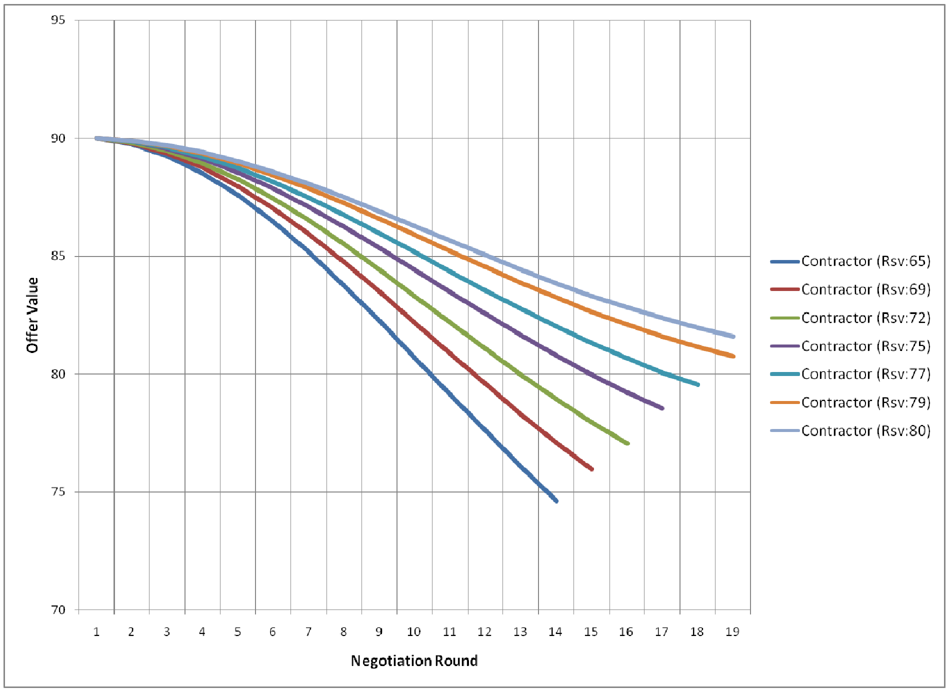


Figure 4-23 Effect of increasing reservation amount on the offer values (Time Dependent Concession)

Settlement values and given offers shows that increasing reservation amount of the contractor agent results in increasing settlement amounts and longer negotiation times. This is due to the fact that as reservation value approaches to the first offer value contractor has less space to negotiate and make concession. So as can be seen Figure 4-23 with higher reservation amounts contractor agent makes lower concessions.

Effect of First Offer Value

Last variable of the protocol is the first offer value. Sensitivity analysis is done by changing contractor agents first offer value while keeping all other values as fixed.

Contractor Agent	
	Value
Reservation Value	65
First Offer Value	Variable
Time Penalty (%)	1

Client Agent	
	Value
Reservation Value	85
First Offer Value	60
Time Penalty (%)	1

Table 4-29 Effect of changing first offer value to the settlement amount (Time Dependent Concession)

$\text{Ctr}_{\text{First Offer}}$	Settlement Value
100	76.59
99	76.26
98	75.93
97	75.60
96	75.37
95	75.37
94	75.37
93	75.37
92	75.37
91	75.02
90	74.63
89	74.25
88	73.93
87	73.93
86	73.93
85	73.86

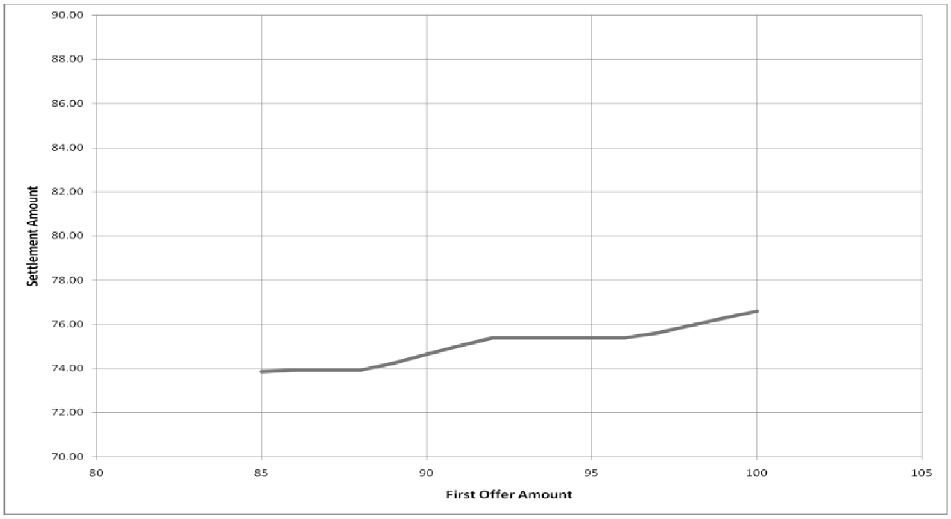


Figure 4-24 Effect of changing first offer value to the settlement amount (Time Dependent Concession)

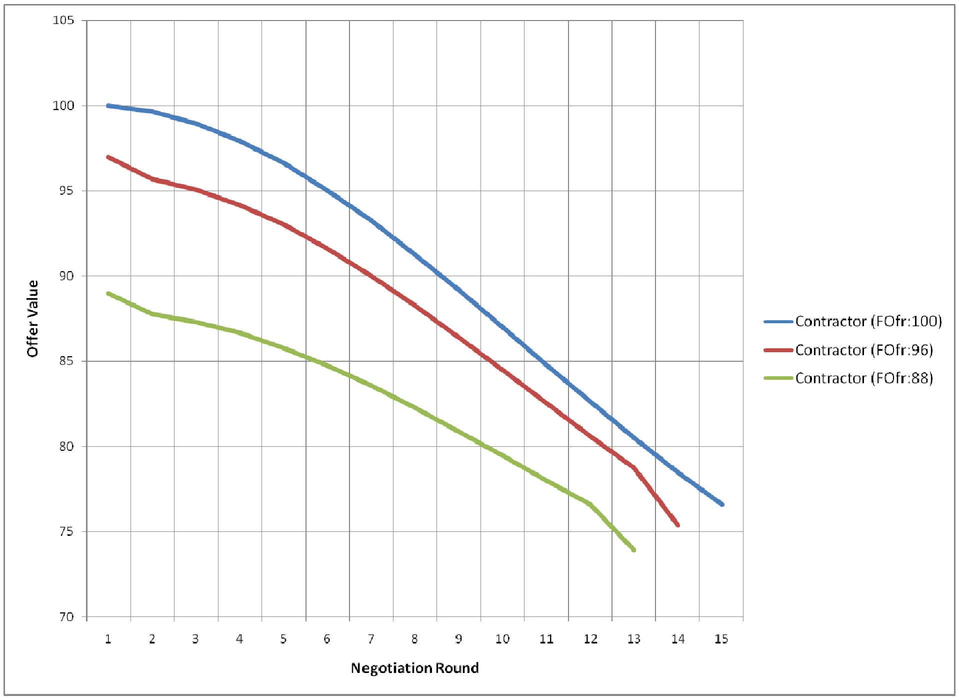


Figure 4-25 Effect of changing first offer value to the offer values (Time Dependent Concession)

From the results it can be seen that as the first offer value increases settlement value shows a slight increase (difference between top and bottom extreme is only 3%). Also negotiation duration does not show a significant change. Reason for this behavior is as distance between first offer and reservation value increases agent makes greater concessions and model balances itself.

4.4 Agent Characteristics

Claim negotiation process is a typical case for multi-agent resource allocation problem. The nature of this kind of problems in general and competitive nature of claim negotiations defines the agents' properties. Agents defined in this study have the fallowing characteristics;

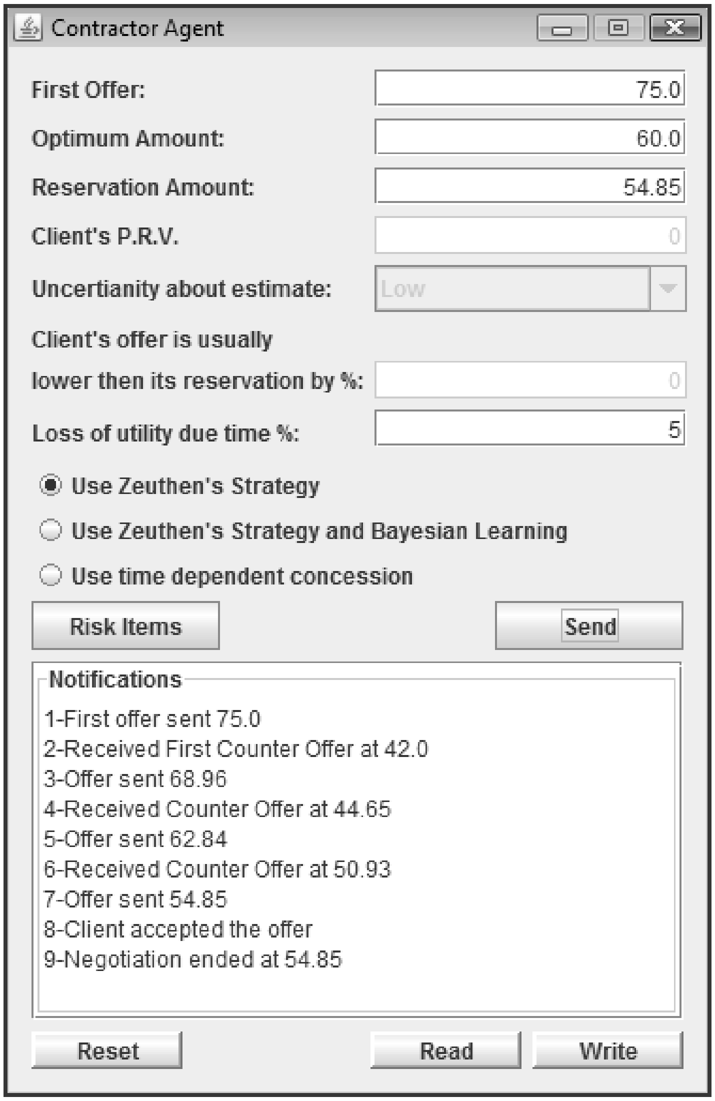
- Agents are self-motivated: Agents act only according to their interests. In the claim negotiations domain each agent tries to maximize its own utility. Agents do not work as a team and overall utility of the system is not taken into consideration.
- Agents are rational: At every step of the negotiation agents try to make the best choice for their offer. Definition of a best choice for the system is selecting the option that will maximize agent's own utility. So since the agents determine their strategy by rational decisions, they always follow the path that will increase their utility.
- Agents do not regret about their decisions: Agents only takes the outcome of the agreement into the consideration. While giving their final decision they do not care about the sequence of offers that produced this particular solution. So there is no decision-regret. An agent's offer is always lower than its previous offer.

4.4.1 Contractor Agent

Contractor agent is the agent that represents the contractor. It makes the initial offer to the client agent and determines the claim amount using fuzzy logic approach. Its ultimate goal is to have the highest possible claim amount and has a utility function which increases linearly with the claim amount. It has access to the contract details and can communicate with the Client and Contract agent. It has two interfaces;

- Risk Items Graphical User Interface
- Contractor Graphical User Interface

4.4.1.1 Contractor Agent Graphical User Interface



First Offer: 75.0
Optimum Amount: 60.0
Reservation Amount: 54.85
Client's P.R.V. 0
Uncertianity about estimate: Low
Client's offer is usually
lower then its reservation by %: 0
Loss of utility due time %: 5

● Use Zeuthen's Strategy
○ Use Zeuthen's Strategy and Bayesian Learning
○ Use time dependent concession

Notifications

1-First offer sent 75.0
2-Received First Counter Offer at 42.0
3-Offer sent 68.96
4-Received Counter Offer at 44.65
5-Offer sent 62.84
6-Received Counter Offer at 50.93
7-Offer sent 54.85
8-Client accepted the offer
9-Negotiation ended at 54.85

Figure 4-26 Contractor Agent GUI

This interface is the main interface of the Contractor agent. It shows the fundamental inputs needed for the negotiation mechanism. It also informs the user about the negotiation process and displays the incoming and outgoing messages. Below are the definitions of the objects used in the interface.

First Offer: This is the first offer of the contractor agent. This field is filled using the information given in the Risk Items GUI. Although no input needed for this filled as it is filled by the software it is still possible to change calculated amount with user input.

Optimum Amount: This field displays the calculated claim amount with no fuzziness. Its calculation also depends on the information provided in the Risk Items GUI. This amount is also editable by the user.

Reservation Amount: This field represents the reservation value for the contractor agent. Even it can be changed by the user it's originally calculated by the software using the definitions in the Risk Items GUI.

Client's PRV: Client's predicted reservation value. This field is only activated if Zeuthen's Strategy and Bayesian Learning is selected as negotiation protocol.

Uncertainty about estimate: Uncertainty about the estimate of Client's PRV. May be selected as "Low", "Medium" or "High". This field is only activated if Zeuthen's Strategy and Bayesian Learning is selected as negotiation protocol.

Client's offer is usually lower than its reservation value by %: Prediction of the relationship between Client's offer and reservation value. This field is only activated if Zeuthen's Strategy and Bayesian Learning is selected as negotiation protocol.

Loss of utility due time %: This is the time penalty of the agent. It represents the utility reduction of utility at each round for the contractor agent.

Risk Items: This button hides the Contractor Agent GUI and displays the Risk Items GUI.

Send: This button is activates the send method in the Contractor agent. Send method in the contractor agent adds "send offer" behaviour to the agent's active pool of behaviours and dispatch a message containing the first offer to the Client agent.

Use Zeuthen's Strategy: When selected agent uses Zeuthen's strategy as its negotiation protocol.

Use Zeuthen's Strategy and Bayesian Learning: When selected agent uses Zeuthen's strategy with Bayesian Learning as its negotiation protocol.

Use Time Dependent Concession: When selected agent uses Time Dependent Concession as its negotiation protocol.

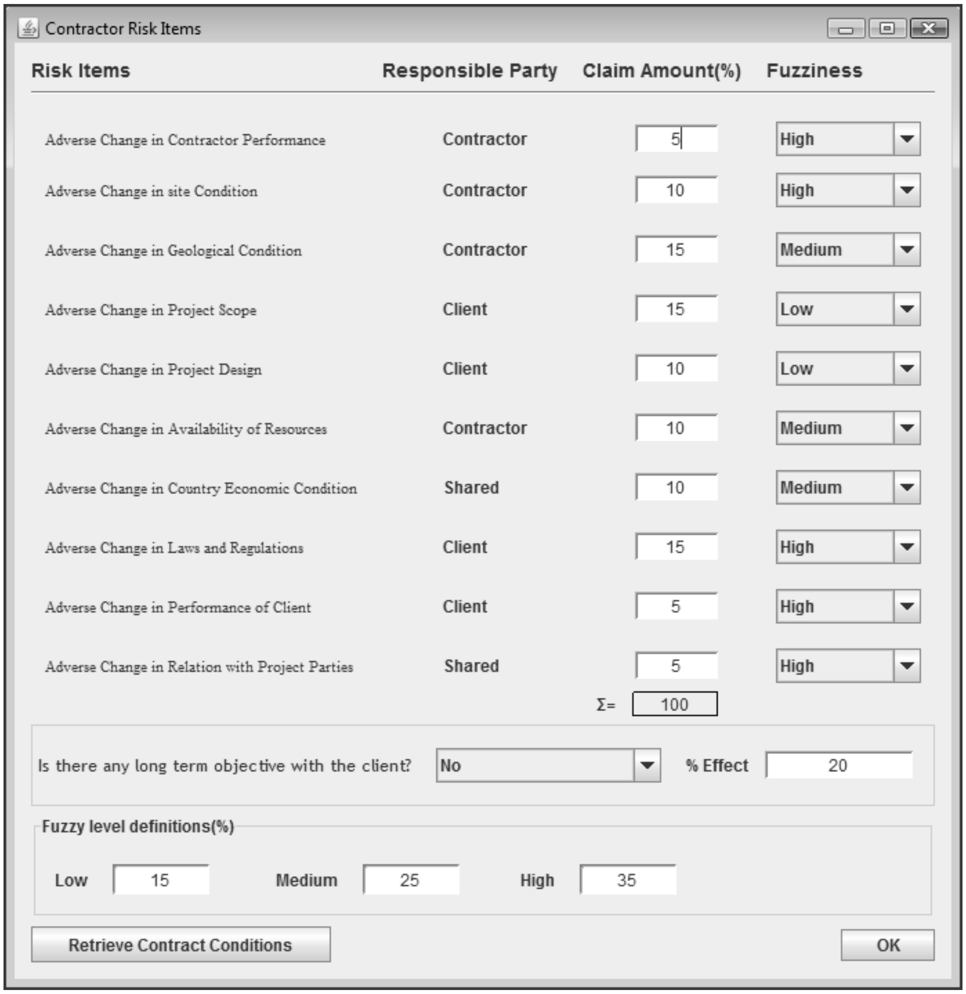
Notifications: This text area component used to inform user about the negotiation process. It notifies the user about the incoming and outgoing messages, stages of the negotiation and error messages.

Reset: Empties the agent active behaviors and empties the notifications area. Resets the agent for a new negotiation.

Save Simulation: Button is used to save the current simulation. It provokes a write method to create an ASCII file containing the information represented in Contractor Agent GUI and Risk Items GUI for later use.

Load Simulation: When activated this button opens a file explorer window to select an ASCII file. It also creates a read method to retrieve the simulation information stored in the file and then creates another method to fill this information into Contractor Agent GUI and Risk Items GUI.

4.4.1.2 Risk Items Graphical User Interface



Contractor Risk Items

Risk Items	Responsible Party	Claim Amount(%)	Fuzziness
Adverse Change in Contractor Performance	Contractor	5	High
Adverse Change in site Condition	Contractor	10	High
Adverse Change in Geological Condition	Contractor	15	Medium
Adverse Change in Project Scope	Client	15	Low
Adverse Change in Project Design	Client	10	Low
Adverse Change in Availability of Resources	Contractor	10	Medium
Adverse Change in Country Economic Condition	Shared	10	Medium
Adverse Change in Laws and Regulations	Client	15	High
Adverse Change in Performance of Client	Client	5	High
Adverse Change in Relation with Project Parties	Shared	5	High
		Σ= 100	

Is there any long term objective with the client? No

% Effect 20

Fuzzy level definitions(%)

Low 15

Medium 25

High 35

Figure 4-27 Contractor Risk Items GUI

This interface is used to enter and retrieve items associated with the risk events occurred during the construction. It also determines the Contractor agent's behavior and makes definitions necessary for the determination of optimum claim amount and reservation value. Below are the definitions of the objects used in the interface.

Risk Items: This list consists of the items that created the total loss during the construction. Each item represents an event that impacted the construction process and caused an increase in the project expenses (i.e. scope change, weather conditions, chance in material costs, low quality, cost of rework, accidents etc..).

Responsible Party: This list consists of the responsible parties for each of the risk items used. Responsible party for each of the items is defined in the contract conditions. Responsibility for each of the item is taken by Client agent, Contractor agent or it can be a shared responsibility. These items are also retrieved from the Contract agent upon the trigger of the Retrieve Contract Conditions button.

Claim Amount: Claim amount list is the first input that has to be filled by the user. This list consists of the percentage amount of each risk item over the overall cost increase. Input values are in percentage format and for program to be executed they should sum up to 100%. These items are open to Contractor agent (since it is the one who carried out the construction process) and can only be accessed by Client agent under certain conditions.

Fuzziness: Claim amounts entered by the user are not certain amounts. Each amount has a fuzziness level associated with it. This list contains these fuzzy level definitions. User can input each definition as High, Medium or Low.

Long term objective & % Effect: This drop down menu determines the Contractor agent's future intentions about the Client agent. It is used to input weather Contractor agent has any plan to have another project with the Client or not. If there does not exist a long term objective with the client then %Effect field is activated. This field represents the impact of not having a long term objective on the Contractors claim amount.

Fuzzy level definitions: These fields are used to input definition of each fuzzy level. They represent the percentage deviation from the entered claim amount for amount of uncertainty entered.

Retrieve Contract Conditions: Triggers the Retrieve Contract method in the contractor agent which in turn adds Retrieve Contract behavior and retrieves contract conditions from the Contract agent.

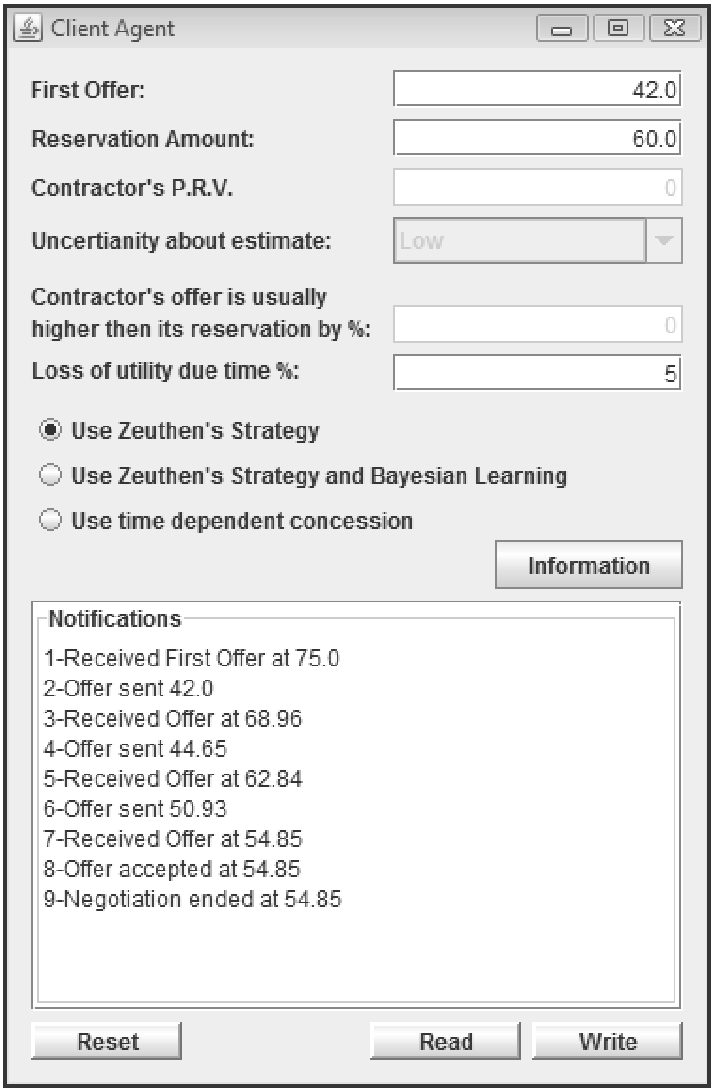
OK: Dismisses the current interface and opens the Contractor Agent graphical user interface.

4.4.2 Client Agent

Client agent is the agent that represents the client. It receives the initial offer from the contractor agent and makes the first counteroffer. Its ultimate goal is to have the lowest possible claim amount. It has two interfaces;

- Client Information Graphical User Interface
- Client Agent Graphical User Interface

4.4.2.1 Client Agent Graphical User Interface



First Offer: 42.0
Reservation Amount: 60.0
Contractor's P.R.V. 0
Uncertianity about estimate: Low
Contractor's offer is usually higher then its reservation by %: 0
Loss of utility due time %: 5

● Use Zeuthen's Strategy
○ Use Zeuthen's Strategy and Bayesian Learning
○ Use time dependent concession

1-Received First Offer at 75.0
2-Offer sent 42.0
3-Received Offer at 68.96
4-Offer sent 44.65
5-Received Offer at 62.84
6-Offer sent 50.93
7-Received Offer at 54.85
8-Offer accepted at 54.85
9-Negotiation ended at 54.85

Figure 4-28 Client Agent GUI

This interface is the main interface of the Client agent. It shows the fundamental inputs needed for the negotiation mechanism. It also informs the user about the negotiation process and displays the incoming and outgoing messages. Below are the definitions of the objects used in the interface.

First Offer: This is the first offer of the contractor agent. This field is filled using the information given in the Client Information GUI. Although no input needed for this filled as it is filled by the software it is still possible to change calculated amount with user input.

Reservation Amount: This field is filled by the software using the information provided in the Client Information GUI. Editing and giving user input to this field is optional.

Contractor's PRV: Contractor's predicted reservation value. This field is only activated if Zeuthen's Strategy and Bayesian Learning is selected as negotiation protocol.

Uncertainty about estimate: Uncertainty about the estimate of Contractor's PRV. May be selected as "Low", "Medium" or "High". This field is only activated if Zeuthen's Strategy and Bayesian Learning is selected as negotiation protocol.

Contractor's offer is usually lower than its reservation value by %: Prediction of the relationship between Contractor's offer and reservation value. This field is only activated if Zeuthen's Strategy and Bayesian Learning is selected as negotiation protocol.

Loss of utility due time %: This is the time penalty of the agent. It represents the utility reduction of utility at each round for the client agent.

Use Zeuthen's Strategy: When selected agent uses Zeuthen's strategy as its negotiation protocol.

Use Zeuthen's Strategy and Bayesian Learning: When selected agent uses Zeuthen's strategy with Bayesian Learning as its negotiation protocol.

Use Time Dependent Concession: When selected agent uses Time Dependent Concession as its negotiation protocol.

Information: Hides the Client Agent GUI and displays the Client Information GUI.

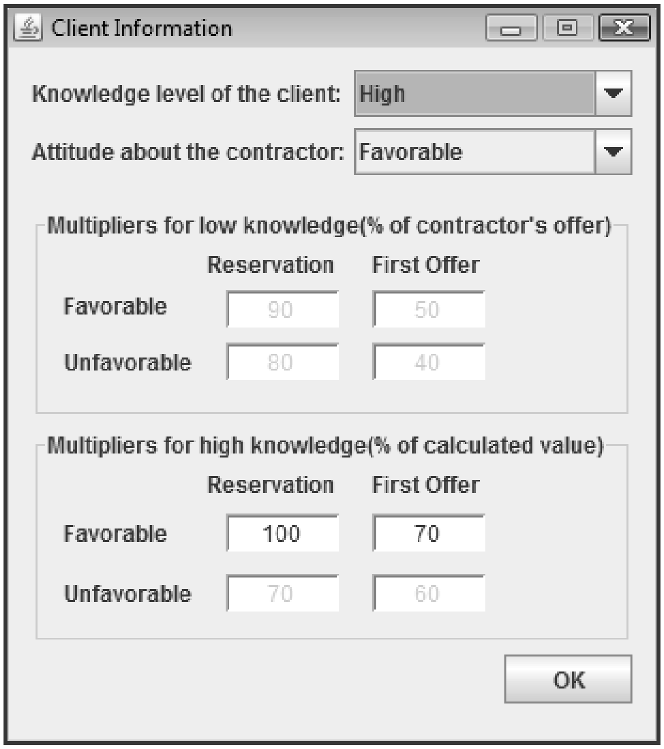
Notifications: This text area component used to inform user about the negotiation process. It notifies the user about the incoming and outgoing messages, stages of the negotiation and error messages.

Reset: Empties the agent active behaviors and empties the notifications area. Resets the agent for a new negotiation.

Save Simulation: Button is used to save the current simulation. It provokes a write method to create an ASCII file containing the information represented in Contractor Agent GUI and Risk Items GUI for later use.

Load Simulation: When activated this button opens a file explorer window to select an ASCII file. It also creates a read method to retrieve the simulation information stored in the file and then creates another method to fill this information into Contractor Agent GUI and Risk Items GUI.

4.4.2.2 Client Information Graphical User Interface



Client Information

Knowledge level of the client: High

Attitude about the contractor: Favorable

Multipliers for low knowledge(% of contractor's offer)

	Reservation	First Offer
Favorable	90	50
Unfavorable	80	40

Multipliers for high knowledge(% of calculated value)

	Reservation	First Offer
Favorable	100	70
Unfavorable	70	60

Figure 4-29 Client Information GUI

This interface is used to enter the knowledge level of the Client and its attitude about the contractor. It also determines the Client agent’s behaviour and makes definitions necessary for the determination of first offer and reservation values. Below are the definitions of the objects used in the interface.

Knowledge level of the client: This drop down menu used for entering the level of knowledge of the client about the construction process. There are two possible values as input; High and Low. A high value represents that the client has good understanding of the construction stages and has an experience in the sector. A low value represent Client is inexperienced in the construction sector and has limited or no knowledge about the construction stages.

Attitude about the contractor: This menu represents the Client agent’s attitude about the Contractor agent. Two possible input values are; Favourable, Unfavourable. A Favourable input means that Client agent is satisfied with the work done by the Contractor agent whereas Unfavourable input means the Client is not satisfied with the work done.

Multipliers for the low knowledge: This component is activated when Knowledge level of the client is selected as low. There are two input fields for low knowledge; Favourable and Unfavourable. Favourable field is activated when the Attitude about the contractor is selected as Favourable. Input made to this area by the user defines the percentage of Contractor agent’s offer that will be used as the client agent’s reservation value. Unfavourable field is activated when the Attitude about the contractor is selected as Unfavourable.

Multipliers for the high knowledge: This component is activated when Knowledge level of the client is selected as high. There are two input fields for low knowledge; Favourable and Unfavourable. Favourable field is activated when the Attitude about the contractor is selected as Favourable. Input made to this area by the user defines the percentage of calculated value that will be used as the client agent’s reservation value. Calculated value is the value that is retrieved from the Contractors claim amount definitions. As the Client has an high knowledge about the construction process it is assumed that the Client also has the information about the claim amounts. Unfavourable field is activated when the Attitude about the contractor is selected as Unfavourable. Input field represents the percentage of calculated amount that will be used as the client agent’s reservation value for this condition.

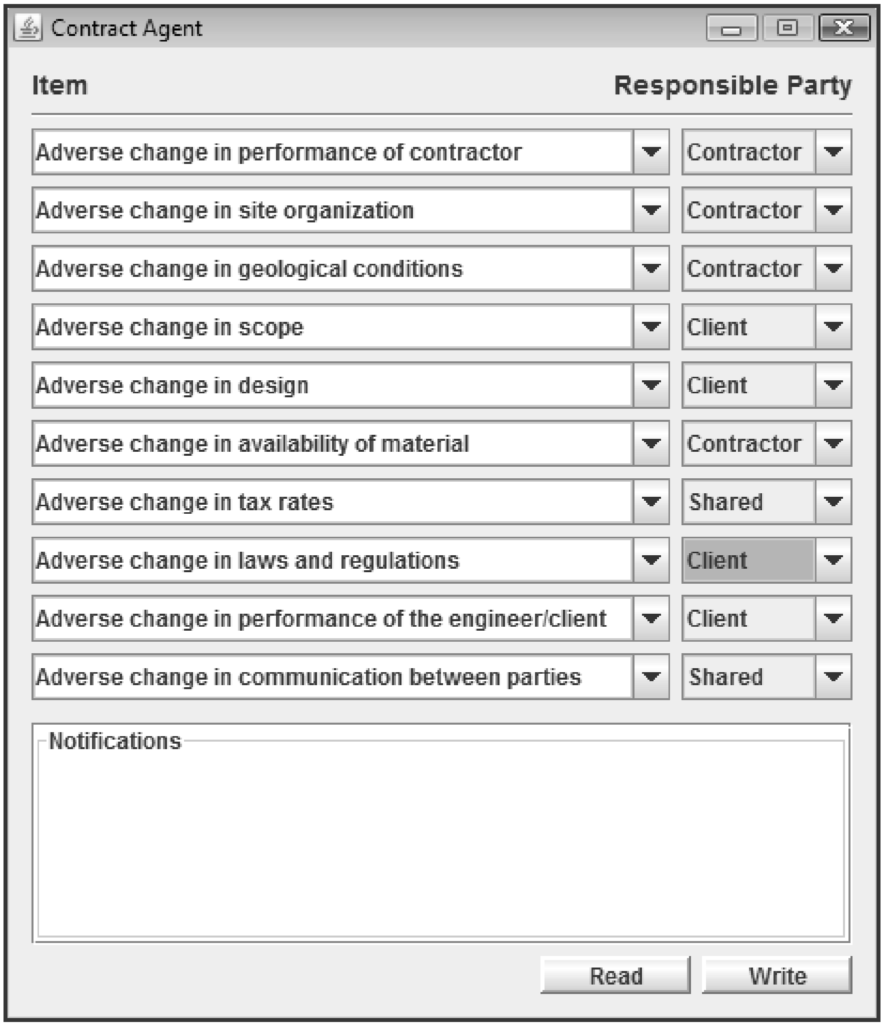
OK: Dismisses the current interface and opens the Client Agent graphical user interface.

4.4.3 Contract Agent

Contract agent is the agent that represents the contract conditions. It holds the information about the contract conditions. It informs both the Client and Contractor agents upon request. It does not involve into the negotiations and has no goal other then informing the agent. It has one interface;

- Contract Agent Graphical User Interface

4.4.3.1 Contract Agent Graphical User Interface



Item	Responsible Party
Adverse change in performance of contractor	Contractor
Adverse change in site organization	Contractor
Adverse change in geological conditions	Contractor
Adverse change in scope	Client
Adverse change in design	Client
Adverse change in availability of material	Contractor
Adverse change in tax rates	Shared
Adverse change in laws and regulations	Client
Adverse change in performance of the engineer/client	Client
Adverse change in communication between parties	Shared

Figure 4-30 Contract Agent GUI

This interface is used to enter the contract conditions. User can select the items from the risk items defined in the FIDIC contract conditions or enter the items manually. It can also save and retrieve data from ASCII files. Below are the definitions of the objects used in the interface.

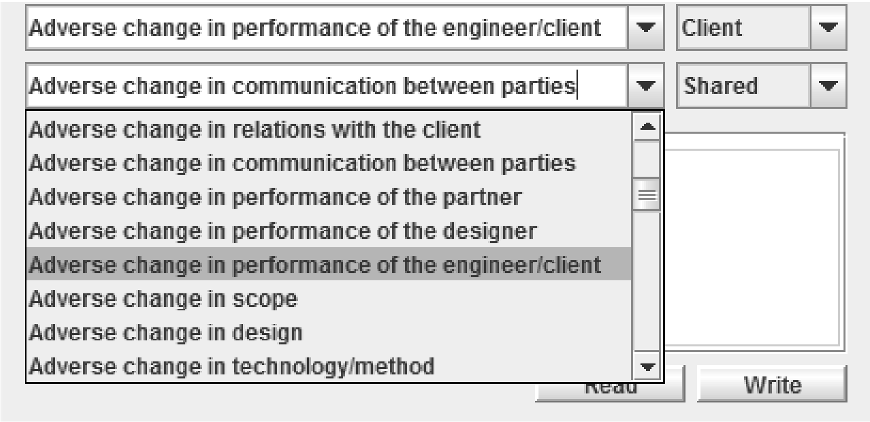


Figure 4-31 Selection of Risk Items from FIDIC contract conditions

Item: This list consists of the items that created the total loss during the construction. Each item represents an event that impacted the construction process and caused an increase in the project expenses (i.e. scope change, weather conditions, chance in material costs, low quality, cost of rework, accidents etc..) . These items can be selected among the items defined in FIDIC contract conditions. User can also define custom values instead of selecting from the list.

Responsible Party: This list consists of the responsible parties for each of the risk items used. Responsible party for each of the items is defined in the contract conditions. Responsibility for each of the item is taken by Client agent, Contractor agent or it can be a shared responsibility. These items are retrieved automatically from the FIDIC conditions when an item is selected. Custom selection can also be made by the user via a drop down menu.

Read: When activated this button opens a file explorer window to select an ASCII file. It also creates a read method to retrieve the contract conditions stored in the file and then creates another method to fill this information into Contract Agent GUI.

Write: Button is used to save the current contract conditions. It provokes a write method to create an ASCII file containing the information represented in Contract Agent GUI.

4.4.4 Sniffer Agent

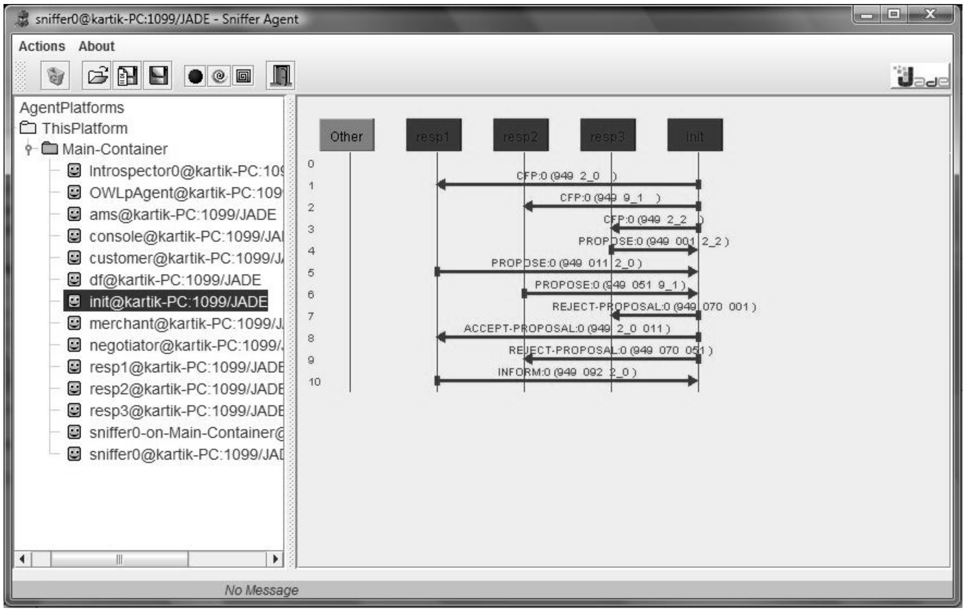


Figure 4-32 Sniffer Agent GUI

Sniffer agent is a built in class of the JADE platform. It provides a GUI that maps the agent interactions. User can select the agents to be monitored and follow the sent and received messages between the agents. It can intercept Agent Communication Language (ACL) messages while they are exchanged between agents. Captured messages are displayed graphically with using diagrams similar to Unified Modeling Language diagrams. This agent is essential for watching agent communications and debugging large agent communities by observing how they exchange ACL messages (Bellifemine, Caire, & Greenwood, 2007).

CHAPTER 5

SYSTEM EVALUATION

5.1 Introduction

System evaluation is one of the basic parts of the model evaluation. In this chapter system evaluation will be described. Evaluation of the system is done in two parts; theoretical evaluation of the system and evaluation of the results of the model. First a theoretical evaluation of the system is done under the guidance of the some key issues required by the literature on the subject. Than evaluation of the results are carried out by comparing results of the model with the assessments made by some of the real life industry professionals.

5.2 Theoretical Evaluation

Some of the basic conditions of a negotiation protocol are defined by Kraus, Wilkenfeld, and Zlotkin (1995) with some well accepted key features. These features are defined for a distributed multi-agent domain which would satisfy each agent designer. In the domain of this study the definition “conditions that will satisfy each agent designer” can be taken as the conditions that would satisfy each agent that would enter the negotiations. Since this is the preliminary condition for starting a claim negotiation, theoretical evaluation of the model will be done by inspecting model features in the context of these items.

Distribution: Distribution of the system means having no central unit for decision making process. These gives agents power of giving their own decisions and carry out the negotiations with their priorities. In the study decision making process is well distributed between agents. Each agent is separate and free to give its decision; no external influence is applied on the agents during the negotiation process.

Instantaneously: Conflict should be resolved without delay. In the model time penalty applied on the agents prevents delays. There are no infinite loops that would result in endless negotiations. Agents are also capable of identifying deadlocks and end the negotiation immediately by rejecting further proposals.

Efficiency: Outcome of the negotiation should be efficient; mechanism should allow agents to reach Pareto-Optimal solutions with high probability and conflict should be avoided if possible. Pareto-Optimal solution means that settlement value maximizes the sum of the utilities of each side. In the model if both of the agents use Zeuthen Strategy the outcome will be Pareto-Optimal as shown by Harsanyi (1956). Also model ensures that the results will be individually rational, which means utility of each agent is greater than 0.

Simplicity: The negotiation process should be simple and efficient. Process should consume a reasonable amount of communication and computation resources. Model developed in this study is very lightweight in terms of computation. JADE platform used in the model is the fastest framework when compared with the other frameworks like Zeus or Jack (Shakshuki & Jun, 2004). Since negotiations are bilateral, communication between the agents is also limited.

Symmetry: Agents in the negotiation mechanism should be treated equally. Model treats agents only with their relevant attributes; time penalty, utility curve etc. All other attributes like name or manufacturer of the agent is irrelevant.

Stability: There should be distinguishable equilibrium points in the protocol. Model in the study is designed to preserve stability. No protocol used in the model leads to divergent offers, and also deadlocks are identified and handled without leading to instable conditions.

Theoretical analysis shows that the model satisfies the key evaluation criteria. But relaxation of some of these items is also possible since negotiation process takes places in a closed domain with no interaction with outside agents. To have a better fit to another real life negotiation conditions, constrains like distribution can be relaxed without violating the others. For example a mediator agent could be presented to the system relaxing the distribution constrain without violating the symmetry (mediator should treat agents equally).

5.3 Result Evaluation

5.3.1 Evaluation Process

Evaluation of the results is done with 8 professional from the industry. Results are evaluated with making a survey which is compatible with the model data and can be used for comparing the answers with the results produced by the model. Also this information is used for the calibration of the model. Some of the input variables like fuzzy level definitions can be entered by the user to the model. Information from the survey is used to give better initial values for these values thus guiding the user for the simulation process. All of the surveys are done by direct interview and a survey form consisting of information of an artificial project is presented to the participants. Given project is a project with a cost increase of 100 and reasons for increase of the cost is given as follows;

Table 5-1 Survey used for the evaluation of the model (Case 1)

Case 1 Original Case		
Risk Event	**Risk Sharing**	**Approximate loss**
Adverse Change in Contractor Performance	Contractor	5
Adverse Change in site Condition	Contractor	10
Adverse Change in Geological Condition	Contractor	15
Adverse Change in Project Scope	Client	15
Adverse Change in Project Design	Client	10
Adverse Change in Availability of Resources	Contractor	10
Adverse Change in Country Economic Condition	Shared	10
Adverse Change in Laws and Regulations	Client	15
Adverse Change in Performance of Client	Client	5
Adverse Change in Relation with Project Parties	Shared	5

Risk Event: The items that resulted in the total cost increase of the project.

Risk Sharing: Responsible party for the given risk event.

Approximate Loss: Loss occurred due to the given risk item.

Attendees are also informed with the following information about the negotiation process;

- Given information is accessible for both contractor and client agent
- There is no possibility of having a future relationship between the client and contractor agents
- Client agent has a favourable attitude against the contractor
- Each side of the negotiation have the same time constrains

With the given information participants are requested to answer following questions and fill the given table.

Opening offers of each party: First offers given by each party.

Reservation amount of each party: This value is the limit for each party in accepting offers. For contractor agent this is the minimum value that can be accepted and for client agent this value is the maximum value that can be offered.

Settlement Amount: Value which the negotiations will settle. Given value is the amount that will be compensated by the client.

Table 5-2 Answer sheet for the survey results

	Contractor	**Client**
First Offer Value		
Reservation Value		
Settlement Amount (percentage compensated by the client)		

In addition to these numeric questions which can be directly compared with the model results one more question is presented to evaluate the assumptions of the system;

Factors affecting the negotiation: In your experience, what other factors do you think will affect the negotiation process?

This question is presented for both observe the validation of the assumptions of the study on factors affecting the system (like client's attitude about the contractor or client's knowledge about the work). Also new factors suggested by the participants may be treated as a future study.

A more through survey process is also done with 3 participants who showed greater interest into the subject. To these evaluators other than the original case 2 different example projects are also presented. Each of these projects has the same properties as the original case except the risk sharing information. While first case contains a more homogeneous distribution (Table 5-1) between parties 2nd project (Table 5-3) is created by giving higher weight to the contractor agent and 3rd one (Table 5-4) is by giving higher weight to client agent. This is done to investigate model behaviour under different conditions.

Table 5-3 Survey used for the evaluation of the model (Case 2)

Case 2 Contractor Extensive		
Risk Event	**Risk Sharing**	**Approximate loss**
Adverse Change in Contractor Performance	Contractor	5
Adverse Change in site Condition	Contractor	10
Adverse Change in Geological Condition	Contractor	15
Adverse Change in Project Scope	Client	15
Adverse Change in Project Design	Contractor	10
Adverse Change in Availability of Resources	Contractor	10
Adverse Change in Country Economic Condition	Shared	10
Adverse Change in Laws and Regulations	Contractor	15
Adverse Change in Performance of Client	Client	5
Adverse Change in Relation with Project Parties	Shared	5

Table 5-4 Survey used for the evaluation of the model (Case 3)

Case 3 Client Extensive		
Risk Event	**Risk Sharing**	**Approximate loss**
Adverse Change in Contractor Performance	Contractor	5
Adverse Change in site Condition	Contractor	10
Adverse Change in Geological Condition	Client	15
Adverse Change in Project Scope	Client	15
Adverse Change in Project Design	Client	10
Adverse Change in Availability of Resources	Contractor	10
Adverse Change in Country Economic Condition	Client	10
Adverse Change in Laws and Regulations	Client	15
Adverse Change in Performance of Client	Client	5
Adverse Change in Relation with Project Parties	Shared	5

5.3.2 Evaluators' Background

Evaluators are selected both from academicians and industry professionals. Work experience of the 8 participants varies from 4 to 35 years of experience with an average of 17 years. 7 participants are from civil engineering profession and 1 is from architecture. Two of the evaluators have attended to negotiation processes both on the contractor and the client side and two of the attendees have performed as an expert in the arbitration or court cases of similar construction claims.

5.3.3 Responses to the Questions

Reponses to the questions are tabulated as follows. Values in the tables represent the amount of money to be compensated by the client;

Table 5-5 Evaluation results for Case 1

	Case 1 Original Case				
	First Offer Value		**Reservation Value**		**Settlement Amount**
	Contractor	Client	Contractor	Client	
	72.5	42.5	65.0	55.0	60.0
	89.0	59.5	70.0	77.5	70.0
	100.0	55.0	55.0	55.0	55.0
	80.0	50.0	50.0	70.0	60.0
	90.0	60.0	72.5	85.0	77.0
	70.0	30.0	35.0	60.0	45.0
	70.0	20.0	45.0	60.0	45.0
	60.0	40.0	47.0	52.0	50.0
Average	**78.9**	**44.6**	**54.9**	**64.3**	**57.8**
Model	**75.0**	**42.0**	**54.9**	**60.0**	**54.9**
Difference	3.9	2.6	0.1	4.3	2.9
StDev (σ)	13.2	14.3	13.2	11.9	11.5

Table 5-6 Evaluation results for case 2

	Case 2 Contractor Extensive				
	First Offer Value		**Reservation Value**		**Settlement Amount**
	Contractor	Client	Contractor	Client	
	50.0	20.0	25.0	35.0	32.0
	40.0	25.0	25.0	40.0	30.0
	40.0	15.0	20.0	20.0	20.0
Average	**43.3**	**20.0**	**23.3**	**31.7**	**27.3**
Model	**43.3**	**24.5**	**31.2**	**35.0**	**31.2**
Difference	0.1	4.5	7.9	3.3	3.9
StDev (σ)	5.8	5.0	2.9	10.4	6.4

Table 5-7 Evaluation results for case 3

	Case 3 Client Extensive				
	First Offer Value		**Reservation Value**		**Settlement Amount**
	Contractor	Client	Contractor	Client	
	95.0	60.0	70.0	80.0	78.0
	75.0	25.0	70.0	70.0	70.0
	80.0	60.0	70.0	75.0	72.0
Average	**83.3**	**48.3**	**70.0**	**75.0**	**73.3**
Model	**93.8**	**52.5**	**70.6**	**75.0**	**72.9**
Difference	10.4	4.2	0.6	0.0	0.4
StDev (σ)	10.4	20.2	0.0	5.0	4.2

In the tables predictions of the evaluators and the model are given for all of the three cases. Also difference of the model from the survey results is presented together with the standard deviation of the participants answers. For all the three cases same calibration of the simulation is used and settlement amount is found with using Zeuthen's Strategy as the negotiation protocol. When the difference values are compared with the standard deviation of the evaluators results it can be seen that for most of the cases the difference is less than half of the standard deviation.

Calibration of the program and the input variables of the simulation are as follows;

Table 5-8 Model calibration

Contractor Agent			
	Low	**Medium**	**High**
Fuzzy Level Definitions	15	25	35
Long term effect multiplier	20		
Time Penalty	1%		
Client Agent			
	Value	**Multiplier**	
Knowledge	High	100	
Attitude	Favourable	70	
Time Penalty	1%		

Evaluators' responses to the factors affecting the negotiation protocols question can be summarized as follows;

- Possibility of having another job in the same region or market. Even if there will be no relationship between the contractor and the client in the future, reputation of the contractor/client would be affected from the result.

- Exchanging some of the items instead of making the negotiation for all of the items. For example one side accepts to compensate 3 items in exchange with other side's compensation of 1 more weighted item.

- The type/domain of the client whether government or private

- Nationality of the parties

- Client attitude against the contractor
- Documentation of the work done
- Items that can be easily shared between the sides should be treated first
- Knowledge level of the client
- Agents current economic situation and financial viability of the sides
- Contract type
- The maturity of the legal system prevailing in the country (whether the parties trust in the legal system or not, existence of a fair dispute resolution or arbitration system
- Risk attitude of the parties (risk-taking, risk-neutral or risk-averse)
- Time restrictions for both parties

5.4 Discussion

Results show some interesting information about the nature of claim negotiations. When we observe the reservation values we see that determination of the agreement zone which is the zone between agents' reservation values is more important than the negotiation process. Agreement zone defines the range for negotiations, when we check this range for the first case we see the following results;

Table 5-9 Agreement zone values for Case 1

	Agreement Zone
	10.0
	7.5
	0.0
	20.0
	12.5
	25.0
	15.0
	5.0
Average	9.4
Model	5.2

As can be seen from the (Table 5-9) if we take the average value, negotiation protocol can only affect the settlement value about 10% at maximum. So we can conclude that more emphasis should be given to determination of reservation values for the future studies. It is encouraging to observe that the approach used in this study determines reservation values quite well. But when we check the users' comments we can see that although some of these items are already included in the model others may also be added as a further study. Some items like "financial viability of the sides" or "documentation of the work done" can be added with few more variable definitions but items like "exchange of items" or "sharing the easy items first" may need more statistical input and a higher level of artificial intelligence.

CHAPTER 6

CONCLUSION

A multi-agent system has been developed to simulate the construction claim negotiation process and determine sensitivity of outcome to various variables. Java development language and JADE framework is used to construct the simulation in accordance with FIPA specifications. 3 agents are defined in the study; contractor, client and contract agents. While negotiations take place between contractor and client agents, contract agent acts as a legal advisor about the conditions in the contract. As the first step of the negotiation process the reservation and first offer values for contractor and client agents are calculated. These items are calculated based on the risk events defined in the contract and negotiation environment. Risk items that actually resulted in cost overrun are defined with their associated costs, responsible party assignments taken from the contract agent and fuzziness related with the costs. Negotiation environment is defined by contractor agent's possible future relationship with the client agent, client's knowledge on the sources of cost overrun and client agent's attitude towards the contractor agent.

Negotiations are carried out with three different negotiation protocols. These protocols are Zeuthen's Strategy, Zeuthen's Strategy with Bayesian Learning and Time dependant concession. Each agent can select the negotiation protocol that it wants to use and this approach also enables asymmetric negotiations. During the negotiations, to reflect the time pressure on each party, different time penalties can be defined for the contractor and client agents. Negotiations may end with a settlement amount but agents can also identify a deadlock and end the negotiations with a conflict deal.

The impacts of first offer value, reservation value and each negotiation protocol on the negotiation outcome were assessed by sensitivity analysis. Effect of the input variables is observed considering the extreme conditions. Results show that first offer and reservation values are very sensitive to the changes in responsible party assignments. When the results for settlement amounts produced by each negotiation protocol are considered they are, found to be especially sensitive to reservation value and time penalties of the parties.

If a comparison is made between negotiation protocols, Time Dependant Concession is found to produce most stable negotiations. But its major drawback is, it does not take into account the utility curves of the agents and settlement value is only dependant on the time penalties of each party. Second negotiation protocol, Zeuthen's Strategy compensates this drawback by taking utilities of the agents also into account. But its major assumption that all the agents are fully informed about the utility curves of the opponent agent, is not always applicable to real life cases. Third negotiation protocol, extension of Zeuthen's Strategy with Bayesian Learning on the other hand has a potential of reflecting real life cases since it does not use the full information assumption and tries to predict the utility curves with Bayesian Learning Theorem. But in practice it can be seen that its prediction capacity is highly dependent on the possibility distributions defined by the user and convergence of the predictions to the real utility values is very slow for a claim negotiation environment. Due to this reason it is also most unstable model in terms of approaching a settlement amount.

For the evaluation of the performance of the system a survey with industry professionals is also made. Responses of the experts showed that settlement amounts are highly dependent on the reservation values. Regardless of the negotiation protocol used, mainly reservation values determine the settlement amount of the negotiation. For various cases, when we compare the results produced by the model with the average of the answers of the experts, it is seen that model shows a close fit to the results with less than a half of the standard deviation of the responses.

Simulation of claim negotiations or simulation of any negotiation in general, greatly depends on the human behavior. Usual way of overcoming this difficulty is using statistical techniques. But retrieving statistical data for items like reservation amounts of the sides, or attitude of the client against contractor is very difficult and gathering enough data to create a statistically meaningful sample size is usually impossible. So usual approach to the problem is defining some key features of the model and building an artificial intelligence tool to simulate the negotiations. Selection of the items that will affect the process should be the first step for this kind of a study. At the evaluation part of this dissertation, survey results for the factors affecting the negotiation process give some points for future studies and many more may be found with more detailed surveys. But the real challenge is converting these linguistic items into a meaningful mathematical model. When converted into mathematical terms verbal terms usually become very ambiguous and hard to rely on. Any attempt of modeling negotiation process should be supported with a sound mathematical model.

This study presented a way for determining the initial conditions of the negotiation process, reservation and first offer values. Other studies cited in the literature take these values as input variables given by the user but evaluation of the results in this study shows that reservation values of each side is the most important variable affecting the settlement amount. So in the future studies more importance may be given to determination of this item. Agents' economic situation and financial viability of the sides may be included. Also this study considered claim amount as the argument to be passed between agents. To enhance the negotiation process a future study can consist of other arguments to be passed during negotiation process. Items may be grouped for negotiations and some of the items may be compensated by the agents even before starting the negotiations, also exchange of claim items in the case of conflicts may be considered.

The MAS developed in this study is a part of an ongoing research project funded by TÜBİTAK. In this study total cost overrun is accepted as 100% but for the forthcoming parts of the research project another agent will be introduced to the system to predict the cost increase. List of risk items will also be taken from a risk-vulnerability ontology which is defined beforehand. The raised system can be capable of calculating cost overrun for a project and will be able to distribute this increase between parties by using the methods introduced in this study.

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