Automated Negotiation
in Multi-agent based E-business

by

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Doctor of Philosophy

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Dedication

The author would like to express her deepest gratitude and love to her husband, Rafiq Huq and son, Taofiq Huq. Without their moral support, encouragement and patience, it would not have been possible to complete this study over the difficulties encountered during the period of this research. To express her appreciation, the author would like to dedicate this study to Rafiq and Taofiq and to all her well-wishers.
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The author is grateful to the School of Computing and Mathematics (SCM) for offering her the opportunity of working as a Teaching Fellow and to undertake this study.

Finally, the author sincerely acknowledges the well-wishing and moral support from her parents, family and friends throughout her endeavour.
The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

(Signature)
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<td>Average production cost</td>
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<td>B2C</td>
<td>Business-to-Consumer</td>
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<td>BO</td>
<td>Business Organisation</td>
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ABSTRACT

Negotiation is one of the most important activities for organisations in conducting electronic business. Traditional purchasing and selling have been conducted through complex processes involving negotiation that includes coordination and cooperation. To conduct automated negotiation for electronic business, a multi-agent system is needed where agents interact with each other. To perform this activity effectively and efficiently agents need to be able to negotiate, coordinate and cooperate with each other within the system.

The research detailed in this thesis investigated the negotiation process in business-to-business (B2B) transactions in supply chain management for multi-agent based electronic business (e-business). Specifically, it answers the following research question: How can the negotiation process in B2B transactions be formulated and applied in multi-agent based e-business?

The research strategy utilized an exploratory case study framework, with methods from decision theory, game theory, fuzzy logic and simulation for analysis. A series of integrated studies were undertaken to develop: an automated negotiation protocol; negotiation strategies; and a coordination and cooperation model. These were analysed in the context of the case study, Trading Agent Competition Supply Chain Management (TAC SCM) game scenario. Currently, the TAC SCM is the only international competition involving an electronic marketplace (e-market).

The studies involved the negotiation strategy between two agents, where the agents will be able to solve a problem by finding the best feasible strategy to bind an agreement for negotiation. By adopting a maximin and minimax strategy, this research proposes that agents will reach a reasonable positive intention approach towards negotiation, and will increase the agreement binding rate.

A negotiation strategy was also examined by Fuzzy Logic using possibility theory and linguistic variables in which it also proposes a negotiation strategy in an uncertain situation for the TAC SCM. This will aid in binding the agreement to achieve the agent’s expected profit.
Next, this research reviewed the TAC SCM game and explored the procurement performance of agents. The monotonic concession negotiation protocol, which determines the rules in which the agents can offer and counter-offer in the negotiation process was investigated. The author proposes two types of protocols. The first protocol is a Non-Monotonic Protocol with theoretical analysis. The second protocol is an Extended and Flexible Iterated Negotiation Process. This research also developed an Extended Bilateral Negotiation Model based on OMG (1999). The Negotiation Mechanism involving Offering and Counter-Offering models were also developed.

Next, this research reviewed the cooperation and coordination process. This study identified problems in conducting e-business and supply chain management and expected benefits for supply chains with agents working together in coordinated and cooperative processes. The utilization of the multi-agent system in supply chain management with the Enhanced and Effective Cooperative Processing Stages is discussed. To apply these stages, the author proposes an architecture of Effective Cooperative Processing for Agents, and some characteristics in modelling coordination and cooperation for TAC SCM have been outlined.

The research detailed how the negotiation process in B2B transactions can be formulated and applied in multi-agent based e-business. Through the proposal of a Flexible and Iterated Negotiation Framework, consisting of an Extended Bilateral Negotiation Model and a Cooperation and Coordination Model, the research community moves further towards the ultimate goal of an efficient, economic and automated negotiation process.

In summary, the main contributions of the thesis include: a theoretical analysis of the negotiation process with coordination and cooperation; proposed models for an automated negotiation process; development of strategies and protocols for automated negotiation; and the coordination and cooperation model that can be used not only in supply chain management but also in any type of e-business.
PUBLICATIONS FROM THIS THESIS


The following book chapter has been accepted, and is scheduled for publication in November 2007:


The following conference paper has been accepted, and is scheduled for publication in July 2007:

CHAPTER 1

Introduction

1.1 Introduction

This chapter presents the introduction of this dissertation in an epigrammatic format. The thesis furthers the understanding of the research process into automated negotiation in multi-agent system. This understanding is achieved with the development of: definitions and theory to formulate negotiation strategies; a negotiation protocol; an enhanced bargaining model; a coordination and cooperation model for business-to-business (B2B) transactions; and a flexible iterated negotiation process.

Negotiation is the basic activity to perform selling, buying and other services in businesses. A multi-agent based system is needed to conduct automated negotiation for business in an electronic environment, where agents are able to interact with each other. Therefore, we need to develop and improve activities of negotiation specifically protocol strategies that enable appropriate sustainable processes. In this regard, this chapter discusses the background of electronic business/commerce, and then explains electronic negotiation, and the need for negotiation in e-business. Following, negotiation in multi-agent systems is explored as well as emerging trends. The research problem, theoretical framework, aim and objectives and scope of the research are presented.
1.2 Background of electronic business/commerce

Electronic business (e-business), derived from terms such as "e-mail" and "e-commerce", involves the activity to conduct business on the Internet, not only buying and selling but also servicing customers and collaborating with business partners. Alternatively e-commerce (electronic commerce or EC) is the buying and selling of goods and services on the Internet, particularly the World Wide Web. In practice, the term e-commerce and the newer term, e-business, are often used interchangeably. One of the first to use the term was IBM, when, in October, 1997, it launched a thematic campaign built around this term. In addition to this, the term “electronic commerce” (e-commerce) generally defines an advanced step of modern commerce in which the figures of buyer and seller are replaced by electronic entities (Baily and Bakos, 1997). In late 1999, the National Office for the Information Economy (NOIE) provided the following broader definition in Australia’s e-commerce report card (1999):

In e-commerce, business is communicated and transacted over networks and through computer systems. The most restrictive definition limits e-commerce to buying and selling goods and services, and transferring funds through digital communications. However, e-commerce also may include inter-company and intra-company functions (such as marketing, finance, manufacturing, selling and negotiation) that enable commerce and use electronic mail, EDI, file transfer, facsimile, video-conferencing, workflow, or interaction with a remote computer. E-commerce also includes buying and selling over the World Wide Web and the Internet, transferring electronic funds, using smart cards and digital cash, and doing business over digital networks. (p.60).
E-commerce reduces transaction costs for enterprises and provides customers with better bargaining tools (Deitel et al, 2001; Schneider and Perry, 2000). For instance, there are some automated systems, which allow customers to compare prices of a variety of products (Papazoglou and Ribbers, 2006).

In general, e-business has a wider perspective than e-commerce (Chan et.al., 2001). It involves using information technologies in all aspects of the business. Hence, e-commerce can be viewed as a subset of e-business. Therefore, like other publications, this thesis will use the terms e-business, e-commerce, internet commerce and Web-based electronic business in an interchangeable manner.

Nowadays, major corporations are rethinking their businesses in terms of the Internet and its new culture and capabilities. Companies are using the Web to buy parts and supplies from other companies, to collaborate on sales promotions, and to undertake joint research. Exploiting the convenience, availability, and world-wide reach of the Internet, many companies (such as Amazon.com) have already discovered how to use the Internet successfully.

1.3 Electronic negotiation in business

Negotiation in business is the process aimed at modifying the local plans of each organisation in order to achieve an agreement among a subset of businesses. Conversely, negotiation is a form of decision-making where two or more agents jointly search a space of possible solutions through interaction with the goal of reaching a consensus (Wooldridge, 2002). Negotiation usually proceeds in a series of rounds, with every agent making a proposal at each round. Some examples:
• Negotiating an agreement about the price of purchasing and selling, for example, stock markets, auction houses, flower auctions.

• Negotiating a meeting time and venue, or

• Negotiating a joint action or a joint objective.

Consequently, electronic negotiation (e-negotiation) is when software agents perform the above negotiation activities on behalf of businesses in an electronic environment.

Furthermore, negotiation in e-commerce is a decision-making process where two or more parties multilaterally bargain resources for a mutual intended gain, using the tools and techniques of e-commerce. In 2000, Strobel argued, “Negotiation takes place when, based on offers made in the information phase, an agreement cannot be reached or the agreement has potential for optimisation and the parties intending to carry out the transaction want to discuss their offers” (p.2). Actually, the most basic form of e-negotiation is no negotiation at all (also called fixed-price sale) where the seller offers goods or services through a catalogue at take-it-or-leave-it prices (Benuoucef and Keller, 2000). Auction, mediation, and brokering are three key concepts of commerce (Sun and Finnie, 2003). These concepts are discussed in detail in Chapter 2. At present B2C auctions, such as Ebay Auctions, are the most visible type of e-negotiation on the Internet. Examples of B2B auctions include Liquidation.com, and Business.ebay.com, as well as many B2B auction sites for a range of industrial components.

Auctions are performed when only one attribute of the object needs to be considered, rather than multi-attributes, for example quality, quantity, warranty, and delivery date. For this reason auctions are not applicable for everyday trading operations and transactions. To facilitate a flexible, effective and sustainable negotiation in e-
commerce, a multi-issue based bargaining system needs to be developed. This system can be based on auction principles and applied to B2B transactions (see Chapter 2 for more detail). It involves making proposals and counter-proposals until an agreement is reached or until the negotiation is aborted (Su et. al., 2000). The Object Management Group (OMG) considers bargaining as a bilateral or multi-lateral negotiation depending on whether there are two parties (one-to-one bargaining) or many parties (many-to-many bargaining) involved in the negotiation (Object Management Group, 1999). The bargaining system will provide businesses and/or customers with more attractive and competitive value for the intended product. Recently, to focus on this issue, extensive investigation has been conducted within the research community.

This thesis focuses on B2B negotiation rather than B2C negotiation as B2B is significantly larger than B2C commerce. Also, B2B transactions deal with a higher volume of goods, and higher net value of goods. In addition, prior agreements between partners involved in the e-commerce business cycle require higher levels of documentation and information exchange. For these reasons the whole process of B2B e-commerce is much more complex than B2C, and requires more sophistication in a software system.

1.4 Need for negotiation in e-business

Because of the diffusion of Internet technology in the mid-90s, the business world encountered a new disruptive possibility to exchange data by computer networks at low cost (Christensen, 1997; Bower and Christensen, 1995). Likewise, computer-based networking has created a significant change in business activities. Therefore these changes need a fundamental rethinking of the development of business models. A
business involves different processes such as buying, selling and services that require negotiation process. Software agents can be used to automate several of the most time consuming stages of the buying process (Sandholm 2000; Ma, 1999; Maes, Guttman and Moukas 1999).

For example, let us consider an organisation that needs to order some products, and could have a buying agent that moves through all the stages of the buying process. An agent can be designed to automatically gather information on vendors and products, which may match the requirements of that organisation. After evaluation of the various offers, a decision is made on which merchants and products to investigate. This is followed by negotiation on the terms of the transactions with these merchants. Following successful negotiation, orders are placed and finally payment made automatically.

Generally, the negotiation process occurs in all electronic transactions at the time of the communication of agents in order to reach mutual beneficial agreements. The agents might have some common interest in cooperating, but might have some conflicting issues over exactly how to cooperate. Agents can mutually benefit each other in reaching agreement on a particular outcome from a set of possible outcomes, but might have some conflicting interests to overcome in achieving the outcome that they prefer. Before moving into any cooperation they need to decide how to cooperate in order to obtain the associated benefits. On the other hand, each agent would like to reach an agreement that is favourable to itself as far as possible. Therefore, they need to make a series of offers and counter-offers before any agreement is reached. This procedure makes negotiation a time-consuming process. While software agents not only save labour time of human negotiators, they also will find solutions that are as beneficial as possible to all the parties (Sandholm, 2000). As a result, negotiation in an electronic
environment will increase the efficiency of negotiations through the assistance and automation of decision tasks. This increase in efficiency will provide the following benefits (Strobel, 2003):

1. The complexity and uncertainty of non-automated decisions in electronic negotiation can be reduced due to adequate information being provided.
2. Structured negotiation tasks with a well-defined solution approach can be applied.
3. Increase the total number of potential transaction participants, which will provide more options, flexibility and ultimately attract more efficient agreements when moving towards negotiation.
4. More transparency can be enabled between participants.
5. Reduce the total cost and time of negotiation.

1.5 Negotiation in multi-agent system

A multi-agent system (MAS) is one that consists of a number of agents, which interact with one another, typically by exchanging messages through some computer network infrastructure (Wooldridge, 2002). Generally, the agents in a multi-agent system represent or act on behalf of users or owners with a diversity of goals and motivations. Therefore, these agents require the ability to cooperate, coordinate and negotiate with each other for successful interaction.

Today negotiation plays an important role in multi-agent systems. When one business organisation wants to buy or sell goods or have services in an electronic environment then it always needs some processes that involve negotiation.
To conduct efficient business, the system needs to interact from one business organisation to other business organisations. For example, in supply chain management (SCM) the suppliers, manufacturers, retailers and consumers, are all in a related network, which needs proper, efficient and timely coordination, cooperation and negotiation processes. Therefore, in an electronic environment when the above entities interact with each other the system needs diverse automated software agents to perform tasks on behalf of real-world business organisations. As a result, this can be achieved by applying multi-agent systems in an electronic environment to improve efficient performance among software entities. Detailed discussion on agent-based technology and multi-agent system will appear in Chapter 8 of this thesis.

1.6 An Emerging Trend

The potential for business-to-business (B2B) e-commerce is now projected to be much larger than that for consumer oriented e-commerce (Chan et al. 2001). The automation of electronic B2B activities is an emerging issue. For example, in the supply chain, manufacturer organisations or retailers are dependent on supplier organisations. There are many processes in selling and purchasing that can be conducted electronically. Particularly, at the time of purchasing, many processes are complex and involve negotiation, cooperation and coordination. In the real world, these processes are very time consuming and complicated. Therefore, if these processes can be utilised electronically, then complexity can be reduced, and overall time reduced. Figure 1.1 shows B2B e-commerce growth from 1998 to 2005 (Gartner, 2006, and Chan et al. 2001).
From Figure 1.1, it is noticed that B2B e-commerce only started from 1998, which is relatively new. This growth is increasing rapidly. If businesses utilise this electronic environment then it will become more popular and the growth will be increased quickly. Businesses currently need to (Chan et al., 2001):

a) Sell and distribute the goods to the other businesses.

b) Perform procurement of goods and services.

c) Maintain logistics to move goods to the right place at the right time and in correct quantities known as Just-in-Time (JIT) management.

d) Maintain inventory facilities properly, that is, according to requirement store right goods in right time.

e) Gather correct information, forecasts and market intelligence to achieve best activities towards their benefits.

To conduct the above activities, automation of the business processes need to be developed. Therefore, if business organisations can perform these processes then we can predict that this trend in e-business utilisation will dramatically increase in the future.
1.7 The Research Problem and Scope

In 2000, John Mitchel argued that e-commerce is permanently destroying some old ways of doing business and creating new ones. Therefore, new strategies are required for proper planning and managing the businesses. To develop these strategies, automation of businesses processes is required. Negotiation processes is one of the most important processes in business communities. In addition to this, automation of negotiation, which corresponds to negotiation-based e-commerce, has received a great deal of attention from the Multi-agent community, because such endeavours have the important potential for significantly reducing negotiation time and removing some of the reticence of humans to engage in negotiation and then facilitating the intelligent negotiation agents that are able to perform negotiation on behalf of users (Lomuscio et al., 2001). Again, many researchers noted that the automated negotiation has been of particular interest due to the relevant role that negotiation plays among trading agents at the activity of auction, mediation or brokerage (Paurobally, 2001; Jennings, 2000; Faratin et al, 2000; Beam and Krishnan, 1999).

Until now, there have been many research studies carried out involving automated negotiation to enable efficient and effective global business. However, current practices are not adequate for B2B transactions in an electronic environment. From the literature, the following problems are identified in current electronic negotiation in business:

i) Lack of bilateral negotiation process,

ii) Lack of appropriate negotiation strategies,

iii) Lack of proper negotiation protocols,

iv) Lack of an iterated negotiation process,
v) Lack of adequate coordination and cooperation models, which will facilitate the negotiation process

Therefore, developments and improvements need to be made to solve the above problem of inadequate electronic negotiation. The author has solved the first part of the above identified problems as far as possible within the timeframe of this thesis, and has provided an indication for future research to be undertaken for the business community to conduct sustainable electronic business.

The scope of the research includes the development of a bilateral negotiation process, negotiation strategies, protocols and coordination and cooperation model which will facilitate negotiation mechanism. These functionalities are more important for B2B transactions rather than B2C transactions, as B2B e-commerce is characterised by the following factors (Schneider and Perry, 2000; Turban, Lee, King, and Chung, 2000):

- Trading of bulk volumes of goods and high net value of goods,
- Repeated and regular purchasing,
- Payment is made in multiple format,
- Higher levels of documentation,
- Multiple levels of authorisation of purchases, each level having its own limits on expenditure or even type of goods,
- Maintain long-term relationships with business partners.

These factors make the whole process of B2B e-commerce much more complex than B2C e-commerce. This requires new environments of software to be developed to enable efficient and effective electronic business (Chan et al., 2001). Therefore, B2B e-commerce is the focus and scope of this research. As automated negotiation research is
relatively new, it is not yet possible to conduct studies between real organisations. Subsequently, this research is bounded within a single case, the Trading Agent Competition Supply Chain Management (TAC SCM), which is the only current test bed scenario in the software world available for research.

1.8 Theoretical Framework

The analysis for this thesis is undertaken by using different theoretical approaches such as decision theory, game theory and fuzzy logic. These theories are discussed in detail in chapters 3 and 4.

Decision theory (Raffia, 1968) is a means of analysing a series of options that could be taken, when it is uncertain exactly what the result of taking the option will be. That is, decision theory focuses on identifying the “best” option, where the notion of “best” has a number of different meanings and, one of the most common is maximising the expected benefit to the decision maker. Because every agent or decision maker is self-interested they always seek their benefit mostly by rational choice. As a whole, decision theory provides a powerful tool to analyse cases in which the agent’s decision must be made in an uncertain or unpredictable environment.

Game theory is a mathematical theory that studies interactions among self-interested agents (Binmore, 1992). Recently, the tools and techniques of Game Theory have found many applications in computational multi-agent systems research, particularly when applied to problems such as negotiation (Wooldridge, 2002). Many of the solution concepts developed in Game Theory (such as Nash equilibrium) are playing an important role in analysing the negotiation mechanism.
This research uses mathematical modelling and simulation to address the research questions related to electronic negotiation and bargaining. A case study approach is used, namely the ‘Trading Agent Competition Supply Chain Management (TAC SCM)’, which is an autonomous game where researchers from different universities around the world participate in contributing information about electronic marketplaces using autonomous software agents. The game simulates the overall supply chain challenges where it requires agents to concurrently compete in multiple markets (markets for different components on the supply side and markets for different products on the customer side) (Arunachalam et al, 2003).

Simulation is one of the testing tools in which agents can predict a better result. Therefore, the research has undertaken some negotiation strategy analysis by simulation using Nash Equilibrium and developed a theoretical model. The agents can learn from simulation analysis by identifying which strategies will give better results, that is, which results are feasible.

In an uncertain situation it is very difficult to make the right decision at the right time. Therefore, negotiation analysis also needs to be explored using fuzzy logic. Fuzzy logic is a branch of mathematics that allows a computer to model the real world the same way that people do. It provides a simple way to reason with vague, ambiguous and imprecise knowledge (Zadeh, 1987). It also incorporates a rule based approach to solving a control problem rather than modelling them mathematically. In Fuzzy Logic, a linguistic variable (not numerical) can be used, making it similar to the way humans think. For these reasons, Fuzzy logic theory was used to measure negotiation strategies in a practical way for this research.
Fuzzy Logic is an analytic technique, which is useful for measuring the viability of a negotiation strategy. The concept of a linguistic variable is simple for common sense reasoning, as this variable employs words rather than numbers to describe the values of variables. In addition it formalises the human capacity of imprecise or approximate reasoning, as in Fuzzy Logic all truths are partial or approximate. To apply this fuzzy strategy in electronic negotiations, it will be easier to prototype because of its simplicity.

The negotiation process involves almost all business processes, and is very complicated and time consuming. Today the Internet and Web-based facilities allow business organisations to conduct transactions efficiently and effectively by being able to undertake negotiations electronically. This can be achieved by taking a theoretical approach to feasible negotiation strategies that includes protocols, bargaining models, and a cooperation and coordination model.

1.9 Aim and objectives

Today's internet connection has created a tremendous revolution among business organisations. Nowadays running global business electronically is one of the most important emerging topics. Many researchers and software developers have been investigating and developing software tools and mechanisms that allow others to build distributed systems with greater ease and reliability to conduct e-business (Wooldridge, 2002). However, when coupled with the need for systems that can represent an organisation’s best interests, distribution can introduce other fundamental problems. An example of a problem is the type of protocols and strategies that will need to be followed at the time of interaction, particularly in the negotiation process. When a computer
system acts on our behalf, it needs to interact with another computer system that represents the interests of another, and these interests are not the same. In this context Michael Wooldridge specifies (Wooldridge, 2002, p. 3):

> It becomes necessary to endow such systems with the ability to cooperate and reach agreements with the other systems, in much the same way that we cooperate and reach agreements with others in everyday life. This type of capability was not studied in computer science until very recently.

Then again, traditional purchasing and selling B2B or B2C have been conducted through different complex processes involving negotiation. Nowadays selling and buying via the Internet is common practice, which is based on a fixed priced strategy, meaning an online customer will either buy it or leave it. This does not allow any bargaining process. Consequently, it was quickly realised that e-commerce represents a natural - and potentially very lucrative – application domain for multi-agent systems. Therefore, if this type of activity is performed electronically then it can be easier and faster, and at the same time complexity can be avoided. To perform these activities electronically, negotiation protocol, negotiation strategies and finally a decision-making model needs to be investigated. A cooperating and coordinating ability to perform flexible and reliable activities towards negotiation is also needed.

The overall aim of this thesis is to examine automated electronic negotiation in depth, and propose a flexible iterated negotiation process. The following objectives were established to achieve this aim.

### 1.9.1 Objectives

The objectives of this research are to: 
i) formulate negotiation strategies;

ii) design a negotiation protocol in which agents will be able to reach an agreement with each other in multi-agent based e-business;

iii) develop a coordination and cooperation model, which will ultimately facilitate the whole negotiation process;

iv) increase the capability of electronic commerce globally, reduce time for the selling and buying task; and finally;

v) identify ways to increase total profits of the supply chain.

This research facilitates the ability for cooperation and coordination among multi-agents in e-commerce. In addition, it provides the capacity to enhance customer satisfaction, streamline business-to-business transactions and reduce transaction costs of business tasks at every stage of the supply chain. Finally, this research provides a framework to increase trust and confidence within the component market and the product market.

1.10 Research Question

This research is undertaken to solve the following question, which was identified through extensive literature reviews, and are discussed in relevant sections of the thesis, that is, in chapters 2, 4, 6, 7 and 8.

*How can the negotiation process in business-to-business (B2B) transactions be formulated and applied in multi-agent based e-business?*

To simplify the above question, it is broken into the following sub-questions:

1. What protocols and strategies are needed for the negotiation process?
2. What is the way that makes agents enter into negotiation process which will reduce cost and time?

3. What bargaining procedure can be followed?

4. How would a coordination and cooperation model be developed, which will facilitate the negotiation process in multi-agent based e-commerce?

1.11 Contribution to Knowledge

The contribution of the research detailed in this thesis is summarised in the following table.

<table>
<thead>
<tr>
<th>Contributions</th>
<th>Contribution appears in the following Chapters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Developed some definitions and theory to formulate negotiation strategies in a positive intention</td>
<td>Chapter 4. Decision theory and Game theory</td>
</tr>
<tr>
<td>2 Developed negotiation protocol from monotonic to non-monotonic.</td>
<td>Chapter 5. Negotiation Analysis based on Trading Agent Competition Supply Chain Management (TAC SCM)</td>
</tr>
<tr>
<td>3 Extended and flexible iterated negotiation process</td>
<td>Chapter 5. Negotiation Analysis based on Trading Agent Competition Supply Chain Management (TAC SCM)</td>
</tr>
<tr>
<td>4 Developed definitions for negotiation strategies using linguistic variable as fuzzy logic</td>
<td>Chapter 6. Negotiation Analysis based on Fuzzy Logic</td>
</tr>
<tr>
<td>5 Developed enhanced bargaining model using state chart diagram which will help how to operate bargaining operation in the negotiation mechanism</td>
<td>Chapter 7. Bargaining Process</td>
</tr>
<tr>
<td>6 Developed coordination and cooperation model for B2B transactions in multi-agent e-commerce</td>
<td>Chapter 8. Coordination and Cooperation</td>
</tr>
</tbody>
</table>
The significance of this research can be described as satisfying a need for increased knowledge in automated negotiation for B2B transactions.

1.12 Overview of the Thesis

Chapter 1 - Introduction

This chapter firstly briefly describes the background of electronic business and electronic commerce. Then it provides the importance of negotiation in multi-agent based e-business, and an emerging future trend for B2B e-commerce. After that, it describes the aim and objectives of the research, research questions and then highlights the contributions to knowledge of this research. Finally it provides the organisation of the thesis structures.

Chapter 2 – Literature Review

Chapter 2 presents the literature review for the Bargaining Process. Literature reviews also appear in relevant chapters throughout the thesis according to requirements, such as, analysis of negotiation based on decision theory, game theory, fuzzy logic and cooperation and coordination.

Chapter 3 – Methodology

This chapter provides an overview of the complete study of the research in discovering solutions to the research question. The philosophical viewpoint of the research, selection of research methods, and the tools used for data analysis are included.

Chapter 4 – Analysis of Negotiation by Decision Theory and Game Theory

In this chapter, Decision Theory and Game Theory are discussed. The Decision Theory facilitates negotiation by decision analysis involving utility theory and
preference relation. Game Theory including Nash equilibrium is investigated to uncover which situations are suitable for a negotiation process. In addition, the negotiation situation is formalised with $\text{maximin}$ and $\text{minimax}$ strategies that will ensure a maximum or minimum payoff for each agent, with a guarantee to bind an agreement.

**Chapter 5 – Negotiation Analysis based on Trading Agent Competition Supply Chain Management (TAC/SCM) Game Scenario**

This chapter explores the negotiation process using the game scenario TAC SCM. The negotiation protocol of TAC SCM is analysed and this research develops extended protocols. Some definitions for the process are also constructed.

**Chapter 6 – Analysis of Negotiation Strategy based on Fuzzy Logic**

This chapter provides an analysis of the negotiation strategy in uncertain situations based on Fuzzy Logic using the TAC SCM. scenario Possibility theory and linguistic variables are also reviewed. This chapter constructs various definitions using linguistic variables to make the system simple for implementation.

**Chapter 7 - Bargaining Process**

This chapter addresses the bargaining models that include early bargaining models, Nash bargaining solution, and alternating offers models. It also presents extended bilateral bargaining model based on OMG (1999) and constructs state chart models for offers and counter-offers.

**Chapter 8 - Coordination and Cooperation Modelling**

Firstly, this chapter discusses the advantages and disadvantages in conducting electronic business. Then it investigates agent-based technology and multi-agent system that how it can be applied in supply chain management. The enhanced and effective
cooperative processing stages are discussed and based on these stages; this chapter presents architecture of effective cooperative processing for agents. In addition, some characteristics in modelling coordination and cooperation for TAC SCM have been outlined that will ultimately facilitate the negotiation processes in a multi-agent based system in electronic business.

Chapter 9 – Discussion and Implication of Research Outcomes

This Chapter discusses the analysis and results of the research. It also provides a summary of the research, the contribution to new knowledge, recommendations, limitation of the research, and ideas for future research.

1.13 Conclusion

Parts of the research from this thesis have been published (see page x for details) in refereed conferences and will also appear in *Advances in Electronic Business, Volume 3*, which is due for publication in November 2007.

In summary, this chapter has addressed the background of electronic business/commerce, electronic negotiation in business, importance of negotiation in e-business and multi-agent systems. The aim and objectives of the research, research problem and scope, research questions and contribution are also included, and finally, an overview of the chapters is given.

The following chapter specifically explores the literature review of the negotiation process.
CHAPTER 2
The Negotiation Process

2.1 Introduction

The negotiation process is very complex and is a feature of traditional buying and selling. This thesis examines this process in the context of automated negotiation for B2B transactions, as applied in multi-agent based e-business. This chapter reviews the literature related to the current research in the negotiation process and includes negotiation strategy, negotiation protocol, bargaining models and auctions. As this research is a series of integrated studies, the review of the literature is placed at the appropriate place to maintain continuity in this thesis. Decision Theory and Game Theory are discussed in Chapter 4, Negotiation analysis in Chapter 5, analysis of Negotiation Strategy based on Fuzzy Logic in Chapter 6, the Bargaining Process in Chapter 7, and Coordination and Cooperation in Chapter 8.

2.2 Negotiation in e-commerce

In 1995, Bower and Christensen noted that the business world had the possibility to exchange data by computer networks at low costs using Internet technology. Christensen (1997) argued that computer-based networking has changed business activities and constellations of businesses significantly. Subsequently, business activities have continued to change over time. Likewise, changes in the fundamental equations of business models require rethinking of these models (Zlatev et.al, 2004).
One of the business activities, which requires such rethinking, is coordination among business partners. In the analysis of the potential impact of Information and Communication technology (ICT) on business, Malone et.al. (1987) predicted that in an e-business environment, more transactions will be executed through markets than among departments within one company. In 2000, Gebauer and Zaglar (2000) argued that fewer options were available to support or automate the complex processes in the categories of cost and technology-oriented procurement. They also noted that the lack of powerful and flexible applications in e-commerce, for example, comprehensive online supplier directories, strong collaboration tools, complex bidding and multi-stage decision support applications or context-sensitive, project-specific information systems. Therefore, in particular e-commerce needs an automated negotiation mechanism to conduct business electronically.

In market environments, business activities are coordinated through price, which is one of the values of business that is assigned to a resource. Various businesses assign different values to resources, and for this reason, they need to negotiate to reach mutually acceptable agreements with other businesses. Therefore, it is most important to enable businesses to engage in negotiation in an electronic business environment. There are many fields of research that have studied negotiation in an electronic environment, such as: the Information Systems field with negotiation support systems; the Multi-Agent Systems field with searching, trading and negotiating agents and the Market Design field with electronic auctions.

Many conceptualisations of negotiation exist. Jennings et.al. (2001) decomposes negotiation into the elements as negotiation protocols, negotiation objects and agent’s decision-making models. Negotiation protocols define the rules that govern the negotiation. Negotiation objects are the matters that the participants
negotiate about, that is, goods or services. Agents’ decision-making models are the
decision-making framework that the participants employ to achieve their objectives
in accordance with the protocol. Furthermore, in 2000, Sun argued that negotiation
basically consists of a negotiation protocol, negotiation strategies, negotiation
issues, and negotiation processing. While negotiation protocols are the rules
(legitimate actions) of the negotiation process and negotiation strategies or tactics are
the actions which lead to binding an agreement by negotiation.

In addition, automated negotiation has been of particular interest due to the
relevant role that negotiation plays among trading agents in the activities of auction,
mediation or brokerage (Paurobally and Cunningham, 2001; Faratin et.al., 2000;
Fischer, 2000; Beam et.al., 1999). To model an agent negotiation strategy, Matos and
Sierra (1999) proposed two types of agent architecture based on: a) Case Based
Reasoning (CBR), and, b) Fuzzy Logic. At the time of the negotiation process, this
architecture updated the weighted combination of tactics to employ and the
parameter values related to these tactics (Sun and Finnie, 2003). In the instance of
CBR architecture, the agent uses its previous knowledge (history) and information of
the environment state to change its negotiation behaviour. While at the time of using
fuzzy architecture, it employs a set of fuzzy rules to find out the values of the
parameters of the negotiation model for implementation. The authors did not
describe the specific fuzzy rules that can be employed.

In the situation of the selling and buying environment in an electronic market
place, the negotiating agents require their own strategies. Most recently used e-
commerce trading systems do provide some e-negotiation based on predefined
strategies (Strobel, 2003; Wagne et.al., 2003; Maes et.al. 1999; Guttman et.al 1998).
Market Maker, the successor of Kasbah is an example of e-commerce negotiation
systems (Paula et.al. 2001) that assist negotiation between buyers and sellers by providing agents that can autonomously negotiate and make the best possible deal on behalf of the user. This allows the agents to use predefined negotiation strategies in the generation of offers and counter-offers. In this case, the user needs to decide which strategy it should use at the time of negotiation process.

The negotiating agent can use different strategies from existing negotiation strategies to achieve an agreement. According to the changing situation, Li et al (2000) defined the following for agents, which may:

- Relax the soft constraints of the sub-goal.
- Change the values of the properties in the bid.
- Further decompose the sub-goal into a further set of sub-goals that make it easier for the seller / buyer agent to be satisfied.

These e-commerce negotiation systems are limited for business-to-business negotiation and also for the bargaining purpose. As with complexity of the negotiation process in a real world scenario, it needs to be developed as an economic point of view, which will accommodate real world problems by using an e-commerce negotiation system in a sustainable way.

Automation of negotiation, which corresponds to negotiation-based e-commerce, has received a great deal of attention from the multi agent system (MAS) community (Sierra et.al. 1999), as such endeavours have the important potential for significantly reducing negotiation time and removing some of the reticence of humans to engage in negotiation on behalf of users (Lomuscio et.al 2001; Mammar et.al. 2001).
2.3 Multi agent Negotiation in e-commerce

In 1983 negotiation became a metaphor for distributed problem solving in MAS (Davis and Smith, 1983). From that time, it has been recognised that negotiation is a central issue in distributed artificial intelligence (DAI) and MAS (Dignum and Cortes, 2001). Primarily it was focused on negotiation as collaborative, distributed problem solving, as a means towards improving coordination of multiple agents working together on a common task (Preist et.al. 2001; Davis and Smith, 1983). According to the potential importance of e-commerce involving negotiation, research began expanding into agent technology, which ultimately represents real-world users or businesses including their conflicting interests. This situation is considered to be automated negotiation (Jennings et.al., 2000), or multi-agent negotiation or negotiation in e-commerce (Sun and Finnie, 2003), where intelligent agents bargain for products and services according to the requirements of end-users.

The field of multi-agent systems is quite new at this stage in the research community. To date, the quantity of this type of work reported in the public domain is quite small. The trend to interconnection and distribution has, in mainstream computer science, long been recognised as a key challenge, and much of the intellectual energy of the field throughout the last three decades has been directed toward software tools and mechanisms that allow us to build distributed systems with greater ease and reliability. When a computer system acts on behalf of a user, then it must interact with other computer systems that represents the interests of other users. It may well be that (indeed, it is likely), that these interests are not same. In this regard, in 2002, Wooldridge argued that it becomes necessary to endow such systems with the ability to cooperate and reach agreements with the other systems, in much the same way that we cooperate and reach agreements with others in everyday life.
Wooldridge (2002) also noted that this type of capability was not studied in computer science until very recently.

A multi-agent system is one that consists of a collection of agents that need to interact with one another by exchanging messages through some computer network infrastructure (Wooldridge, 2002). In most general cases, the agents in a multi-agent system are representing or acting on behalf of users or owners with variety of goals and motivations. In order to successfully interact, these agents require the ability to cooperate, coordinate, and negotiate with each other (Rahwan et al., 2007; Wooldridge, 2002). The main issue in the research is to consider how to build protocols for agents that allow them to make constructive agreements. The solutions to the issue normally depend on the domains. In relation to this, some work presented by Rosenschein and Zlotkin (1994) is very much related to binding an agreement on price, on military arrangements, on a meeting place, joint action, or a joint objective. It presents the negotiation problem in different domains and categorises it into a three-tier hierarchy of Task Oriented Domains (TODs), State Oriented Domains, and Worth Oriented Domains. Task Oriented Domains are a subset of State Oriented Domains, which are in turn a subset of Worth Oriented Domains. This hierarchy is not complete, but covers a large proportion of the types of real-world interactions. In the Task Oriented Domain an agent’s activity can be defined in terms of a set of tasks that it has to achieve. These tasks can be carried out without concern about interference from other agents; all necessary resources are available to the agents to accomplish the tasks. Alternatively, it is possible that agents can reach agreements where they redistribute some tasks, for everyone’s benefit. Therefore here negotiation is aimed at discovering mutually beneficial task redistribution.
In the State Oriented Domains (SODs), each agent is concerned with moving the world from an initial state into one of a set of goal states. Most artificial intelligence research has dealt with these domains. The Block World is a classic State Oriented Domain. A SOD is a superset of TODs. It points out that there is the possibility of real conflict here. For example, competition over resources where agents might have different goals, and there may be no goal states that satisfy all agents. At other times, there may be goal states that satisfy all agents but, that are expensive to reach and which require the agents to do more work than they would have had to do in isolation. In this domain there are limited resources, such as, space, time, and agents need to resolve conflicts over those resources.

In the Worth Oriented Domains (WODs), agents assign a worth to every potential state, which captures its desirability for the agent. These domains are the generalisation of the SODs – which means in SODs, the worth functions are essentially binary – all non-goal states have zero worth. The key advantage of a WOD is that the worth function allows agents to compromise on their goals, sometimes increasing the overall efficiency of the agreement.

In all these domains the situation arises with conflicts and the need for some joint plan to overcome conflict. However, there still needs to be resolution to the negotiation among agents, which needs procedures and a mechanism.

Aknine et.al. (2004) presented an extended multi-agent negotiation protocol that provides a task allocation protocol. This is an extension of Contract Net Protocol (Smith and Davis, 1981; Smith, 1980). Basically this protocol involves an auction approach and also includes different tasks in that negotiation processes. They did not focus on the bargaining protocol. In B2B transactions it is possible to enable a
bargaining system, which needs a flexible negotiation protocol to automate that process.

The Monotonic Concession Protocol defined by Rosenschein and Zlotkin (1994) specifies the rules of the negotiation, the rules by which the agents will come to a consensus by agreeing to carry out one of the deals in the negotiation set. According to this protocol the negotiation proceeds in a series of rounds. The agents start by simultaneously proposing one deal from the possible space. An agreement is reached if one of the agents finds that the proposed deal is at least as good as or better than previous proposal that was made. If the demand of an agent does not match or exceeds, then the protocol continues to another round. An agent is not allowed to offer less than the other agent’s offer that was proposed. This issue may not always be true in an automated situation. Indeed, it may depend on the current production situation, availability of products and agents can influence a decision according to that situation. Finally, if neither agent concedes at some stage, then the negotiation ends, and the protocol specifies that the agreement reached is a conflict deal. The author notes that it is possible to enable that type of protocol that will give an opportunity for agents to bargain based on the current situation. This may give a better result, that is, the price of goods might be less than a previous deal or it might be more expensive.

An alternating offers bargaining model is used for computationally limited negotiations (Larson and Sandholm, 2002; Kraus, 1996). The equilibrium strategies for the model results in a single shot take-it or leave-it strategy. The agents wait without exchanging offers until one of the agent’s deadlines arrives and then the agent with the earlier deadline concedes and makes an offer that the other agent may accept. Because of limited negotiation, it can be extended to iterative negotiation
until agreement reached. In addition, if agents are in conflict status in the bargaining situation, that is they fail to make any agreement, then it is also possible to enable an iterated negotiation process to give more chance to make an agreement binding and also it will reduce time and cost involved that in the negotiation processes.

A bargaining model was defined for a Negotiation Facility by the OMG (1999), which relies on a restricted form of a State chart. But this model is not detailed enough to clearly define the model. The author finds it also needs to be improved for use in an automated negotiation process through bargaining in the electronic market for purchasing and selling purpose.

The work reported by Paurobally et.al. (2003) defined flexible interaction mechanisms, such as automated negotiation to enable trading in dynamic and unpredictable environments, whilst allowing the participants to deal with different and conflicting preferences and goals. Paurobally et.al. (2003 presented the issues associated with negotiation in facilitating agent mediated mobile e-commerce.

Another paper by Sandholm and Lesser (1995) highlighted commitment, which means one agent binds itself to a potential contract while waiting for the other agent to either accept or reject its offer. They propose that protocols should have continuous levels of commitment based on a monetary penalty method, where a commitment break cost is assigned to each commitment strategy. The cost can change with time, the environment or be negotiated. This type of commitment based on penalty may cause a threat to negotiation or result in less chance of binding an agreement.

The work presented by Parsons and Wooldridge (2002) is very much related to binding an agreement. It discusses the key concepts of Decision Theory and Game Theory (discussed in detail in chapter 4 of this thesis), and also introduces the
importance of these special issues in Autonomous Agent and Multi-Agent Systems, but they did not present anything on how these can be applied to electronic business.

In 1968, Raffia, defined Decision Theory as an analysis consisting of a series of options in an uncertain situation. It focuses on identifying the “best” decision option that maximises the utility of the decision maker. Therefore this decision theory is most useful at the time of binding agreements.

Game Theory (Michael et.al. 2003) is a close relative of Decision Theory, and studies interactions between self-interested agents. Their research explores the problems of how interaction strategies can be designed that will maximise the welfare of an agent in a multi-agent encounter, and how protocols or mechanisms can be designed that have desirable properties. Decision Theory can be considered to be the study of games against nature, where nature is an opponent that does not seek to gain the best payout, but rather acts randomly. From this point of view, it comes as no surprise to learn that many of the applications of Game Theory involve negotiation and coordination.

Subsequently, electronic commerce is one of the most important market places in today’s electronic environment where buyers and sellers are involved in trading activities. Day-by-day electronic commerce is expanding and becoming more popular to both business organisations and consumers. However, undertaking digital business brings many significant risks. In circumstances where there are no tried and tested models, developing an e-business strategy involves ventures into uncharted waters for most managers (Wagne et.al. 2003).
2.4 The Supply Chain

The supply chain is a worldwide network of suppliers, manufacturers, warehouses, distribution centres, and retailers through which raw materials are acquired, transformed and delivered to customers (Fox et al. 2000). In recent years, new software architecture for managing the supply chain at the tactical and operational levels have emerged. In 2002, Geunes et al. argued that the traditional supply chain literature does not account for the recent development in B2B e-commerce, especially with regard to Internet-based exchanges. Thus, there is an urgent need for new models that address B2B exchanges and their impact on current procurement practices. It also argued that the complexity of the problems, the number of parameters involved and their characteristics make simulation techniques a useful approach for solving such problems (Geunes et al., 2002).

Buyer-oriented e-commerce business models are most appropriate for large companies that purchase considerable volumes of various items (Chan et al. 2001). One of these items is components or raw materials used in manufacture, as the procurement practice is involved in many processes including negotiation. In addition, coordination and cooperation facilitate negotiation (discussed in chapter 5 and 8 of this thesis). Therefore, this research highlights the lack of a negotiation mechanism for B2B transactions which needs to be implemented by using multi-agent based in e-business.

As this research uses the scenario TAC SCM as case study to investigate the above problem, the following section presents an overview of TAC SCM.
2.4.1 Trading Agent Competition Supply Chain Management (TAC SCM)

Trading Agent Competition Supply Chain Management (TAC) provides a set of web-based multi-agent simulation environments to examine artificial e-market models and to evaluate business strategies for electronic commerce (Sadeh et al., 2003; Wellman and Wurman, 1999). At the same time TAC SCM is focused on evaluation of trading agents, as well as trading agent architectures, decision-making algorithms, theoretical analysis and empirical evaluations of agent strategies in negotiation scenarios (Arunachalam and Sadeh, 2005). As a result trading agents have become a prominent application area in Artificial Intelligence, in the large part because of their obvious potential benefits in e-commerce.

Strategies in negotiation mechanism have not yet been widely explored. For example, what techniques are needed to be adopted in negotiation strategies in which the agent can achieve maximum profit? How can the agent decide when and what price for components will produce maximum benefit? These problems directly belong to the strategies in the negotiation mechanism. In the TAC SCM game, usually the agent purchases components on the early days, and thereafter purchasing falls into completely uncertain situations. After manufacturing, the final products (PCs) are sold to customers. This can result in the market price of the PC being more or less the same as the reserve price. Again, according to a supplier’s component pricing policy, the agents are forced to purchase fixed-priced components, and agents do not have any alternative ways to purchase. The author considers that the coordination and cooperation facility would be useful to the TAC SCM, as it will facilitate the procurement processes. However, the TAC SCM environment, which is valuable for research purposes, is a long way from a real-world market.
The details of TAC SCM and the author’s analysis can be found in chapter 5 and the literature review for cooperation and coordination is discussed in chapter 7 of this thesis.

2.5 Negotiation using Fuzzy Logic

Sierra et.al. (1999) used fuzzy techniques to compare proposals or contracts exchanged between agents and also generate trade-offs as contracts that are similar to contracts offered by opponents through a fuzzy logic measure. Basically, they included negotiation between the European Union and Morocco over fishing rights off the coast of Morocco. They did not focus on automated negotiation for B2B transactions in e-business, which is the focus of this thesis. In addition they pointed out it also needed the modelling of fuzzy preferences and fuzzy qualitative modelling of weights or issues’ importance.

He and Jennings (2004) presented a successful application of fuzzy set theory in agent-mediated electronic commerce in TAC Classic game that was involved in a travel agent scenario. They used an adaptive bidding strategy to change its strategy depending on the assessment by using fuzzy set. Moreover, He et.al. (2005) used a fuzzy reasoning inference mechanism in the same travel agent scenario of the TAC classic game. This reasoning involved different parameters, such as, customer demand and inventory level. This is not enough in B2B transactions in e-business. It needs further extension that will be able to make more constructive and effective agreements using negotiation.
2.6 Negotiation in Auctions

An auction is one of the popular trade types that involves a seller and many potential buyers (Jung and Jo, 2000), and an auctioneer conducting the auction. Four basic types of auctions are widely used and analysed: the ascending-bid auction (also called the open, oral, or English auction), the descending-bid auction (used in the sale of flowers in the Netherlands and so also called the Dutch auction by economists), the first-price sealed-bid auction, and the second-price sealed-bid auction (also called Vickrey auction by economists) (Klemperer, 2004).

In an ascending auction (English auction), the price is successfully raised until only one bidder remains and the bidder wins the object with the final price. In this auction, the price is announced by the auctioneer and the bidders call out prices themselves, or by having bids submitted electronically with the best current bid posted.

The descending auction works in the opposite way of the ascending auction. The auctioneer announces at a very high price of objects and then gradually lowers the price. The first bidder who calls out that he/she will accept the current price wins the object at that price.

In the case of first-price sealed-bid auction, each bidder submits a bid and they are not able to see others bids and the winner is decided by the highest price submitted. The second-price sealed-bid auction is operated like a first-price sealed-bid auction, with the difference that the winner is declared who submitted highest offer but the second highest price is paid.

Auction is a popular model of negotiation for open multilateral bidding (Cardoso and Oliveira, 2001). Auctions are a simple form of negotiation specifying a single issue with predefined rules and conditions. An auction is better used for one-
time transactions or for obtaining a first supplier (buyer) in a new line of business that may develop into a relationship (Viatle and Giglierano, 2002). At present auctions are the most visible type of e-negotiation on the Internet as conducted by eBay (an example of a B2B auction is Liquidation.com).

Auctions are performed with only one attribute of the object, usually price. For this reason auctions are not applicable for either the B2B or B2C where goods require a customised and service format.

2.7 Overview of Relevant Research of this thesis

Table 2.1 Relevant Research of this Thesis

<table>
<thead>
<tr>
<th>Research</th>
<th>Authors</th>
</tr>
</thead>
</table>
In summary, the gap addressed by this thesis focuses on how the negotiation process in B2B transactions can be formulated and applied in multi-agent based e-business.
2.8 Conclusion

Firstly this chapter discussed negotiation in e-commerce and then reviewed multi-agent negotiation in e-commerce including auctions which are the basic and innermost issue for next generation e-commerce. This literature review highlighted that there is a lack of negotiation strategies, negotiation protocols, appropriate bargaining model, cooperation and coordination facilities which will ultimately help to conduct B2B transactions in e-business. These all are critical in the negotiation mechanism in e-commerce, as real-world transactions are happening everyday in traditional trading.

Finally, it is noted that real-world commerce negotiation involves difficult issues such as:

- Multiple attribute negotiation,
- Similar product suggestion,
- Correlated product suggestion,
- Learning or experience from previous negotiation,
- Tricky (deceptional) reasoning in negotiation, and
- Bargaining and compromise in negotiation

From these issues only the first four have been mentioned and examined by Paula et.al.(2001) and only the first of the above features has been incorporated in e-commerce in negotiation systems so far (Fatima et al., 2007). The rest of the features are not widely touched in the multi-agent negotiation (Sun and Finnie, 2004). Therefore, the research detailed in this thesis moves towards reaching a real-world solution in an electronic environment. Decision Theory and Game Theory are the
focus of Chapter 4 and Coordination and Cooperation are detailed in Chapter 8 of this thesis.

In summary this chapter has discussed the literature review of the study of this research. The next chapter entails a detail discussion of the methodology that was adopted for this research.
CHAPTER 3

Methodology

3.1 Introduction

This chapter presents an overview of the methodology for this research and includes the selection process for the research strategy. How can the negotiation process in B2B transactions be formulated and applied in multi-agent based e-business? is the research question addressed by this thesis. To answer this question, a theoretical analysis of the negotiation process was undertaken with a focus on coordination and cooperation. Research outcomes include a proposed model for an automated negotiation process in multi-agent systems; strategies and protocols for automated negotiation; as well as a coordination and cooperation model that can be used not only in supply chain management, but also in any type of e-business transaction. The research was carried out between 2003 and 2006, and has resulted in a number of referred publications (see Page x at the front of this thesis).

The previous chapter reviewed the research literature on the negotiation process, and this chapter will detail the Methodology, including the philosophical viewpoint, research strategy, theoretical framework, and methods used for analysis. The chapters that follow outline the analysis undertake in a series of studies to address the research question.
3.2 Philosophical Research View

The philosophical perspective for this research was considered from the underlying assumptions related to what the author believes is valid research, and which methods are appropriate. In the same way, Hirschheim (1992) argues that epistemology refers to the assumptions about how knowledge is obtained.

In the literature, authors describe various views that are fundamental to the paradigms of research. Guba and Lincoln (1994) define four underlying categories of philosophical research, namely, Positivism, Post-Positivism, Critical Theory, and Constructivism. Conversely, Chau (1986) presents a framework for analysing research that categorises the philosophies as Positivist, Interpretive, and Critical. Orlikowski and Baroudi (1991) adopted this framework for analysing the field of Information Systems (IS) research.

The author has applied the framework defined by Chau (1986) and adopted by Orlikowski and Baroudi (1991) for IS research. The following sections outline this philosophical research view, and justifies the most appropriate view for this research.

3.2.1 Positivist Research

Positivism is a philosophical system founded by French Philosopher, Auguste Comte (1798-1857) and continued by English Philosopher, A. J. Ayer in the 20th century. Both philosophers were concerned with positive facts and phenomena. Positivism is a strict form of empiricism, which is a doctrine that states all knowledge is derived from experience without using a science or theory.

Comte (1853) suggested that all real knowledge should be derived from human observation of object reality. The senses are used to accumulate data that is “objective and measurable”, and anything else should be rejected as transcendental.
Therefore, it is very safe to state that Positivism adopts a clear quantitative approach to investigating phenomena, as opposed to Post-Positive approaches that aim to describe and explore in-depth phenomena from a qualitative perspective.

Positivist studies serve primarily to test theories in an attempt to increase predictive understanding of phenomena. This philosophy can be used in the field of IS where there is evidence of formal propositions, quantifiable measures of variables, hypothesis testing, and the drawing of inferences about a phenomenon from the sample to a stated population (Orlikowski and Barouda, 1991). The Positivist Research view is not appropriate, as this research does not include hypothesis testing, quantitative approach including quantifiable measures of variables, and does not have a stated population.

3.2.2 Interpretive Research

Interpretive research is a more specific term and is defined in terms of epistemology. According to Klein and Myers (1999), the foundation assumption for Interpretive Research is that knowledge is gained, or at least filtered, through social constructions, such as, language, consciousness and shared meanings. In addition, Interpretive Research acknowledges an intimate relationship between the researcher and what is being explored, and the situational constraints shaping this process.

In terms of a methodology, Interpretive Research does not redefine dependent or independent variables, does not set out to test hypothesis, but aims to produce an understanding of the social context of the phenomenon and the process whereby the phenomenon influences and is influenced by the social context that makes sense to those being studied (Walsham, 1995). Furthermore, this type of research is directed at understanding the deeper structure of a phenomenon within its cultural context by exploring the subjective and inter-subjective meanings that
people create as they interact with the world around them (Orlikowski and Baroudi, 1991).

Subsequently, ontologically, the Interpretive Perspective emphasises the importance of subjective meanings, and socio-political as well as symbolic action in the processes through which humans construct and reconstruct their reality (Morgan, 1983). Boland (1979) also noted that “individuals act towards things on the basis of the meanings that things have for them, that meanings arise out of social interaction, and that meanings are developed and modified through the interpretive process” (p.260).

The author believes that the Interpretive Research Philosophy is appropriate for the research detailed in this thesis, due to its subjectivity and interpretive methods for research that are directed at the understanding of real world business issues. Certainly, this approach is suitable for exploring ways to conduct sustainable business processes in an electronic environment that involves negotiation as well as coordination and cooperation. Consequently, by applying the Interpretive Research approach, the author can focus on the entire research effort on continuously interpreting data, sources and results produced by different methods for gathering and analysing data.

3.2.3 Critical Research

The aim of Critical Research is to assume that social reality is historically produced and reproduced by people. Although people can consciously act to change their social and economic circumstances, critical researchers recognise that their ability to do so is constrained by various forms of social, cultural and political domination (Myers, 1997). The main activity of Critical Research is to critique the social aspect that restricts and alienates the conditions of the status quo, and bring
these into focus. Oppositions, conflicts and contradictions in contemporary society are the main theme of Critical Research, which looks to be emancipatory, and facilitates to confiscate the causes of alienation and domination. The Critical Research view is not appropriate to this research as it does not allow for criticism of social, cultural and political domain.

In summary, the Philosophical Research View adopted by the author to conduct this research is the Interpretive Research approach, which allows for continuous interpretation and analysis of data.

3.3 Research Methodology

In the literature, authors define research methodology in varying ways. Some have used two basic types of methodologies, namely Quantitative and Qualitative (for example, Thomas, 2003; Burns, 2000; Ticehurst and Veal, 1999; Myers, 1997).

The Quantitative Methodology usually involves an experimental approach that tests hypotheses, and data collection that relies on measurement and statistical techniques for analysis (Hiles, 1999). Examples of methods used with this Methodology include: surveys, laboratory experiments, formal methods (econometrics) and numerical methods such as mathematical modelling (Myers, 1997). This methodology is suitable to the parts of this research using mathematical modelling.

The Qualitative Methodology mainly attempts to collect data in the form of descriptions and meanings, particularly in a way that it is phenomenologically sensitive and honours the experimental component of all knowledge, participation and observation (Hiles, 1999). Action research, case studies and ethnography are common examples of this type of methodology. Moreover, Silverman (2005) argues
that qualitative research finds order in the precise detail of matters such as people’s understanding and interactions. This methodology is suitable to the parts of this research using analysis and simulation.

*The author selected a combination of both Quantitative and Qualitative Methodologies for this research in order to present a convincing case for the research outcomes by adopting a process of triangulation.* Triangulation is a strategy for researchers to take advantage of the strengths of a mixed approach (Yin, 2003; Mingers, 2001, Myers, 1997). The justification for selecting a triangulation strategy is due to the nature of the research, which is to further understanding of the negotiation process in B2B transactions when applied to multi-agent based e-business.

Consequently, the outcomes of this research can benefit future researchers by discovering new knowledge about an automated negotiation process, as follows:

i) business organisations will be able to efficiently and effectively conduct business electronically by applying negotiation strategies, negotiation protocols following a coordination and cooperation model;

ii) SMEs as well as large organisations will be able to conduct business globally by working together using a coordination and cooperation model; and

iii) researchers, academics and practitioners will be able to benefit by building on the new knowledge detailed in this thesis. In addition, researchers and academics can verify the outcomes of this research as well as improve and generate new knowledge. Conversely,
practitioners can use the new knowledge for their business and for continuous improvement.

In summary, a combination of Quantitative and Qualitative methodologies will be used for this research, within the framework of the Interpretive philosophical view.

### 3.4 Research Strategy

Firstly, this research was undertaken to investigate feasible negotiation strategies and protocols, which include modelling B2B transactions. Secondly, developing a B2B coordination and cooperation model to facilitate the negotiation process in multi-agent based e-business. In developing these models, the author also investigates current issues related to problems of negotiation and cooperation/coordination in conducting e-business and developing new ideas.

In developing these models, the author uses the scenario called Trading Agent Competition Supply Chain Management (TAC SCM) as a case study. This scenario is currently using as a test bed simulation globally. The TAC SCM is an international competition in which researchers from different universities are participating in investigating real-world business problems in a dynamic environment. The game was designed and organised jointly by a team of researchers from the e-Supply Chain Management Lab at Carnegie Mellon University, the University of Minnesota, and the Swedish Institute of Computer Science (SCIS). TAC was first organised in 2000 (Wellman et al., 2001) using the Travel Agent scenario termed as TAC Classic. In addition to this, in 2003, a new scenario was introduced as “TAC SCM” (Trading Agent Competition Supply Chain Management), which represents an overall supply chain situation. The challenge was
that agents are required to concurrently compete in multiple markets (markets for different components on the supply side and markets for different products on the customer side) (Arunachalam et al, 2003). On both sides, that is the selling side and the purchasing side, there are different processes that include negotiation, cooperation and coordination of the supply chain. Moreover, TAC SCM is the only test bed environment that is currently available. Researchers from different universities around the world are also using this scenario to investigate electronic market (e-market) place to investigate sustainable, effective and efficient business processes to facilitate B2B transactions in an electronic environment. Therefore, the author also believes that TAC SCM is the best case study for her research to examine the predefined research questions. This is the reason the author has chosen this case study due to the required activities that are modelled in the TAC SCM scenario. Full details of this case study are discussed in Chapter 5.

The main research question (How can the negotiation process in B2B transactions be formulated and applied in multi-agent based e-business?) and the subsequent sub-questions listed below are associated with the relevant studies in Table 3.1:

1. What protocols and strategies are needed for negotiation process?
2. What is the way that makes agents enter into negotiation process, which will reduce cost and time?
3. What bargaining procedure can be followed?
4. How would a coordination and cooperation model be developed, which will facilitate the negotiation process in multi-agent based e-commerce?

The overall Research Strategy is shown in Figure 3.1 and the series of integrated studies in Table 3.1 below:
Figure 3.1. The Overall Research Strategy
The overall aim of this research was to provide an answer to the research question by developing a framework that could be used by multi-agents for the negotiation process in B2B transactions. Following are the objectives for the series of studies designed to progressively move towards the aim.

### 3.4.1 Study 1: Analysis of negotiation based on Decision Theory and Game Theory

This study is detailed in Chapter 4 and is an analysis of negotiation using Decision Theory and Game Theory. The objective of this study is to discover the best possible strategies that agents can apply when trying to secure a binding agreement in the negotiation process. From the analysis a theoretical solution of the negotiation strategy is developed, and subsequently verified using a simulation tool.
3.4.2 Study 2: Negotiation analysis based on TAC SCM game

This study is detailed in Chapter 5 and involves an analysis of the negotiation process of the TAC SCM game. The objective of this study is to investigate negotiation protocols. As a result of the analysis a theoretical solution is developed, which reveals two types of protocols, that is: i) the non-monotonic negotiation protocol; and, ii) the extended and iterated negotiation protocol. This study also measures the negotiation strategies by using Fuzzy Logic.

3.4.3 Study 3: Analysis of negotiation strategy based on Fuzzy Logic

This study is detailed in Chapter 6 and measures negotiation strategies in an uncertain situation by using Fuzzy Logic. The main objective of this study is to investigate how agents will make decisions in an uncertain situation in relation to negotiation. The theoretical solution is developed with respect to using term set at the time of the negotiation process.

3.4.4 Study 4: Analysis of the Bargaining Process

This study is detailed in Chapter 7 and is an analysis of the bargaining process inherent in negotiation. The objective of this study is to examine the mechanism of the bargaining process. The outcome of this study is an extended bargaining model that is beneficial to the negotiation process.

3.4.5 Study 5: Coordination and Cooperation Modelling

This study is detailed in Chapter 8 and involves the coordination and cooperation facilities needed for the negotiation process. The main objective of this study is to develop a cooperation and coordination model that will ultimately facilitate the negotiation process.
To address the objectives of the series of studies the next sections outlines the appropriate methods and techniques used.

3.5 Methods

While adopting a combination of Quantitative and Qualitative methodologies, the next step taken by the author is to select appropriate methods for the various studies. Kock (2003) describes methods as outlined in Table 3.2:

<table>
<thead>
<tr>
<th>Research Method</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Experimental Research</td>
<td>Generally, the experimental research approach is used to investigate the causes of phenomena under a controlled environment. The variables are manipulated over time, associated numeric data is collected and causal or correlation models are tested through standardised statistical analysis procedures (Kock, 2003). In this type of research, a situation needs to be created under controlled conditions. Therefore the researcher can carry out the experiment repeatedly on various subjects (Kazanis, 2004)</td>
</tr>
<tr>
<td>Survey Research</td>
<td>The survey research approach uses a considerable samples to analyse certain characteristics or frequencies of a population. Most questionnaires are close-ended questions to carry out quantitative evaluations. The main purpose of this research is to generalise the data to a whole population where its accuracy depends on the sample size and the percentage of response.</td>
</tr>
<tr>
<td>Case Study research</td>
<td>Case study research is mostly used in business studies where the researchers study a small sample of organisations in depth. Cases are analysed to build or validate theories, typically through collection of qualitative information using observations and interviews.</td>
</tr>
<tr>
<td>Action Research</td>
<td>Action research is uniquely identified by its duel goal of both improving the situation being studied, and at the same time generating relevant knowledge. The researcher is expected to positively influence the situation in depth using a participatory approach using observations and interviews as key data collection mechanisms</td>
</tr>
</tbody>
</table>

An evaluation of Table 3.2 reveals that experimental, survey and action research are not suitable for this research based on the following justification.
As experimental research requires a created situation under controlled condition, such as limiting the business environment of an organisation. Therefore, this is not possible to apply experimental research to this research as it is not concerned with a controlled condition.

Survey research uses a reasonable sized sample for analysing particular characteristics of a population. Questionnaires are used to research quantitative evaluations. As this research is not using a sample for quantitative analysis therefore the author did not consider using survey research to her study.

According to Burns (2000) “action-research is the application of fact finding to problem solving in a social situation with a view to improving the quality of action within it, involving the collaboration and cooperation of researchers, practitioners and layman” (pp.443-458). In addition, Burns (2000) also identified the four basic characteristics of action research as:

i) Action-research is situational – diagnosing a problem in a specific context and attempting to solve it in that context.

ii) It is collaborative, with teams of researchers and practitioners working together.

iii) It is participatory, as team members take part directly in implementing the research.

iv) It is self-evaluative – modifications are continuously evaluated within the ongoing situation to improve practice.

As the action research is situational, collaborative, participatory and self-evaluative, this method does not match with the objectives of the current research.

The case study research method is the most widely used qualitative research method in information systems research (Myers, 1997; Orlikowski and Baroudi,
1991) and is well suited to understanding the interactions between information technology (IT) related innovations and organisational context. The case study is an ideal methodology when a holistic, in-depth investigation is needed (Feagin et al, 1991). Generally the case study focuses on the historical perspective rather than a participative and a collaborative approach to making improvements to a situation.

According to Yin (2003), a major strength of the case study is that it allows the researcher to understand the problem, the nature and complexity of the process taking place, and valuable insights can be gained into new topics emerging in the rapidly growing field. In addition to this, case study research can contribute to knowledge by relating findings of the particular to generalisable theory. Moreover, case studies typically combine data collection techniques such as interviews, observation, questionnaires, and document and test analysis. Both qualitative data collection and analysis methods, concerned with words and meanings and quantitative methods concerned with numbers and measurement may be used (Yin, 1994).

Yin (1993) identifies some specific types of case studies such as Exploratory, Explanatory, and Descriptive. The exploratory case study is sometimes considered as a prelude to social research. Exploratory case studies may also be used for doing casual investigations. Descriptive theory is needed for descriptive cases in which it is required to be developed before commencing the project.

Alternatively, Stake (1995) added three different case studies, namely, Intrinsic, Instrumental, and Collective. The Intrinsic is when the researcher has an interest in the case, the Instrumental is when the case is used to understand more than what is obvious to the observer; and the Collective is when the researcher studies a group of cases. All of these types of case studies, including single-case or multiple
cases can be used (Darke et al, 1998; Tellis, 1997). A single case study is used when it represents a critical case where it is an extreme or unique case or it is a revelatory case (Yin, 1994).

This research matches the exploratory case study, which is used for doing casual investigations. It also matches with the intrinsic case study that creates interest in the case by the researcher. Although this research matches both types of case studies, the author chose to use the exploratory case study for her research. The author uses a single case for the main study but also uses some case examples with explanations in some chapters according to the requirements of the analysis.

Within the Case Study framework, a number of other techniques were utilised as analysis tools within the various studies of this research, namely, Decision Theory, Game Theory, Simulation and Fuzzy Logic as applied to this research are described in the following sections.

3.5.1 Decision Theory Technique

To enter into a negotiation process, agents need to decide what options they should take when moving towards establishing an agreement. Therefore, how will agents make decisions in the negotiation process that will give robust and effective decisions? Decision Theory is used to analyse some of the data for negotiation mechanism.

Raffia (1968) argues that Decision Theory is a means of analysing which of a series of options, should be taken when it is uncertain exactly what the result of taking the option will be. That is, Decision Theory focuses on identifying the “best” option, where the notion of “best” has a number of different meanings. One of the most common is maximising the expected benefit to the decision-maker. Because every agent or decision maker is self-interested they will always seek their benefit
mostly by rational choice. As a whole, Decision Theory provides a powerful tool to analyse cases in which the agent’s decision must be made in an uncertain or unpredictable environment. Decision Theory is used for the decision making analysis of the negotiation process detailed in Chapter 4.

3.5.2 Game Theoretical Technique

Game Theory is a branch of modern applied mathematics, and its main purpose is to analyse various problems of conflict between parties that are opposed, but have similar or simply different interests (Petrosjan and Zenkevich, 1996). Binmore (1992) also defines that Game Theory as a mathematical theory that studies interactions among self-interested agents. In 1921, Game Theory was introduced by Emile Borel and established in 1928 by John von Neumann and Oskar Morgentern (1953), who developed it as a means of decision making in complicated economic systems. They saw many common factors such as conflicting interests, different preferences of decision makers, and the dependence of the outcome for each individual from the decisions made by the other individuals both in actual games and economic situations. Basically, Game Theory aims to help us understand situations in which decision-makers interact. In everyday sense, a game is a competitive activity in which players contend with each other according to a set of rules. Recently, the tools and techniques of Game Theory have found many applications in computational multi-agent systems research, particularly when applied to problems such as negotiation (Wooldridge, 2002). Nash equilibrium is one of the solution concepts in Game Theory, which is playing an important role in analysing the negotiation mechanism.

A multi-agent system is one that consists of a number of agents, which need to interact with one another by exchanging messages (Rahwan et al., 2007;
Wooldridge, 2002). Generally, the agents in a multi-agent system represent or act on behalf of users or owners with very different goals and motivations. For successful interaction, these agents require the ability to cooperate, coordinate and negotiate with each other. Negotiation is a complex issue and it can be very hard to reach an agreement in an automated situation. In multi-agent systems, negotiation is not supported very well, and still lacks the ability to bind an agreement properly. **The author uses this Game Theory technique to analyse the interactions among agents and investigates feasible negotiation strategies.** Chapter 4 details this analysis.

### 3.5.3 Simulation Technique

Modarres (2006) argued that the application of information (Modarres and Bahrami, 1997) and simulation (Profozich, 1998) technologies enhance the capabilities of an organisation to achieve in-depth understanding of internal process performance and correct allocation of resources. Previously, Towill (1991) argued that simulation, as a very generic technique that is more suitable for analysing complex and dynamic systems. Subsequently, Lee (2006) noted that the simulation task played an important role in making strategic business decisions. Therefore, simulation provides a prediction of the outcome of reengineering strategies prior to implementation.

As a result, simulation is one of the testing tools in which agents can predict a better result. Therefore, **this research has undertaken analysis of the negotiation strategy by simulation using Nash Equilibrium.** As a result of the simulation, a theoretical model is developed. Agents can learn from simulation analysis by identifying which strategies will give better results, that is, which results are feasible.
3.5.4 **Fuzzy Logic Approach**

Some data analysis has been undertaken using a Fuzzy Logic approach to measure the negotiation strategy. *Fuzzy Logic* is a branch of mathematics that allows a computer to model the real world the same way that people do. It provides a simple way to reason with vague, ambiguous and imprecise knowledge (Zadeh, 1987). It also incorporates a rule-based approach to solving a control problem, rather than modelling them mathematically. In Fuzzy Logic, a linguistic variable (not numerical) can be used, making it similar to the way humans think. For these reasons, *Fuzzy Set Theory* is investigated to measure negotiation strategies in feasible and possible ways for this thesis.

Fuzzy Logic is an analytic technique, which is useful for measuring the feasible negotiation strategy. The concept of a linguistic variable is simple to make common sense reasoning as this variable employs words rather than numbers to describe the values of variables. In addition it formalises the human capacity of imprecise or approximate reasoning. As in Fuzzy Logic all truths are partial or approximate. The analysis to measure the negotiation strategy using Fuzzy Logic is detailed in Chapter 7.

3.5.5 **Collecting the Data**

Some simulated data was collected from the TAC SCM competitions (2003, 2004) to analyse the agents’ purchasing and selling behaviour in a multi-agent system. Subsequently, *the author also collected data from the simulation using Nash equilibrium analysis to determine better strategies of negotiation.*
3.6 Limitations of the Research Strategy

One limitation of the research strategy is the use of a single case study, the TAC SCM. However, undertaking this research in a real-world setting is not as yet possible, due to the nature of the research outcomes (flexible and iterated negotiation framework). TAC SCM is the only available dynamic test bed involving supply chain management mechanism in an electronic market. Therefore, TAC SCM is currently a good example of multi-agent based e-business. Future research is discussed in Chapter 9 and takes account of the outcomes of this research.

Another limitation is the use of a mainly analysis approach based on Decision Theory, Game Theory and Fuzzy Logic. Based on the outcomes of this research, other methodologies can be utilised in the future, for example, Action Research and Survey Research, when the area of automated negotiation is further advanced.

As this is a very new emerging research area, it is important to firstly develop potential theoretical solutions that can be progressed towards implementation at the industry level. Consequently, implementation of the theoretical solutions from this research can be applied to a real-world automated negotiation problem in the future.

3.7 Conclusion

A triangular research strategy provided evidence to answer the research question and objectives. The Case Study framework incorporating both quantitative and qualitative methodologies, and utilising a number of techniques for analysis provides information on the decision making and interaction activities of an automated negotiation process. In addition, outcomes of the research formulate a flexible and iterated framework for multi-agents involved in the negotiation process of B2B transactions.
In summary, this chapter has provided an overview of the research undertaken in this thesis. It includes the philosophical view, research plan, overview of the integrated studies, and techniques used for analysis. The following chapter present the results of the empirical studies, starting with the analysis based on Decision Theory and Game Theory (Chapter 4). The research question and plan were directed towards furthering the understanding of an automated negotiation process in multi-agent e-business.
CHAPTER 4

Analysis of Negotiation by Decision Theory and Game Theory

4.1 Introduction

In this chapter, Decision Theory is discussed. This theory facilitates negotiation by decision analysis including utility theory and preference relation. The main focus is on how agents can act to perform better decision making when moving towards negotiation. Subsequently, game theory has been investigated in relation to Nash equilibrium to reveal which situations are suitable for a negotiation process involving interaction. Also the negotiation situation is formalised and maximin and minimax strategies revisited to determine the maximum or minimum payoff that an agent can guarantee in binding an agreement. In addition, analysis of negotiation with implementation is undertaken. The results demonstrate an agent with a positive intention when moving towards negotiation.

This chapter is structured as follows: firstly, Decision theory and the values of the Decision-making Conditional, which includes utility theory is discussed; then Game Theory that encompasses the theory of Rational Choice, actions, preferences and payoff functions, as well as the interaction of agents is examined. Next, Nash equilibrium is explored and maxmin and minmax strategies reviewed. Then, the negotiation process with Nash equilibrium is analysed. Finally, the outcome of the feasible negotiation strategies is discussed.
4.2 Decision theory and values of Decision-making Conditional

Decision theory (Raffia, 1968) is a means of analysing which of a series of options should be taken when it is uncertain exactly what the result of taking the option will be. That is, decision theory focuses on identifying the “best” option, where the notion of “best” has a number of different meanings. This theory is one of the most common that maximises the expected benefit to the decision maker. Because every agent or decision maker is self-interested, they will always seek to benefit mostly by rational choice. As a whole, decision theory provides a powerful tool to analyse cases in which a decision must be made.

Currently, it is widely known that for selling or buying a product through e-commerce, designing autonomous agent technology is a crucial issue, and as a result an agent needs to decide on the best action from range of possible actions (Wooldridge, 2002). Agent-based e-commerce is usually a complex environment, and is inherently uncertain. Therefore, when an agent operates in such an environment, it does not have enough information about the environment to know the precise current state of its environments, or how that environment will evolve. Therefore, the agent/decision maker can only evaluate according to a degree-of-belief expectation of the objective expected value.

Consider an agent has \( m \) hypothesis \( H_j \) about ways in which the objective conditional chances could be fixed. Let us suppose that the act together with the consequence determines the payoff. Then the measure of merit for an act is:

\[
U(A) = \sum_j DB(H_j) \sum pr_j(C_i | A) U(A \land C_i)
\]
where DB is the degree of belief according to hypothesis \( H_j \) and the conditional probability (Adam, 1988) \( pr_j (C_i | A) \) is the conditional chance of consequence \( C_i \) on at \( A \). This is the degree-of-belief expectation over an objective chance expectation. This is one version of causal decision theory (Gibbard & Harper, 1978; Lewis, 1980; Skyrms, 1980).

According to the general theory of rational decision, what is the appropriate value for decision-making conditional in the general case in which conditional chances are unknown? Therefore what is the value \( Val (if A, then C) \) such that:

\[
U (A) = \sum_i Val (if A, then C_i) U (A \land C_i)
\]

The answer is that:

\[
Val (if A, then C) = \sum_j DB (H_j) \sum pr_j (C | A) U (A \land C)
\]

\( Val \) must be the subjective expectation of conditional chance. Then:

\[
\sum_i Val (if A, then C_i) U (A \land C_i) \\
= \sum_j DB (H_j) \sum pr_j (C_i | A) U (A \land C_i) \\
= \sum_j DB (H_j) \sum pr_j (C_i | A) U (A \land C_i) = U (A)
\]

The decision-making conditional carries a value that is not the probability of truth. The computation of that value is slightly more complex. It is the value appropriate to weighting the possible payoffs in assessing the utility of an act.

As a result, if an agent wants to make a decision under some condition then it is easier to compute the value by evaluating its utility.
4.2.1 Utility Theory

Any agent will make a decision based on its own preference from a set of available actions to achieve its goal. Now, we assume that there is a set \( \Psi = \{g_1, g_2, \ldots \} \) of “outcome” or “states” that agents have preferences over. The agent will choose the action from the set \( \Psi \) which provides the best outcome, that is, how good it is. And it can consider that a large number is better from the agent’s point of view as a utility function. So, the preferences of an agent \( i \) will be captured by a function:

\[
u_i : \Psi \rightarrow \mathbb{R}
\]

Preference ordering over outcome can lead to providing a better utility function. For instance, if \( g \) and \( g' \) are possible outcomes in \( \Psi \) and \( u_i(g) \geq u_i(g') \), then outcome \( g \) is preferred by the agent \( i \) at least as much as \( g' \). It can express as:

\[
g \succeq_i g'
\]

Therefore the outcome is denoted as:

\[
u_i(g) \geq u_i(g')
\]

If the \( u_i(g) > u_i(g') \), then outcome \( g \) is strictly preferred by agent \( i \) over \( g' \).

Then it can write:

\[
g \succ_i g'
\]

and, as utility it can be written:

\[
u_i(g) > u_i(g')
\]

In other words:

\[
g \succ_i g' \text{ if and only if } u_i(g) \geq u_i(g') \text{ and } u_i(g) \neq u_i(g') \quad (4.1)
\]

Consequently, if both \( g \) and \( g' \) are both possible outcomes and are the same in \( \Psi \) and \( u_i(g) = u_i(g') \), then it is called indifference preference and can be expressed as:

\[
g \sim_i g'
\]
and, as an abbreviation:

\[ u_i(g) = u_i(g'). \]

According to microeconomic theory, individual preferences are assumed to be rational (Mas-Colell et.al., 1995).

**Definition 4.1** (Mas-Colell et.al., 1995): The preference relation of the individual is rational if it possesses the following properties:

(i) **Completeness**: for all \( g, g' \in \Psi \), we have that \( g \succeq g' \) or \( g' \succeq g \)

(ii) **Transitivity**: For all \( g, g', g'' \in \Psi \), if \( g \sim g' \), \( g' \succeq g'' \), then \( g \succeq g'' \)

(iii) **Comparability**: For all \( g \in \Psi \) and \( g' \in \Psi \), we have either \( g \succeq g' \) or \( g' \succeq g \)

As a result, equation (4.1) as a strict preference relation, satisfies the second and third properties.

Utility is a value, which is associated with the state of the world, and which represents the value that the agent places on that state of the world. Utilities provide a convenient means of encoding the preferences of an agent; as Neumann and Morgenstern (1953) demonstrated. It is possible to define utility functions that faithfully encode preferences, such as, state \( S_i \) is preferred to \( S_j \), if and only if it has a higher utility for the agent.

Therefore, an agent’s preference is useful in calculating its utility function to make decision-making towards negotiation a binding mechanism. Electronic commerce is conducted for selling and buying activities, where the negotiation process is a crucial and important issue. So, the basic mechanism of decision theory will fit the context of a negotiating purpose in e-commerce.
4.3 Game Theory

Game theory studies interactions between self-interested entities (Binmore, 1992). The aim of game theory is to help us understand situations where decision-makers interact. In a general sense a game is “a competitive activity ….. in which players contend with each other according to a set of rules” (Osborne, 2004, p.1). Alternatively, the Macquarie Concise Dictionary (1998) defines a game as an example of such a situation in which to reveal some strategy or secret. Consequently, the scope of game theory is very much broader. There are some applications that will give an idea of the range of situations in which game theory can be applied. For example, firms competing for business, bidders competing in an auction, competing experts’ voting behaviour under pressure from interest groups, incentives to correctly diagnose a problem and the role of threats and punishment in long-term relationships (Mendelson, 2004; Osborne, 2004; Brams, 2003).

Game theoretic modelling starts with an idea related to some aspect of the interaction of decision makers. The following sections analyse this model mainly based on the analysis by Osborne (2004) to discover the implications, which are useful to the negotiation mechanism.

4.3.1 Theory of Rational Choice

The theory of rational choice is one of the components of game theory. In a precise format, this theory defines that the player/agent chooses the best action from existing available actions in order to earn something according to its preferences. In this case the players/agents do not have any restriction on preferences of actions. Therefore the agent/player “rationality” stays in the consistency of its decisions when
faced with different sets of available actions, not in the nature of personal likes and dislikes.

### 4.3.1.1 Actions

Two components belong to the theory: $A$ is a set which contains the actions, under some special situations, which are available to the agent and a specification of the agent’s preferences. In a particular situation, the agent is faced with a subset of $A$, so the agent must choose a single element which is known to the agent. The set $A$ could be a delivery date of a product.

### 4.3.1.2 Preferences and Payoff Functions

When any pair of actions are presented, assume that the agent knows its preferences of which pair to choose, or knows that both pairs of actions are equally important, meaning that there is little difference between actions. For example, if an agent prefers action $a$ to action $b$ and action $b$ to action $c$, then action $a$ is preferred to action $c$. However, this will depend on how much the agent prefers an outcome over another’s welfare.

The agent’s preferences can be described as either: for each possible pair of preferred actions, or the agent is indifferent to the actions. Conversely, it can express that the preference of a payoff function or utility function (as economic theory), which associates a number with each action in such a way that actions with higher numbers are preferred. Therefore, let $u$ be the payoff/utility function that represent the agent’s preferences for any action $a$ in $A$ and $b$ in $A$,

$$u(a) > u(b) \text{ if and only if the agent prefers } a \text{ to } b. \quad (4.2)$$
Example 4.1 (Payoff Function representing Preference): A person wants to travel to India, and there is the choice of three airlines: Singapore Airlines, Malaysian Airlines and Thai Airlines. The person prefers Singapore Airlines to the other two, which are regarded as equivalent. Therefore, the payoff function is:

\[ u(\text{Singapore})=1 \text{ and } u(\text{Malaysian})=0, u(\text{Thai})=0. \]

From this example it does not express ‘how much’ that person prefers Singapore Airlines, is only conveys ordinal information. Therefore, the payoff function represents an agent’s preferences and also conveys ordinal information. That is, if \( u \) represents an agent’s preferences and the payoff function \( v \) assigns a higher number to the action \( a \) than to the action \( b \) if and only if the payoff function \( u \) does so, then \( v \) also represents these preferences. Therefore it can represent as:

\[ v(a) > v(b) \text{ if and only if } u(a) > u(b) \]

More precisely, if \( u \) represents an agent’s preferences, then any increasing function of \( u \) also represents these preferences. In some cases it is usual to formulate a model according to preferences and then find the payoff functions. But in other situations it needs to eventually find the payoff functions, if the extraction depends on only the preferences, not the way it is chosen.

4.3.1.3 Definition of Theory of Rational Choice

For a given situation, the theory of rational choice can be defined as: “the action chosen by an agent is at least as good, according to its preference, as every other available action” (Oborne, 2004, p.6).
In the theory of any business organisation, the set of available actions is the set of all input-output vectors, and action \( a \) is preferred to action \( b \) if and only if \( a \) yields a higher profit than does \( b \).

The theory of rational choice is well known and is successful in a wide range of areas. No general theory currently challenges the supremacy of rational choice theory (Osborne, 2004).

### 4.3.2 Interaction of Agents

In the model of rational choice the agent chooses an action from set \( A \) and only cares about this action. This does not always happen. Sometimes the agent needs to care about other actions, which will affect its action (Mendelson, 2004; Osborne, 2004). In this case it is very difficult to make a decision with isolated decision making. To study this type of situation the author refers to a model as a game, for example, organisations competing for business. Each and every organisation sets their product price and they must care about the other organisation’s price of the product, because this will affect their sales. Therefore, how does the organisation choose the price of the product? Or, if the organisation wants to purchase some components from another organisation, then how do they offer to sell and negotiate with each other? All these fall within game theory and need to be analysed thoroughly.

### 4.4 Nash Equilibrium

In 1950, John F. Nash introduced the equilibrium notion in his thesis that is now well known as “Nash equilibrium”. The Nash equilibrium arises when each player’s strategy choice is a best reply to the strategy choices of the other players. The Nash
equilibrium is one of the important tools, not only for game theorists but also for other researchers using interaction analysis. The following sections provide some discussions in relation to Nash equilibrium.

4.4.1 Strategic games

To interact with decision-makers, the model of a strategic game is widely used (Mendelson, 2004; Osborne, 2004). If decision makers are agents, then each agent has a number of possible actions for interacting. This model is defined as affecting all agents’ actions that are related to each other, and not only its own action. That is, every agent has preferences from the action profile (see Appendix A for an example).

A strategic game can be defined as follow:

**Definition 4.2**: A strategic game (with ordinal preferences) consists of:

- a set of agents,
- for each agent, a set of actions, and
- for each agent, preferences over the set of action profiles (Osborne, 2004).

This model can be used to analyse the negotiation process. For example, agents might be sellers (business organisations (BO)), or buyers (customers), the actions might be prices, or other attributes and preferences, or a reflection of the BO’s profit or customer’s satisfaction.

**Example 4.2**.

Let us consider two BOs that produce the same product, such as, a PC. In this duopoly model, each BO wants to sell the PC as either High priced or Low priced to earn more profit. If each BO chooses the price as High, then each BO makes a profit
of $1,200. If one BO chooses High and the other chooses Low priced, then the BO who chooses High will loose customers as well as $300. Alternatively, the BO who chooses Low makes a larger profit of $1,400 (unit profit is low but sell high volume). If both BOs choose Low priced then each earns a profit of $700. Both BOs care about their profit. Therefore, it can be represented in the following game (Figure 4.1) as their preference towards profit they earn:

<table>
<thead>
<tr>
<th></th>
<th>BO₂ High</th>
<th>BO₂ Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>BO₁ High</td>
<td>1200, 1200</td>
<td>-300, 1400</td>
</tr>
<tr>
<td>BO₁ Low</td>
<td>1400, -300</td>
<td>700, 700</td>
</tr>
</tbody>
</table>

*Figure 4.1. A model of price setting of duopoly (Mendelson, 2004, Osborne, 2004)*.

In this situation, it is modelled as follows:

- **Agents**: BO₁, and BO₂.
- **Actions**: each agent set of actions {High, Low}
- **Preferences**: BO₁ prefers (Low, High) to (High, High) to (Low, Low) to (High, Low) and BO₂ prefers (High, Low) to (High, High) to (Low, Low) to (Low, High).

As this abstract model has only two actions to choose from for each BO – it is not complicated. If the BOs may choose among many prices, then the structure of the interaction may change.

### 4.4.2 Nash equilibrium

In a strategic game, which action S will be chosen by the BOs. As a rational decision-maker, each BO will choose the best available action. This best action also
depends on the other BOs actions. Therefore, each BO will choose an action in such a way that it forms a belief about what will happen with the other BOs actions. In addition, this belief will be formed on the basis of their past experience or history.

In summary, two components were identified for the Solution Theory. Firstly, each BO chooses an action according to the model of rational choice, given the belief about the other BOs’ actions. Secondly, every BO’s belief about the other BOs’ actions is correct. These two components are embodied in the following definition.

**Definition 4.3.** A Nash equilibrium is an action profile $a^*$ with the property that no $BO_i$ can do better by choosing an action different from $a^*_i$, given that every other $BO_j$ adheres to $a^*_j$.

To simplify this definition - let $a$ be an action profile, where the action of each $BO_i$ is $a_i$. let $a'_i$ be any action of $BO_i$ (either equal to $a_i$, or different form it). Then $(a'_i, a_{-i})$ denotes the action profile in which every $BO_j$ except $i$ chooses its action $a_j$ as mentioned by $a$, whereas $BO_i$ chooses $a'_i$. (the $-i$ subscript of $a$ represent “except $i$”). That is $(a'_i, a_{-i})$ is the action profile in which all the BOs other than $i$ adhere to a while $i$ “deviates” to $a'_i$. If $a'_i = a_i$ then of course $(a'_i, a_{-i}) = (a_i, a_{-i}) = a$.

By using this notation, it can restate the condition for the action profile $a^*$ to be a Nash equilibrium: no $BO_i$ has any action $a_i$ for which it prefers $(a'_i, a_{-i})$ to $a^*$. Equivalently, for every $BO_i$ and every action $a_i$ of $BO_i$, the action profile $a^*$ is at least as good for $BO_i$ as the action profile $(a'_i, a_{-i})$.
Definition 4.4. (Osborne, 2004): (Nash equilibrium of strategic game with ordinal preferences). Action profile $a^*$ in a strategic game with ordinal preferences is a Nash Equilibrium if, for every $BO_i$ and every action $a_i$ of $BO_i$, $a^*$ is at least as good according to $BO_i$’s preferences as the action profile $(a'_i, a_{-i})$ in which $BO_i$ chooses $a_i$ while every other $BO_j$ chooses $a^*_j$. Equivalently, for very $BO_i$,

$$u_i(a^*) \geq u_i(a'_i, a_{-i})$$ for every action $a_i$ of $BO_i$ \hfill (4.3)

where $u_i$ is the payoff function that expressed $BO_i$’s preferences. From this definition the author concluded that in a strategic game it may be one or more, or it may not possess any Nash equilibrium.

The presence of a Nash equilibrium pair of strategies in a game might appear to be the definitive answer to the question of what to do in any given scenario. If the game doesn’t possess any Nash equilibrium then choosing a mixed strategy that has randomly chosen actions from pure strategy may achieve the expected best payoff.

Now the Nash equilibrium is examined for the Figure 4.2.

![Table](image)

**Figure 4.2: Duopoly model**

In this case there are four possible actions. The action pair (Low, Low) is the unique Nash equilibrium. Because: i) $BO_1$ chooses Low, $BO_2$ is better off choosing Low than High in which $BO_1$ yields a payoff of 700 whereas High yields of 300; ii) $BO_2$ chooses Low, $BO_1$ is better off choosing Low than High and it yields a payoff.
of 700 rather than High yields of 300. Hence, no other Nash equilibrium exists in this model. Therefore, the Nash equilibrium action of each BO (Low) is the best action, regardless of whether the other BO chooses an equilibrium action (Low), or another action (High). The action pair (Low, Low) is a Nash equilibrium because if a BO believes that the opponent will choose Low, then it is optimal for the BO to choose Low. But this condition is not satisfactory all of the time. Sometimes a player will choose preferences, and conversely the opponent will choose preferences, which might result in no unique Nash equilibrium. This is the case where one BO knows the other’s information. Therefore, in the case of not knowing information might result in no Nash equilibrium.

4.4.3 Best Response Functions

From the above example we find that each BO chooses the best response to earn the highest payoff functions, which is Nash equilibrium. So Nash equilibrium is an action profile with the property that no agent can do better by changing an action, given other agents’ actions. Therefore, the method used to reveal the Nash equilibrium in regards to best response function of each player/agent is:

- Find the best response function of each agent.
- Find the action profiles a* of ordinal preferences if and only if every agent’s action is a best response to the other agents’ action.

4.4.4 Definition of Negotiation Situation

Let us consider two agents interacting in a negotiation situation. In the negotiation process each time the agent seeks to maximise the payoff by choosing a proper strategy.
**Definition 4.5.** The negotiation process,

\[ \Gamma = (X, Y, K) \]  

(4.4)

where \( X \) and \( Y \) are nonempty sets, and the function \( K : X \times Y \to \mathbb{R} \) is called interaction towards negotiation.

The elements \( x \in X \) and \( y \in Y \) are called strategies of agents 1 and 2, respectively, in the negotiation process \( \Gamma \), the elements of the Cartesian Product \( X \times Y \) (that is, the pairs of strategies \((x, y)\), where \( x \in X \) and \( y \in Y \)) are called situations, and the function \( K \) is the payoff of the agent 1. Agent 2’s payoff in the situation \((x, y)\) is set equal to \([-K(x, y)]\), that is, the agents’ objectives are directly opposite. Consider agent 1’s payoff is 1 and agent 2’s payoff is negative, we call it a win-loss situation and if the sum of both agents payoff is equal to zero then we call it zero-sum situation, which becomes a strictly competitive situation. This zero-sum situation is very important, as it will not provide any cooperation between agents. Because, if agent 1 allows the opponent a positive utility/payoff, then its means that agent 1 will earn a negative utility/payoff – intuitively, agent 1 will be worse off than before this particular situation.

The negotiation process \( \Gamma \) is interpreted as follows: Agents simultaneously and independently choose strategies \( x \in X \) and \( y \in Y \). Thereafter, agent 1 receives the payoff equal to \( K \) and the agent 2 receives the payoff equal to \([-K(x, y)]\) if they agree to negotiate.

**Definition 4.6.** Both agents have finite sets of strategies that are called a *defined strategies (DS).*
Consider that agent $j$ in Figure 4.4 has a total of $m$ strategies. Suppose the order of the strategy set $X$ of the initiator agent $j$, that is, set up a one-to-one correspondence between the sets $M = \{1, 2, \ldots, m\}$ and $X$. Similarly, if agent $i$ has $n$ strategies, it is possible to set up a one-to-one correspondence between the sets $N = \{1, 2, \ldots, n\}$ and $Y$. The negotiation process $\Gamma$ is then fully defined by specifying the matrix $A = \{a_{ij}\}$, where $a_{ij} = K(x_i, y_j)$, $(i, j) \in M \times N$, $(x_i, y_j) \in X \times Y$, $j \in M$, $i \in N$. Let us consider agent $i$ is agent 1 and agent $j$ is agent 2. In this negotiation process $\Gamma$ is realised as follows. Agent 1 chooses row $i \in N$, and agent 2 (simultaneously and independently) chooses column $j \in M$. If $i > j$ or vice versa, and both agents intends to reach agreement then the agent 1 receives payoff $(a_{ij})$ and agent 2 receives $-a_{ij}$. From Figure 4.2, there are four possible situations in the matrix.

### 4.4.5 Maximin and minimax strategies

The maximin and minimax strategies have been adopted from the work done by Mendelson (2004). Assume a two agent negotiation situation $\Gamma = (X, Y, K)$. In this process, each agent seeks to maximise its payoff by choosing the proper strategy. But for agent 1 the payoff is determined by the function $K(x, y)$ and for agent 2 the payoff is determined by $-K(x, y)$, that is, the agents’ objectives are directly opposite. Here the payoff of agent 1 (2) is determined by the set of the situation $(x, y) \in X \times Y$. In each situation, the agent’s payoff not only depends on its own choice, but also depends on what strategy will be chosen by its opponent whose objective is directly opposite. Therefore, obtaining the maximum possible payoff, each agent must take into account the opponent’s behaviour.

In each situation, the agent’s payoff not only depends on its own choice but also depends on what strategy will be chosen by its opponent whose objective is
directly opposite. Therefore, to obtain the maximum possible payoff, each agent must take into account the opponent’s behaviour. Consider agent 1’s payoff is 1 and agent 2’s payoff is negative, we call it a win-loss situation, and if the sum of both agents payoff is equal to zero then, we call it a zero-sum situation, which becomes strictly competitive. This zero-sum situation is very important as it will not provide any cooperation between agents. Because, if agent 1 allows its opponent a positive utility/payoff, then it means agent 1 will earn a negative utility/payoff – intuitively, agent 1 is worse off than before the particular situation.

The negotiation process $\Gamma$ is interpreted as follows: Agents simultaneously and independently choose strategies $x \in X$ and $y \in Y$. Thereafter, agent 1 receives payoff equal to $K$ and the agent 2 receives the payoff equal to $[-K(x, y)]$ if they agree to negotiate. According to Game Theory, both agents’ behaviour is supposed to be rational, that is, both agents have the same intention to obtain a maximum payoff, assuming that the opponent is acting in the best possible way for the agent.

A question arises here: What maximum payoff can agent 1 guarantee itself? Consider that agent 1 chooses strategy $x$. Then, at worse case it will be win min $K(x, y)$. Therefore, agent 1 can always guarantee the payoff of max$_x$ min$_y K(x, y)$. If max and min are not reached, then agent 1 can guarantee a payoff arbitrarily close to the quantity,

$$v = \sup_{x \in X} \inf_{y \in Y} K(x, y)$$

(4.5)

which we define as the lower value of the negotiation process $\Gamma$. The principle of constructing strategy $x$ based on the maximisation of the minimal payoff is called maximin principle, and the strategy $x$ selected by this principle is called the maximin principle strategy of agent 1.
Using the same reasoning for agent 2, if it chooses strategy $y$, then at worse case it will lose $\max_x K(x, y)$, therefore, agent 2 can always guarantee itself the payoff –

$$\min_y \max_x K(x, y).$$

The number, $\max_y \min_x K(x, y)$, which is defined as the upper value of the negotiation process $\Gamma$. The principle of building a strategy $y$, is based on the minimisation of maximum losses, which is called *minimax principle* and the strategy $y$ selected for this principle is called the *minimax strategy* of agent 2.

Let us consider, the $(m \times n)$ is a matrix of negotiation process (Figure 4.3) and the lower and upper value of the process are, respectively equal to:

$$v = \max_{1 \leq i \leq m} \min_{1 \leq j \leq n} a_{ij}.$$  

$$\bar{v} = \min_{1 \leq i \leq n} \max_{1 \leq j \leq m} a_{ij}.$$  

The minimax and maximin for the negotiation process $\Gamma$ can be found by the following schema.
4.4.6 Analysis of Negotiation

Let us consider a two-agent system. Agent $i$ has $n$ strategies like $s_i^1$, $s_i^2$, …… $s_i^n$ to apply. Agent $j$ has $m$ strategies $s_j^1$, $s_j^2$, …… $s_j^m$ to apply. The payoff matrix to the strategy profiles is as follows:

<table>
<thead>
<tr>
<th>$s_j^1$</th>
<th>$s_j^2$</th>
<th>……</th>
<th>$s_j^m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(a_{i1}, b_{i1})$</td>
<td>$(a_{i2}, b_{i2})$</td>
<td>……</td>
<td>$(a_{im}, b_{im})$</td>
</tr>
<tr>
<td>$(a_{j1}, b_{j1})$</td>
<td>$(a_{j2}, b_{j2})$</td>
<td>……</td>
<td>$(a_{jm}, b_{jm})$</td>
</tr>
</tbody>
</table>

The strategies of agent $i$ lie in the rows and the strategies of agent $j$ lies in the column of the matrix. For example, $a_{i1}$, $a_{i2}$, … $a_{im}$, are the payoffs of agent $i$ for the strategy $s_j^1$ and $b_{j1}$, $b_{j2}$, … $b_{jm}$, are the payoffs of the agent $j$ for the strategy $s_i^1$. The author
then designed an algorithm that can find all possible strategy profiles in Nash equilibrium in pseudo code, as follows:

4.4.6.1 Nash equilibrium algorithm

After creating 2-dimension tables for agent $i$ and agent $j$, enter utilities for each agent’s action. Then create 2-dimension tables (Nash tables) to address maximum values of both agents.

1. Find maximum utility for each agent

```c
//loop to find maximum for agent j
for (i=0;i<row;i++)
{max=arraya[0][j];
 for (j=0;i<col;j++)
 {if(max<=arraya[i][j])
  max=arraya[i][j];
 }maxa[j] = max;

//locate "y" in agent j Nash table to indicate maximum values
for (j=0;j<col;j++)
{if(max==arraya[i][j])
 nasha[i][j]="y";
 else nasha[i][j] ="n";

//loop to find maximum for agent i
for (j=0;j<col;j++)
{max=arrayb[i][0];
 for (i=0;i<row;i++)
 {if(max<=arrayb[i][0])
  max=arrayb[i][j];
```
2. Search Nash equilibrium in table if there are any locations where it is indicated ("y") for both agents with their maximum values.

    //loop to find "y" in the Nash tables
    for (i=0;i<row;i++)
    {
        for (j=0;j<col;j++)
        {
            //if the location has maximum values of both agents, it is a Nash Equilibrium.
            if (nasha[i][j] =="y"&& nashb[i][j] =="y")
            {
                //System will display the Nash Equilibrium.
                cout<<"Nash Equilibrium  ";
                cout<<arraya[addi][addj]<<","<<arrayb[addi][addj]<<"   
            }
        }
    }

### 4.4.6.2 Negotiation Protocol

If there is no unique Nash equilibrium or there is no Nash equilibrium, the agreement will be reached by using negotiation strategies. The agreement will be
binding when the utility of one agent is the highest utility and the utility of another agent is not worse than or equal to $\max \min$.

$1^{st}$ Step: Make a list of maximum utilities for each agent in descending order.

$2^{nd}$ Step: Find the maximum of minimum utilities for each agent ($\max \min$).

$3^{rd}$ Step: Start negotiation by comparing two agents’ utilities, take one of any agent’s maximum list and start from the top with highest utility.

- Agreement can be reached when one of the agent’s utility is the highest and another agent’s utility is not less than or equal to the $\max \min$.

- If the first agent’s offer is its highest utility but another agent’s utility is less than $\max \min$, the negotiation process will continue again but change to another agent’s turn.

- If the highest utilities of both agents cannot make an agreement, then use next highest utilities.

- The negotiation process will be re-operated until the agreement reached.

- After using all of the highest utilities in the agent’s strategy profile an agreement still cannot be achieved, the negotiation is terminated. But agreement can be reached if both agents choose their $\max \min$ utilities.

**Example I:**

<table>
<thead>
<tr>
<th>Agent $i$</th>
<th>Action 1</th>
<th>Action 2</th>
<th>Action 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action 1</td>
<td>(1, 2)</td>
<td>(4, -3)</td>
<td>(2, 0)</td>
</tr>
<tr>
<td>Action 2</td>
<td>(-2, -2)</td>
<td>(1, 2)</td>
<td>(-2, 1)</td>
</tr>
<tr>
<td>Action 3</td>
<td>(2, 1)</td>
<td>(-1, -1)</td>
<td>(0, 3)</td>
</tr>
</tbody>
</table>
From the above example, there is no unique Nash equilibrium; therefore the negotiation is performed using the following steps:

**1st Step:** Make a list of maximum utilities of each agent in descending order.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Action 1</th>
<th>Action 2</th>
<th>Action 3</th>
<th>Descending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent i max list</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>4, 2, 1</td>
</tr>
<tr>
<td>Agent j max list</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3, 2, 2</td>
</tr>
</tbody>
</table>

**2nd Step:** Find the maximum of minimum utilities for each agent (max min).

<table>
<thead>
<tr>
<th>Agent</th>
<th>Action 1</th>
<th>Action 2</th>
<th>Action 3</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent i min list</td>
<td>-2</td>
<td>-1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Agent j min list</td>
<td>-2</td>
<td>-3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**3rd Step:** Start negotiation by using highest utilities with Agent i offering first.

**First round: agent i’s offer**

The highest utility of agent i is 4 considering the payoff matrix, as it can be seen, [x, y] at [0,1], utility of agent i is 4 but utility of agent j is –3, thus the agreement cannot be achieved because agent j’s utility is less than max min.

**Second round: agent j’s offer**

The highest utility of agent j is 3, considering the payoff matrix, in the position [x,y] at [2,2], utility of agent j is 3 and utility of agent i is 0, thus the agreement cannot be achieved because agent i’s utility is less than max min. The agreement is reached only if both agents choose their maxmin strategies from the position (0, 0) in which
agent $i$’s utility is equal to maximin and agent $j$’s utility is greater than maximin and the other positions like (0, 2), (1, 1), (2, 0) which are equal to or greater than maximin value. Therefore, these positions are suitable to bind an agreement for the agents.

**Example II:**

<table>
<thead>
<tr>
<th>Action 1</th>
<th>Action 2</th>
<th>Action 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent $i$</td>
<td>10, -5, 4, -6</td>
<td>-1, 10</td>
</tr>
<tr>
<td>Agent $j$</td>
<td>-2, 2</td>
<td>1, -1, 3, -5</td>
</tr>
<tr>
<td>Action 3</td>
<td>2, 1</td>
<td>2, -1</td>
</tr>
</tbody>
</table>

From this example, there is no unique Nash equilibrium; therefore the negotiation might be performed by adopting the following steps.

**1st Step:** Make a list of maximum utilities of each agent in descending order.

<table>
<thead>
<tr>
<th>Agents max list</th>
<th>Action 1</th>
<th>Action 2</th>
<th>Action 3</th>
<th>Descending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent $i$</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>10, 3, 2</td>
</tr>
<tr>
<td>Agent $j$</td>
<td>2</td>
<td>-1</td>
<td>10</td>
<td>10, 2, -1</td>
</tr>
</tbody>
</table>

**2nd Step:** Find the maximum of minimum utilities for each agent (max min).

<table>
<thead>
<tr>
<th>Agents min list</th>
<th>Action 1</th>
<th>Action 2</th>
<th>Action 3</th>
<th>Max Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent $i$</td>
<td>-1</td>
<td>-2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Agent $j$</td>
<td>-5</td>
<td>-6</td>
<td>-5</td>
<td>-5</td>
</tr>
</tbody>
</table>
Both agents have the equal highest utilities, therefore any of the agents can start offering (for this example agent $i$ first).

<table>
<thead>
<tr>
<th>Round</th>
<th>Agent $i$’s utility</th>
<th>Agent $j$’s utility</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\textsuperscript{st} round of agent $i$</td>
<td>10</td>
<td>-5</td>
<td>agreement: might happen, agent $j$’s utility is equal to -5 (i.e. max min)</td>
</tr>
<tr>
<td>1\textsuperscript{st} round of agent $j$</td>
<td>-1</td>
<td>10</td>
<td>No agreement: agent $i$’s utility is less than max min</td>
</tr>
<tr>
<td>2\textsuperscript{nd} round of agent $i$</td>
<td>4</td>
<td>-6</td>
<td>No agreement: agent $j$’s utility is less than max min</td>
</tr>
<tr>
<td>2\textsuperscript{nd} round of agent $j$</td>
<td>0</td>
<td>3</td>
<td>agreement: might happen, agent $i$’s utility is equal to 0 (i.e. max min)</td>
</tr>
<tr>
<td>3\textsuperscript{rd} round of agent $i$</td>
<td>3</td>
<td>-5</td>
<td>agreement: might happen, agent $j$’s utility is equal to -5 (i.e. max min)</td>
</tr>
<tr>
<td>3\textsuperscript{rd} round of agent $j$</td>
<td>-2</td>
<td>2</td>
<td>No agreement: agent $i$’s utility is less than 0 (i.e. max min)</td>
</tr>
</tbody>
</table>

From the above negotiation table, no unique Nash equilibrium exist, therefore no agreement is reached. But if both agents choose their max min and min max utilities in which the positions (1, -1), (3, -5), (0, 3) there may be agreement.

\textbf{4.4.7 Implementation of Simulator}

To test the above negotiation analysis the problem was simulated according to the array (or table) (see Appendix C for source code). It was created using the following:
- Create two 2-dimension double tables to keep utilities of agent \( i \) and agent \( j \) in the matrix.

- Create two 2-dimension string tables (Nash table) to address the maximum utilities of the agent \( i \) and agent \( j \).

- Create two 1-dimension double tables to keep the maximum utilities of the agent \( i \) and agent \( j \) in the matrix.

- Create two “row” and “col” in order to keep the numbers of the agents’ actions and use in for-loop function to operate the data.

**Input data**

- The program asks how many actions each agent can perform. Then keep the number in “row” for agent \( i \) and “col” for agent \( j \).

- After that, the program will ask utilities each agent will get, in a different situation based on “row” and “col” created.

**Find Nash equilibrium**

- Use for-loop function based on “row” and “col” in order to find the maximum utilities of each agent for each action.
- When finding the maximum utility of each action, put “y” in the Nash table at the same location (x, y) where the maximum utility is, and also keep the value in the maximum table in case the highest utility strategy is necessary, and do the same for both agents.

- The screen displays the result of find “y” in Nash table.

- Nash equilibrium will be displayed, if the Nash tables of both agents have “y” at the same location and can find only one location. If there is more than one then “No unique Nash equilibrium” message will be displayed on the screen. And if there is none, “No Nash equilibrium” will be displayed.

- If there is a unique Nash equilibrium, the program is terminated. If not, then start negotiation process.

**Negotiation process**

- Calculate maximum of minimum (max min) of each agent in order to perform negotiation highest utilities and most conservative payoff strategies.

- Sorting maximum utilities the maximum table in descending order for both agents.

  An agreement will be reached if the utility of agent \( i \) and agent \( j \) are greater or equal to max min. If it does not exist then the negotiation will aborted. In this program, imagine that agent \( i \) start offering first.

**The first round**

  Agent \( i \)’s turn: considering the highest (first) utility from the maximum table sorted for agent \( i \), at the same location if the utility of agent \( j \) is greater or equal to max min of itself, agreement will be reached. If not, give agent \( j \) a turn.
Agent $j$’s turn: similarly, considering the highest utility of agent $j$ and if the utility of agent $i$ is more than or equal to maximum of minimum, agreement is reached.

- If at the first round cannot achieve an agreement, then carry out the second round by using the next highest utility.

- If all high utilities cannot provide an agreement, the agreement is that both agents take the most conservative utility (max min).

After having all input data in the system, the application program provides whether any Nash equilibrium point exists or not. If there is an unique equilibrium point then the agents involved in the negotiation process can choose that point to make their agreement towards negotiation. Alternatively, if there is no equilibrium point, then they can find their max min and min max utilities in which they can make an agreement. In this way the agents can find the feasible negotiation strategies from the matrix. Subsequently, in the next section the result that the agents can make a constructive binding agreement is discussed.
4.4.8 Results and Discussion

From the analysis, it has found that there are four possible ways to bind an agreement, which can be represented as follows:

1. Maximum utility function of both agents as

\[ u_i(s^i_k) = \max_{1 \leq k \leq m} a_{kl}, \quad u_j(s^j_l) = \max_{1 \leq l \leq n} b_{kl} \]  

(4.7)

2. if \( u_j(s^j_l) = \max_{1 \leq l \leq n} b_{kl} \) and \( \delta_i > = \max_{1 \leq k \leq m} \min_{1 \leq l \leq n} a_{kl} \) \n
(4.8)

3. if \( u_i(s^i_k) = \max_{1 \leq l \leq n} a_{kl} \) and \( \delta_j > = \max_{1 \leq l \leq n} \min_{1 \leq k \leq m} b_{kl} \) \n
(4.9)

Otherwise

4. by adopting most conservative strategy payoff of each agent by the following equations:

\[ \delta_i > = \max_{1 \leq k \leq m} \min_{1 \leq l \leq n} a_{kl}, \quad \delta_j > = \max_{1 \leq l \leq n} \min_{1 \leq k \leq m} b_{kl} \]  

(4.10)

Number 1 has the least possibility of making an agreement, because both agents cannot reach their maximum utility at the same time. But, if it happens then it will fall at the equilibrium point. Consequently, Numbers 2 and 3 have a good possibility of making an agreement, because one agent will gain maximum and another agent will gain minimum of maximum utility and vice versa. But Number 4 is the most suitable situation in which both agents will make an agreement easily with low utility, which is guaranteed both sides. Number 4 introduces the following definitions:
**Definition 4.7.** At any negotiation situation there is a common belief of the agent’s most conservative, that is, maximin strategy to guarantee the agent’s maximum of minimum payoff. As for the maximin principle, the agent ensures that it will earn the maximum of minimum payoff. Therefore in any circumstances the agent will not gain less than maximin payoff.

**Definition 4.8.** Adoption of maximin strategy ensures agents’ agreement is binding in the negotiation process.

The following assertion holds for any negotiation situation $\Gamma = (X, Y, K)$ that is, the maximum of the minimum value/payoff is always less than or equal to the minimum of the maximum value/payoff.

**Lemma.** In two agents negotiation situation $\Gamma$

\[ \underline{v} \leq \bar{v} \]  

(4.11)

or,

\[ \sup_{x \in X} \inf_{y \in Y} K(x, y) \leq \inf_{y \in Y} \sup_{x \in X} K(x, y) \]  

(4.12)

**Proof.** Let $x \in X$ be an arbitrary strategy of the agent 1. Then we have,

\[ K(x, y) \leq \sup_{x \in X} K(x, y). \]

Hence we get,

\[ \inf_{y \in Y} K(x, y) \leq \inf_{y \in Y} \sup_{x \in X} K(x, y) \]

Here we have a constant on the right–hand side of the latter inequality and the value $x \in X$ has been chosen arbitrarily. Therefore, the following inequality holds,
Assume the optimal behaviour of the agents in the negotiation situation. In this situation $\Gamma = (X, Y, K)$, the optimal point is $(x^*, y^*) \in X \times Y$ and any deviation from this point will not get the agents a better result. This point is called the equilibrium point and the agents can make an agreement at this point.

**Definition 4.9.** The point $(x^*, y^*)$ in negotiation situation $\Gamma = (X, Y, K)$ is called the *-equilibrium point in which the agents can make an agreement if the following inequality holds for any strategies $x \in X$ and $y \in Y$ of the agents 1 and 2 respectively:

$$K(x, y^*) \leq K(x^*, y^*)$$  \hfill (4.13)

$$K(x^*, y) \geq K(x^*, y^*)$$  \hfill (4.14)

We can express this as the following

$$a_{xy^*} \leq a_{x^*y^*} \leq a_{x*y}$$  \hfill (4.15)

The element of the matrix $a_{x^*y^*}$ at the equilibrium point is simultaneously the minimum of its row, that is, for agent 1 and the maximum of its column, that is, for agent 2. From the example it can be seen that the agreement is reached in the first round where agent $i$ performs action 3 and agent $j$ performs action 3.

The set of all equilibrium points in the negotiation situation $\Gamma$ will be expressed as:

$$Z(\Gamma), \ Z(\Gamma) \subset X \times Y$$
Theorem 4.1. Let \((x_1^*, y_1^*), (x_2^*, y_2^*)\) be two arbitrary equilibrium points in the negotiation situation \(\Gamma\). Then:

1. \(K(x_1^*, y_1^*) = K(x_2^*, y_2^*)\);
2. \((x_1^*, y_2^*) \in Z(\Gamma), (x_2^*, y_1^*) \in Z(\Gamma)\)

Proof. From the definition of equilibrium point of all \(x \in X\) and \(y \in Y\), we have,

\[
K(x, y_1^*) \leq K(x_1^*, y_1^*) \leq K(x_1^*, y) \tag{4.16}
\]
\[
K(x, y_2^*) \leq K(x_2^*, y_2^*) \leq K(x_2^*, y) \tag{4.17}
\]

We substitute \(x_2^*\) into the left-hand side of the inequality (4.16), \(y_2^*\) into the right-hand side and \(x_1^*\) into the left-hand side of the inequality (4.17) and \(y_1^*\) into the right-hand side. Then we get,

\[
K(x_2^*, y_1^*) \leq K(x_1^*, y_1^*) \leq K(x_1^*, y_2^*) \leq K(x_2^*, y_2^*) \leq K(x_2^*, y_1^*)
\]

From this it follows that:

\[
K(x_1^*, y_1^*) = K(x_2^*, y_2^*) = K(x_2^*, y_1^*) = K(x_1^*, y_2^*)
\]

To show the validity of second assertion, assume that the point \((x_2^*, y_1^*)\). Form (4.16) to (4.18), we then have,

\[
K(x, y_1^*) \leq K(x_1^*, y_1^*) = K(x_2^*, y_1^*) = K(x_2^*, y_2^*) \leq K(x_2^*, y)
\]

for all \(x \in X\) and \(y \in Y\).

From the theorem it follows that the payoff function takes the same values at all the equilibrium points. Therefore, the following definition is introduced.
Definition 4.10. Let \((x^*, y^*)\) be an equilibrium point in the negotiation situation \(\Gamma\) then the result

\[ v = K(x^*, y^*) \] (4.20)

is called the negotiation value of the negotiation situation \(\Gamma\). Therefore both agents agree to make an agreement with this value.

The second assertion of the theorem suggests that the following fact:

Consider \(X^*\) and \(Y^*\) are the projections of the set \(Z(\Gamma)\) onto \(X\) and \(Y\), respectively, therefore,

\[ X^* = \{ x^* | x^* \in X, \exists y^* \in Y, (x^*, y^*) \in Z(\Gamma) \} \] (4.21)

\[ Y^* = \{ y^* | y^* \in Y, \exists x^* \in X, (x^*, y^*) \in Z(\Gamma) \} \] (4.22)

The set \(Z(\Gamma)\) may then be represented as Cartesian product,

\[ Z(\Gamma) = X^* \times Y^*. \]

Proof of second assertion.

As the set of all equilibrium points in the negotiation situation \(\Gamma\) expressed as

\[ Z(\Gamma), \ Z(\Gamma) \subset X \times Y \]

And as for all \(x \in X\) and \(y \in Y\).

Therefore, from the (12) and (13) we substitute \(x_1^*\) into \(x^*\) and \(y_2^*\) into \(y^*\) and \(y_1^*\) to \(y^*\) and \(x_2^*\) to \(x^*\) respectively, then we get

\[ X^* = \{ x_1^* | x_1^* \in X, \exists y_2^* \in Y, (x_1^*, y_2^*) \in Z(\Gamma) \}, \] (4.23)

\[ Y^* = \{ y_1^* | y_1^* \in Y, \exists x_2^* \in X, (x_2^*, y_1^*) \in Z(\Gamma) \} \] (4.24)

Therefore, \((x_1^*, y_2^*) \in Z(\Gamma), (x_2^*, y_1^*) \in Z(\Gamma)\).
**Definition 4.11.** The set $X^* (Y^*)$ is the set of optimal strategies of the agent 1 (2) in the negotiation situation $\Gamma$, and their elements-optimal strategies of the 1 (2) agent.

It can be noticed that from (4.18) any pair of optimal strategies form an equilibrium point and corresponding payoff is the value of negotiation situation where agents can make an agreement.

**4.5 Conclusion**

Decision Theory and Game Theory are explored in this chapter. Also, information is provided about a negotiation strategy between two agents; the agents will solve the problem by firstly finding the Nash equilibrium where the strategies of both agents can reach the highest utility. If this strategy cannot be used to make an agreement, then the next step is to find any strategy, where one agent can achieve the highest utility. Moreover, if the second strategy still cannot provide the agreement, the last strategy is the most conservative payoff; both agents have to take the maximum of their minimum of each action (max min). If the agents adopt this mechanism to find the best feasible strategy in which they can reach an agreement for negotiation. As a result from the analysis of the negotiation situation, if both agents adopt such behaviour that offers to the other agent have the intention of earning as minimum as possible to make a profit, then it will have the possibility to make an agreement. Otherwise, only as self-interested agent (the agent only focused on themselves) it is very hard to make an agreement binding in the negotiation process.

By adopting the maximin and minimax strategy, it has proposed that the agents will use their *reasonable positive intention approach* towards negotiation, in which it is assumed that will enhance agreement binding rate. Alternatively, both
agents will be satisfied and will build a sustainable electronic marketplace to conduct business such as supply chain management, where negotiation is the first criteria. Ultimately, this automated negotiation will bring efficiencies to inefficient online markets by removing the risk of failed transactions and reducing cost as well as time, rather than traditional way which is not cost effective and is time consuming.

In summary, the contributions of this chapter include the theoretical solutions of negotiation strategy, various definitions and theory. In relation to this agents will be able to find reasonable strategies to bind an agreement towards negotiation in which the agents need to adopt a reasonable positive intention approach.

The next chapter analyses and discusses the negotiation based on TAC SCM.
CHAPTER 5

Negotiation Analysis based on Trading Agent Competition

Supply Chain Management (TAC SCM) Game Scenario

5.1 Introduction

A negotiation protocol is one of the most important features in setting up the negotiation mechanism. The identification of what rules need to be applied for this mechanism is equally imperative. This chapter details the analysis of a negotiation protocol. The scenario “Trading Agent Competition Supply Chain (TAC SCM)” is used to analyse the negotiation mechanism in the management of a multi-agent system that is essential to e-business transactions.

Firstly this chapter introduces TAC SCM that includes an overview of the game, the procurement problem and performance, negotiating the price of components, price uncertainty and the production decision. Then, the negotiation mechanism in TAC SCM is discussed. The next section presents the common issues in the negotiation process, which includes the negotiation space, the protocol and the strategy. This is a theoretical analysis of the negotiation protocol, and subsequently develops a non-monotonic concession protocol and an extended and iterated negotiation protocol. Advantages of this approach are also identified.
5.2 Trading Agent Competition Supply Chain Management (TAC SCM)

The Trading Agent Competition (TAC) is an autonomous game where concerned researchers from universities from different parts of the world participate to integrate information about the electronic marketplace using autonomous software agents. Nowadays electronic trading is one of the emerging issues for the research communities of Artificial Intelligence (AI), Electronic Commerce and Multi-agent System (MAS) as well as for traders.

TAC is an annual game that was proposed by Wellman and Wurman (1999), and first organised in 2000 with the scenario TAC Classic, which involves travel agents. In TAC 2003, a new scenario was introduced as “TAC SCM” (Trading Agent Competition Supply Chain Management), which focuses on research for the overall supply chain. The challenge is that agents are required to concurrently compete in multiple markets (markets for different components on the supply side and markets for different products on the customer side) (Arunachalam, 2003). TAC’03 competition was started in the month of June and finished on 13th August 2003. See Appendix D for more details of the TAC SCM scenario and game.

5.3 Case: Overview of TAC SCM game

The TAC SCM is an international competition where six software agents that are manufacturers of personal computers (PC) in a simulated common market economy, are linked in two markets: the Component market and the Product market (Arunachalam et al, 2003).

<table>
<thead>
<tr>
<th>Component market</th>
<th>Product market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers</td>
<td>Manufacturers</td>
</tr>
<tr>
<td></td>
<td>Customers</td>
</tr>
</tbody>
</table>
TAC SCM is designed as a traditional supply chain model where supplier and end users (customers) are directly involved in an electronic market (Arunachalam et al., 2004). Each manufacturing agent can manufacture 16 types of computers, characterised by different *stock keeping units* (SKUs). A SKU can consist of a combination of components required to build a PC and there are different versions of each component. The component types are CPUs, motherboards, memory, and hard drives. The two families - Pintel and IMD provide CPUs and motherboards. An IMD’s CPU only matches with an IMD motherboard, while a Pintel CPU only incorporates with Pintel motherboards. The CPUs are available in two different speeds (2.0 and 5.0 GHz), memory is in sizes of 1 GB and 2 GB, and hard disks are in sizes of 300 GB and 500 GB. There are 16 different PC configurations available in a Bill of Materials (Collins et al., 2006).

During each TAC day of the game, customers send a set of Request for Quotes (RFQs) to the agents. Each RFQ contains a SKU, a quantity, due date, a penalty rate and reserve price (the highest price the customer is willing to pay). Each agent responds to the RFQ by sending an offer that states a price less than the reserve price. The agent that sends the lowest price wins the bid. The winning agent delivers the entire order and is paid in full if it is delivered within five days of the due date. If the order is not delivered by the due date a penalty is incurred based on the number of days late. Consequently, if the agent cannot deliver the entire order within five days of its due date then this order is cancelled and the maximum penalty is incurred (Collins et al., 2006).

Alternatively, the agents can send a RFQ to the suppliers for the required components with an expected delivery date. The suppliers respond to the RFQ the next day with either partial or full offers, specifying the price per unit. A partial offer
is when a supplier cannot provide the whole quantity requested by the agent, but can deliver a lesser quantity on that day. Full offers either have a delivery date on the day requested, or a delivery date later than the requested day. The agent can accept or reject these offers according to their requirements and enter into an agreement with the supplier (Rahwan, 2007; Zhang, 2005). The agent will be charged for the components on delivery. This simple negotiation mechanism must follow when agents purchase their components from suppliers. This mechanism only focuses on the accept or reject methods.

Each agent must solve daily problems such as (Collins et al, 2006; Dahlgren and Wurman, 2004):

i) Bidding problems for a customer order of PCs.

ii) Negotiating a supply contract when the procurement problem deals with components that need to be purchased from the supplier.

iii) Production problems concerned with everyday scheduling.

iv) Allocation problems that deal with matching SKUs in the inventory to orders.

At the end of the game the agents receive awards based on their profit

5.3.1 Procurement Problem of TAC SCM

The purchasing decision is one of the most critical issues of supply chain management (Chopra and Meindl, 2003) in the TAC SCM in which the winning agent of the competition basically depends on this purchasing decision. Consequently, the supplier component pricing offering process completely depends on the availability of components. At the same time, agents’ ordering components for daily operations also directly depend on this supplier pricing offer that is also completely uncertain.
The supplier pricing offer is set on the basis of the availability of components. Therefore the uncertainty arises based on whether the prices of components might be cheap or expensive.

Suppliers set prices for components based on an analysis of available capacity. The TAC SCM component catalog (Arunachalam et.al, 2004) associates every component $c$ with a base price, $b_c$. The correspondence between price and quantity for component supplies is defined by the suppliers’ pricing formula. The TAC SCM 2005 and 2006 divided the following formula into a series of formulas to calculate the price of components. However, overall the basic operation of the game remains the same.

The price offered by a supplier at day $d$ for an order to be delivered on day $d + i$ is as follows:

$$P(d,d + i) = P_{\text{base}} \left( 1 - \delta_p \left( \frac{C_{\text{available}}(d, d + i) - \text{qty}}{C_{\text{current}}(d) \times i} \right) \right)$$

- $P(d+i)$ is the offer price
- $\delta_p$ is the price discount factor and has a value of 50%
- $P_{\text{base}}$ is the baseline price of the components
- $C_{\text{current}}(d)$ is the suppliers capacity on day $d$
- $C_{\text{available}}(d,d+i) = C_{\text{current}}(d) - C_{\text{ordered}}(d)$
- $\text{qty}$ is the quantity requested by the order.

In the SCM game, the agents purchase the components as direct materials categories, that is, components used to make finished goods (Chopra & Meindl, 2003). These direct materials are further classified into bulk purchase, critical and strategic items. The strategic items are not discussed as they do not relate to the
SCM game. Most of the agents purchase their components in bulk on the first day. On this day suppliers tend to have the same selling price, which is 50% less compared to the rest of the game. Some agents like RedAgent (Keller et al, 2004) and PackaTAC (Dahlgren & Wurman, 2004) also use the critical items, which include components with long lead times and the key sourcing objective of these critical items is not low price, but ensured availability. Both agents used fairly simple offer acceptance strategies that do not reject offers on the basis of price (TAC SCM, 2003 game). Subsequently, the 2004 competition introduced enhancements such as: 1) the price function modified to better reflect demand; 2) storage costs introduced; and 3) customer demand segmented into multiple markets (Collins et al, 2006). This necessitate agents to compete with different strategies from the 2003 competition.

The main objective of the agent is to maximise profit and minimise cost of production and inventory (Keller et al, 2004). How is it possible? What are the strategies that should be adopted to maximise this profit? There are many factors involved in achieving a profit. One of the most important factors is that the agents need to increase productivity with an average of low priced components. Another factor is to sell the finished product as soon as possible to clear the inventory with an average high price according to the market situation. How do they optimise these problems? The next section details how the agents perform in the TAC SCM competition.

To increase production capacity and sell the finished products, the agent needs to achieve some improvements, such as ‘auto-activation’ or just-in-time (Chopra and Meindl, 2003). How are these types of improvements possible? The agent needs to be tactful in identifying market demand for finished products,
calculate how many products need to be produced and order balanced components for the PCs from the suppliers and finally, bid for customer orders.

The agent needs to maintain its competitive edge for as long as possible. This advantage allows them simultaneously, to gain market share while also maintaining prices and improving production costs. Competitiveness and productivity are interrelated in the sense that the former largely depends on the latter. Therefore, it is very important how many (Cournot model) components will be ordered by the agent from the supplier and how bidding (Bartrand model) techniques will be applied for the customers order. The Cournot model defines the quantity competition and the Bartrand model deals with the price competition (Meyer, 1976).

5.3.2 Procurement performance of TAC SCM

The agents can order large quantities of components that will be delivered throughout the game, or separately as small quantities. Two procurement models are proposed from this research for TAC SCM: a) the long-run procurement, and b) the short-run procurement. The first day’s component ordering that involves large quantities is termed long-run procurement, as the average price of the components are comparatively cheaper. Alternatively, agents can order components separately for small quantities throughout the game, which is termed as short-run procurement.

The short-run procurement decision by the agent is to find the output level and the associated input levels that achieve the desired objective, that is, to maximise profits. In this type of procurement, agents can either stop purchasing, or purchase components that achieve positive levels of output. It is assumed that the agents will produce a positive output because the market price of the PC is above the minimum average variable cost. The optimum short-run procurement decision will not be
stopped unless the market price is below the minimum average variable cost. The problem is that an agent always calculates its price for output at the present time, and will sell in the future when the market price of output could be comparatively cheaper, which will decrease profit. Then again, if an agent wants to increase a small amount of output then, if the marginal cost is above the average revenue, then this will also decrease profit.

For the short-run procurement model, the agents can order small quantities of components except on the first day of the game (see Table 5.1). Generally, the price of the components is more expensive than on the first day, and can be completely uneven and uncertain due to suppliers pricing offers. For this reason short-run procurement becomes risky to the agents, however it can reduce storage cost.

**Table 5.1: Average price of initial and late orders for the component Pintel 2GHz Game 1131 of Semi-Final Round Gr-1.**

<table>
<thead>
<tr>
<th>Agent</th>
<th>1st day’s Order (quantity)</th>
<th>1st day’s Average Price</th>
<th>Other day’s Ordered</th>
<th>Late Average Price</th>
<th>Overall Average Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>FreeAgent</td>
<td>11000</td>
<td>532</td>
<td>7</td>
<td>548</td>
<td>532</td>
</tr>
<tr>
<td>SouthamptonSCM</td>
<td>14500</td>
<td>541</td>
<td>2335</td>
<td>681</td>
<td>561</td>
</tr>
<tr>
<td>MrUMBC</td>
<td>10643</td>
<td>544</td>
<td>2675</td>
<td>703</td>
<td>576</td>
</tr>
<tr>
<td>ScrAgent:</td>
<td>10658</td>
<td>529</td>
<td>1000</td>
<td>658</td>
<td>540</td>
</tr>
<tr>
<td>Krokodil Agent:</td>
<td>12000</td>
<td>530</td>
<td>111</td>
<td>1110</td>
<td>536</td>
</tr>
<tr>
<td>Socrates:</td>
<td>12663</td>
<td>541</td>
<td>2200</td>
<td>998</td>
<td>608</td>
</tr>
</tbody>
</table>

From the analysis the author has found that the supplier pricing formula provides a strong incentive to purchase large quantities of components on the first day of the competition, as it has been set up to reduce the inventory cost on the first day’s component ordering. Analysis has also found that the price of components on
the first day was almost half, or more than half, than on all the other days. Sometimes this caused a dramatic delay due to huge ordering on the first day.

As a result, in TAC SCM-04 agents employed increasingly ‘aggressive’ first day procurement policies similar to TAC SCM-03, leading to a mutually destructive overcapacity of components for the aggregate system (Michael et al, 2003). In the real world business, it is not possible to order most of the components on a specific day (like first day of game) when the price of components is cheap. Therefore, we need to optimise how the agents can purchase their components effectively, which will be sustainable.
5.3.3 Negotiating the price of component

The fact that the demand of components is determined based on the demand for the end product. There may be considerable variations in its pricing. *How does the agent negotiate its components pricing and which suppliers’ offer should accepted?* The author observed that the first day’s component price is comparatively lower than the other days. This is mainly due to agents not ordering components before the start of the game. Initially, agents determine their estimated production plan for the whole game. But it is quite complex how agents decide which components they should buy and which they should not. The supplier pricing of the components depends on the availability on the day. If the components are more available then the prices of those components are comparatively low, otherwise suppliers would offer high priced components, which becomes risky to the agents. In this type of uncertain situation, it is very difficult for the agents to make the decision whether to purchase components or not. For this reason the agents need to adopt tactful machine learning or learning from history to predict when the price of components are low and when they are high.

An agent needs to calculate the marginal cost (MC) of each PC in order to purchase components. The marginal cost (MC(x)) measures the additional cost incurred from the production of one unit of output when the current output is x. If the marginal cost (MC) is less than the average production cost (APC) per unit then the APC will decrease. If the MC is greater than the APC then the APC will increase. In this mechanism the agent determines which components need to be ordered and which should not. According to this mechanism it is also difficult to take action when the prediction of the future market price of a PC may be less than the price of this
estimation. For this reason, parts of the game especially the semi-finals gave different results from the others parts.

Alternatively, if there are enough PCs in the market then according to price elasticity of demand, which argues that the quantities sold will increase as price decreases. But this does not hold in business to business markets as component procurement of TAC SCM has regular demand patterns. But in the game it is observed that a reduction in price of PC for example, will have little effect on the total number sold, which is, of course, controlled by the sales of PCs.

5.3.4 Price uncertainty and production decision

Price uncertainty of the component market is the most important issue in the TAC SCM game. How do the agents purchase components in this environment? What is the best strategy to solve this problem? This price uncertainty may cause the agents to be in vulnerable situations in the game which results in agents earning low profits or negative scores.

Assume that an agent’s total costs are \( C(Q) \), the price can be: either \((1+a)P\); or \((1-a)P\) with equal probability, \(0 \leq a \leq 1\). The expected profit will be:

\[
E[\pi] = \frac{1}{2} (1 + a)PQ + \frac{1}{2}(1 - a)PQ - C(Q) \tag{5.1}
\]

where \(Q\) is the quantity of the finished product and \(P\) and \(a\) are given. Increasing \(a\) increases price volatility, while \(a=0\) corresponds to a less risky setting. The agent always seeks to maximise its expected profits, however, must make its production decision before the price is known. If decisions can be postponed until after the random event occurs, then substantial reduction in profit risk can be achieved, as the
essence of a risky planning problem is removed. *How does this uncertainty influence price, quantity demanded or cost? What is the objective of the agent?* Each of these questions must be answered for more complicated problems. Maximising expected profits requires:

\[
\frac{d \ E[\pi]}{dQ} = \frac{1}{2} (1 + a) P Q + \frac{1}{2} (1 - a) P Q - C'(Q) = 0 \tag{5.2}
\]

where \(C'(Q)\) is the marginal cost and the first two terms of the right-hand side of the equation (5.2) is the expected selling price. If the expected price is equal to \(P\), the condition in equation (5.2) is satisfied at the same level of output as in a less risky setting. If the agent commits itself to this level, it will be unable to expand output to take advantage of the higher price of \((1+a)P\), and will produce in excess of demand when the price is \((1-a)P\). Therefore, expected profits will be less than the profit that could be achieved under certainty. In addition, as the variation in price increases (as \(a\) increases), expected profits decline, thus creating an economic value for information, which would reduce the degree of uncertainty. On one hand, if we introduce Rubinstein’s (1982) *alternate offering* model, then it will reduce the degree of risk for the agent. On the other hand, this uncertainty can also be measured by fuzzy logic, which is discussed in the next chapter.

Although a detailed development is beyond the scope of this thesis, the major implications of price uncertainty for a purely competitive agent may be summarised as (Meyer, 1976):

1. For a risk adverse agent, optimal output is less than under certainty.
2. Increased fixed (storage) costs will normally lead to a decrease in optimal output.
3. Increasing marginal cost is no longer a necessary condition for a finite optimal production level.

4. For a risk adverse agent, an optimal production plan is characterised by average total cost less than the expected price.

Fixed cost become relevant when risk is introduced, since the agent will want to provide a margin for possible losses by keeping fixed costs down. The last point indicates that expected economic profits will be positive, not zero, in equilibrium; in fact, they will increase as the agent assumes more risk. This result corresponds to the common assumption that risk taking is a valuable economic function which should command a positive market price.

5.3.5 Negotiation mechanism in TAC SCM

In the TAC SCM scenario, the manufacturing agents negotiate with the suppliers in the component market and with the customers in the product market. The product market involves a bidding technique using an auctioning process (Arunachalam et al, 2003).

In the component market, the agents negotiate with the suppliers through RFQs for a contract. The basic form of negotiation is no negotiation at all, which means it is a fixed-price sale where the supplier offers components through RFQs on a take-it-or-leave-it basis (Rahwan, 2007). In this specification, there is limited interaction among the agents and the suppliers in the negotiation process. To make a more flexible and effective negotiation, a multi-issue based bargaining system needs to be developed. This involves putting forward proposals and counter-proposals until an agreement is reached or until the negotiation aborted (Su et al, 2000). The
bargaining technique needs to be adopted in order to capitalise on the agent’s maximum utility.

5.4 Common issues in negotiation process

Some common issues involved in the negotiation mechanism when an agent decides to enter into a negotiation process are (Wooldridge, 2002):

- **Negotiation Space:** All possible deals that an agent can make, that is, the set of candidate deals.
- **Negotiation Protocol:** Rules that determine the process of negotiation, such as how and when a proposal can be made, when a deal has been struck, when the negotiation should be terminated, and so on.
- **Negotiation Strategy:** When and what proposals should be made. This strategy expresses a particular agent’s behaviour and for this reason can be termed as private.

5.4.1 Negotiation Space:

The negotiation space is a finite set of possible deals in which the agent can make offers according to its preference (Rosenschein and Zlotkin, 1994).

Consider the shaded circle ABCD in Figure 5.1 that illustrates all possible deals of agent $i$ and agent $j$ that agents can make. The x-axis represents the utility for agent $i$ and the y-axis represents the utility of agent $j$. 
The middle point (E) is considered as a conflict deal in which the agents fail to make any agreement. All deals to the left side of the line BD will not be individual rational for agent \(i\). Agent \(i\) could do better with the conflict deal. Using same reason, all deals below the line A-C will not be individual rational for agent \(j\). Therefore, all the deals in the area B-E-C are of the negotiation set. However, all deals in this space are not pareto optimal. If a deal is not dominated by any other deal it is said to be pareto optimal (Osborne, 2004). Generally, the deals are in pareto optimal are also individual rational for both agents will lie on line B-C. As a result, agent \(i\) will start negotiation by proposing the deal at point C and agent \(j\) starts by proposing the deal at point B.

Therefore, according to this point of view, the bargaining mechanism starts by proposing deals that lie on the line B–C in the negotiation space when trying to move towards binding an agreement. The following section focuses on the negotiation protocol.
5.4.2 Negotiation Protocol

A negotiation protocol is a set of rules that determine the process of negotiation. “There is no one single best negotiation protocol for all negotiation situations” (Bichler, 2001, p.82). Because different negotiation rules are appropriate in different situations, any generic architecture has to support a range of rules (Wurman et al, 1998). The negotiation protocol should be public so that both parties can follow the rules, and can be introduced by the following definitions.

**Definition 5.1** (Negotiation protocol). The rules that specify the whole negotiation process in which the agents come to a consensus, or come to disagreement for a specific deal.

**Definition 5.2.** (Public protocol). Negotiating agents follow the same protocol if and only if it is public.

In the negotiation time, the participating agents should follow the same publicly defined protocol. Otherwise, the negotiation situation will not exist.

5.4.2.1 Monotonic concession protocol

Rosenschein and Zlotkin (1994) introduced the monotonic concession protocol. The rules specified for this protocol are as follows:

- The negotiation process can proceed in a series of rounds.
- At the commencement of the first round, the agents will simultaneously propose a deal from the negotiation space.
- If one agent finds that the deal matches with another agent that is asked for based on utility, then the agreement can be made. For example, if Agent 1
and Agent 2 propose the deals $\gamma_1$ and $\gamma_2$ respectively, such that, either: i) $\text{utility}_1 (\gamma_2) \geq \text{utility}_1 (\gamma_1)$; or i) $\text{utility}_2 (\gamma_1) \geq \text{utility}_2 (\gamma_2)$, then one agent may find its utility is at least as good as, or better than the proposal it made. If agreement is reached, then the rule of determining the agreement deal is considered in such a way that if both agents find their offer matches or exceeds that of another agent, then the proposal can be selected as a random basis. Or, if there is only one proposal that matches or exceeds another’s proposal then agreement can be made for the deal.

- If agreement cannot be reached then the agent will proceed to the next round in which the agents begin simultaneous proposals from the negotiation space. In round $t+1$, agents are not allowed to make a proposal that is less preferred by the other agent than the deal it proposed at time $t$.

- If the agent cannot make any concession in a round $t>0$, then the negotiation will terminate with the conflict deal.

According to this monotonic protocol, the agents cannot backtrack, nor can they both simultaneously “stand still” in the negotiation more than once.

**Proposition 5.1.** Let Agent 1’s offer be $o_1$ and Agent 2’s counter-offer is $co_2$ against Agent 1’s offer, and if the $co_2 \leq o_1$ which is a constantly decreasing trend, then the monotonic protocol enables the offer/counter-offer to be in a lower trend, and the opposite one is in higher trend.

**Example:** Consider Agent 1 offers $20.00 for a component, and if Agent 2 does not agree with this price, then Agent 2 can make a counter-offer
against it, for example $15.00. If Agent 1 does not agree on this offer, then Agent 1 can also make a counter-offer, for example $19.00 against Agent 2’s counter offer. Using a monotonous protocol the agent is not allowed to make a higher offer than $20.00. Therefore, we can see that Agent 1’s offer is a lower trend, which satisfies the condition of the theorem. On the other hand, the higher trend will be vice versa.

**Definition 5.3** If the trend of Theorem 1 is replaced by < then the monotony can be said to be a strict monotony protocol.

**Definition 5.4** Agents’ offers and counter-offers in the monotonic concession protocol is a linear trend.

**Example:** Similar to proposition 5.1, which is also a linear trend.

**5.4.2.2 Non-monotonic concession protocol**

Assume we want to apply a negotiation protocol in the TAC SCM for the bargaining process. According to the TAC SCM specification, supplier agents (ag_s) determine the price of components based on the supplier pricing formula (see previous section). Therefore, it is difficult to utilise the monotonic concession protocol due to the monotonic point that the agents are not allowed to propose an offer that is less preferred by the other agent than the deal it proposed before. If it is to be introduced in the bargaining process of the negotiation mechanism in the TAC SCM, then the author proposes a *non-monotonic protocol* to be used. For example, a
manufacturer agent \((ag_m)\) may request quotes (RFQs) for CPUs on a specified day, and the supplier agent \((ag_s)\) offers \(o\) against the RFQ at price \(p\). Then if \(ag_m\) makes a counter /alternating offer (Co-offer) \(\partial\) which is less than \(p\), that it is considered to be a strict monotony, which can be expressed as:

\[
\begin{align*}
\text{(supplier agent’s offer)} & \quad ag_s(o) = p \\
\text{ag}_m(\partial) & < p
\end{align*}
\]  

(5.3)

According to the economic point of view, supply and demand theory, if a customer demand \(d\) is high, then the price of the component will be higher, and if supply \(s\) is surplus then the price will be lower. Therefore, the supplier’s Co-offer price may or may not be less than the manufacturer agent’s \((ag_m)\) requested price, or it can be unable to supply, or the supplier agent can reject it. This situation is considered unavoidable or special circumstances. It can be formalised as:

\[
ag_s(\partial/)=\begin{cases}
\begin{align*}
\leq p & \text{if } d \leq s \\
\geq p & \text{if } d \geq s \\
0 & \text{otherwise}
\end{align*}
\end{cases}
\]  

(5.4)

Because the offer must depend on the availability of components and production capacity of the supplier agent on the particular day. So, the supplier agent can propose offers which may or may not be less than the preferred manufacturer agent’s deal made in a previous time. It can be more or less than the previous offer depending on current situation. As a result, offers and Co-offers are both simultaneously increasing and decreasing. Therefore, the author defines this type of protocol as a non-monotonic protocol. Consequently, it introduces the following definition.
Definition 5.5 (Non-monotonic protocol). Agents can propose any offer according to the present situation need not necessarily always propose lesser than or equal to last offer.

This non-monotonic protocol enables completely uncertain situations for the manufacturer agent. The agents will need to be able to handle this uncertain situation and make the right decision for an agreement moving towards negotiation. The author optimises this uncertain situation using Fuzzy Logic. Due to the uncertain situation, it is assumed that the counter-offer made by agents may not be continued for several times. Therefore, either the agreement is binding for the negotiation process and reached quickly, or can be aborted with conflict resolution. The following definitions and theorems are introduced as:

Definition 5.6 Agent 1 and Agent 2 can make both increasing and decreasing offers, if and only if the protocol is non-monotonic.

Proposition 5.2 A non-monotonic protocol facilitates the bargaining process for manufacturer agents in uncertain circumstances.

Proof: In a non-monotonic situation the price of the components will not be either increasing or decreasing. Let us consider that the supplier offers the price for component of $10.00, and the manufacturer agent makes a counter-offer of $6.00. Then the supplier may offer $12.00 by using the current availability and production capacity. In this way the supplier’s offer may be more or less, which creates an uncertain situation in which the condition satisfies.
Proposition 5.3  A non-monotonic protocol ensures a supplier profit due to the price of components never goes lower than expected price.

Example:  After receiving a RFQ from a manufacturer agent, the supplier agent always checks available components for the specific day and calculates the price according to supplier pricing formula. Therefore, the supplier has full knowledge about the price of the component for the specific day. So, according the supplier’s profit never goes to a lower value compared to the expected price.

Proposition 5.4.  In a non-monotonic protocol situation, the agents either agree or disagree quickly because the situation is uncertain, and as a result the negotiation process time will be short.

Proof of this theorem is the same as Proposition 5.2 which implies uncertainty, and as a result will need less time.

Consequently, each agent has its reserve price that is the price that the agent is ready to pay. So when the agent enters into a negotiation process it then finds the asking (offer of seller agent) price is close to its reserved price, then the agent will make an agreement and the negotiation process will end quickly. Alternatively, if the agent finds a difference between the reserve price and the asked price, which is more, then the agent will make a counter-offer until the offer is close to its reserve price. Or, if the agent finds the offered price is increasing then the agent will stop making counter-offers or make an agreement. Therefore the negotiation process will not last very long and at the same time it will enhance the agreement-binding rate. Therefore
this introduces the following definition. As a result, a non-monotonic protocol will enhance the agreement-binding rate in the negotiation process.

In the negotiation time, the participating agents should follow the same publicly defined protocol. Otherwise, the negotiation situation will not exist.

### 5.4.2.3 Negotiation Protocol of TAC SCM

The existing TAC SCM protocol (Figure: 5.2) is as follows:

1. The agent sends RFQs by specifying component id, quantity, and expected delivery date to the suppliers;
2. Each supplier replies to the RFQs by offering price, expected delivery date and quantity to the agent; and
3. The agent either accepts the proposal or rejects it. At the time of rejection the agent does not respond.

![Figure 5.2. Existing Negotiation protocol in TAC SCM](image)
The proposed iterated negotiation protocol with alternating offers (Figure 5.3) in TAC SCM is as follows:

1. The agent sends RFQs by specifying component id, quantity, and expected delivery date to the suppliers;
2. Each supplier send offers against the RFQs by including price, expected delivery date and quantity to the agent;
3. The agent either accepts the proposal, rejects it, or proposes a counter-offer by specifying an expected price and delivery date;
4. The supplier either accepts the proposal, rejects it, or proposes a counter-offer by specifying an expected price and delivery date;
5. If there is no response then it is considered a disagreement or conflict;
6. Proceed to Point 1 to commence another round of counter-offers.

If the process occurs in such a way then it is called an Iterated Negotiation Protocol as shown in Figure 5.3.
The Nash bargaining solution provides a feasible solution to a two-person bargaining problem. In all bargaining situations, there is usually a set of $S$ alternative outcomes, and the two sides have to agree on some elements of this set. When an agreement has been reached, then the bargaining is over and both sides receive their expected respective payoffs. The case where both agents cannot agree, the outcome is usually status quo and it is called disagreement or conflict deal. It is quite clear that both agents will not engage in bargaining, unless there are outcomes in $S$ that give both sides a higher payoffs than the payoffs they would receive at the disagreement point.
Therefore, if \((d_1, d_2)\) are the payoffs from the disagreement point, then the expected part of \(S\) consists of those outcomes that give both agents higher payoffs than the disagreement payoffs. As a result, the bargaining /negotiation problem can be defined as follows:

**Definition 5.8.** A two-agents negotiation problem consists of two agents 1 and 2, a set \(S\) of feasible alternatives and utility function \(u_i\) on \(S\) for each agent \(i\), therefore,

\[
\begin{align*}
\text{a)} & \quad u_1(s) \geq d_1 \quad \text{and} \quad u_2(s) \geq d_2 \quad \text{for every } s \in S \\
\text{b)} & \quad \text{At least for one } s \in S \text{ we have } u_1(s) > d_1 \quad \text{and} \quad u_2(s) > d_2
\end{align*}
\]

**Definition 5.9 (Conflict deal).** If the agents cannot make any concession in the negotiation process, then the negotiation terminates and is termed as a conflict /disagreement deal.

If the agents fail to reach a consensus then they fall into disagreement or conflict deal.

**Definition 5.10** Alternating offers enhance the negotiation process to reach an agreement. And also increase the agreement rate of negotiation.

**Definition 5.11. (Iterated negotiation process)** Let agent 1 make an alternating offer against the offer made by agent 2. Agent 2 does not agree with this offer and makes an alternating offer against agent 1’s alternating offer. If it continues for some time then the process is called an iterated negotiation process.
An iterated negotiation process will enhance the negotiation process because agents know each other’s behaviour and hence this process will increase the negotiation rate.

5.4.2.4 Extended and flexible iterated negotiation process

An iterated negotiation process can be applied in TAC SCM and also in e-business. Each negotiation situation is bounded by a time frame. When time is out, there is no opportunity for further thinking about the negotiation outcome if it is in disagreement. As a result, the negotiation binding rate will decrease. Assume an agent can enter into an existing negotiation process, which was closed, and if the agent wants to, then another offer can be made, or agreement to the previous offer. This process will create a new opportunity to create a binding agreement.

The author proposes this type of negotiation process as a flexible iterated negotiation process. This negotiation process will only be open to agents that previously participated (see Figure 5.3). Therefore, the agent can give some time to think about it, as we generally take some time to negotiate in the real world. Consequently, the building of a negotiation-based system is needed, in which one of the most important criteria of automated negotiation is simplicity and flexibility. The situation can change at any time, that is, the availability of components and demand of components from both sides (suppliers and manufacturers). Therefore, the suppliers and manufacturers both can change their decisions which were made through previous negotiation. As a result, if there is an opportunity to enter a previous negotiation process then both supplier and manufacturer will be benefited.

For example, manufacturer agent $ag_m$ sends RFQs to the supplier agent $ag_s$ for component at time $t$. Let the $ag_s$ offer the prices of components are $p$ which
seems expensive to $ag_m$ at that time. If the $ag_m$ does not agree with this offer, this becomes a disagreement/conflict. After some time $t + n$, if the $ag_m$ thinks that it can accept the previous offer or can make new offer (new deal). Let the price of the component be cheaper than the previous time, then the agent can make an agreement for this deal. The component is cheaper probably due to increased production or the component becoming available. Therefore, according to the supplier pricing formula the price becomes less than the previous price and the $ag_m$ can decide to agree with this price. On the other hand, the situation may be reverse, that is, the price of the component might be higher than previous time due to less availability. If this type of flexible and iterated negotiation facility can be implemented into the electronic environment, then it will increase the agreement binding rate, and also will reduce the overall time of business processing. As a result, the agent will have more opportunity to make an agreement binding.

5.4.2.4.1 Advantages

More opportunity: By using a flexible iterated negotiation process it will create more opportunities to make an agreement.

Produce more solutions: The traditional negotiation process produces one and only one estimate of the solution. But in the flexible iterated negotiation process it will generate a sequence of trial estimates of the solution.

Flexible: The agents can enter into negotiation process at any time whenever they require.

Increase more participants: More opportunity and flexibility enables more participants to enter the negotiation process.
**Increase rate of agreement:** In the flexible iterated negotiation situation, the agents know the behaviour to each other, therefore there is a possibility that the negotiation binding rate will increase.

**Reduce overall time:** The negotiating agents do not need to send any further RFQ. On the one hand, the negotiation process time will be reduced. On the other hand, agents do not need to find new supplier.

**Reduce duplication of work:** It reduces the duplication of work. As for example, there is no need to prepare new RFQs sending procedures and as well as other necessary tasks for negotiation processes.

**Efficient and effective process:** From the above point of view the process will become efficient and effective.

**Reduce operational cost:** Operating cost will be decreased if a manufacturer is using e-business to sell directly to customers, as fewer supply chain stages touch the product as it makes its way to a customer.

**Timely manner:** By using a flexible iterated negotiation process agreements can be made in a timely manner. Whenever the organisation requires a component it can negotiate an order.

**Minimise overall costs:** It will also be able to reduce overall costs as there are no duplicated tasks or processes.

### 5.5 Conclusion

This chapter reviewed the TAC SCM game and explored the procurement performance of agents. Analysis revealed that this game does not provide a reasonable procurement capability for moving towards a negotiation mechanism. It
also reviewed the existing negotiation protocol of TAC SCM, including the monotonic concession negotiation protocol, which determines the rules in which the agents can offer and counter-offer in the negotiation process. It is difficult to use the monotonic concession protocol in the TAC SCM due to the supplier pricing formula and availability of components on a particular day. The author proposes in this chapter the use of a non-monotonic protocol, which can be applied in the TAC SCM game. This non-monotonic protocol is not only being applied in TAC SCM it can also be used in other automated business processes that involve negotiation. This non-monotonic protocol can facilitate uncertain situations, as well as enhance the agreement-binding rate. Therefore, the negotiation process will end quickly either binding an agreement or aborting the negotiation process.

Subsequently, it is very difficult to use the existing protocol as it does not provide a proper negotiation facility to make a binding agreement. This TAC SCM game only provides fixed priced components where agents either take it or leave it. From the analysis of the result, the author proposes an extended and flexible iterated negotiation process, which can be applied in the TAC SCM game. This process could not only be applied in TAC SCM it can also be used in other automated business processes that involve negotiation. Therefore, the negotiation process will give more time to think and consider which might lead to binding an agreement, aborting the negotiation process, or waiting some time into the future according to requirement. The ultimate goal is to develop an efficient, economic and automated negotiation process, which will support business organisations to avoid complex negotiation processes. Finally, it can reduce the total time for the negotiation mechanism.
In summary, this chapter has presented the existing negotiation protocol in TAC SCM and introduced a non-monotonic negotiation protocol, and an extended and flexible iterated negotiation process with some theoretical solution of these processes. The following chapter discusses the negotiation strategy using Fuzzy Logic in an uncertain situation.
CHAPTER 6

Analysis of Negotiation Strategy based on Fuzzy Logic

6.1 Introduction

Negotiation strategy based on fuzzy logic is discussed in this chapter and analysed using the Trading Agent Competition (TAC). TAC provides a set of web-based multi-agent simulation environments to examine artificial e-market models and to evaluate business strategies for electronic commerce (Sadeh et al, 2003; Wellman & Wurman, 1999). At the same time TAC focuses on evaluating the trading agents, as well as trading agent architectures, decision-making algorithms, theoretical analysis and empirical evaluations of agent strategies in negotiation scenarios. As a result trading agents have become a prominent application area in Artificial Intelligence, in the large part because of their obvious potential benefits in electronic commerce.

Strategies in the negotiation mechanism have not yet been widely explored (Rahwan and Mc-Bumey, 2003). For example, what techniques should be adopted in negotiation strategies to enable the agent to achieve maximum profit? How can the agent decide ‘when’ and ‘what’ price to pay for components to produce the maximum benefit? These problems directly belong to strategies in the negotiation mechanism. In TAC SCM game agents can purchase components early. However, later purchasing can fall into completely uncertain situations due to availability and higher pricing (Benisch et al, 2004; Kiekintveld et al, 2004). After manufacturing, the final products (PCs) are sold to customers. This can result in the market price of the PC being more or less the same as the reserve price. Again, according to a
supplier’s component pricing policy, the agents are forced to purchase fixed-priced components, and agents do not have any alternative ways to purchase. Therefore, the TAC environment is a long way from a real-world market.

Agents may purchase components from suppliers in a random way (Arunachalam et al, 2003; Benisch et al, 2004). The author assumes that if an agent uses possibility theory and a linguistic variable for its decision-making in the negotiation process, then the problem defined above can be resolved. The linguistic approach serves, in the main, to provide a language for an approximate characterisation of those components in the decision process. These can be inherently fuzzy or incapable of precise measurement. The concept of a linguistic variable plays a central role in the application of fuzzy logic, because it goes to the heart of the way in which humans perceive, reason and communicate (Zadeh, 1987). Von Altrock (1997) noted that to develop systems that mimic human-like decisions, mathematical models fall short. Human judgement and evaluation simply do not follow Boolean logic nor any conventional mathematical discipline. For these reasons, implementation of Fuzzy Logic gives the benefit of enabling software to make human-like decisions. Typically, the use of words may be viewed as a form of data compression that exploits the tolerance for imprecision to achieve tractability, robustness, as well as economy of communication. In addition to this, the scope of the application of Fuzzy Logic has been widely extended to many fields due to its effectiveness for uncertainty (Kim et.al, 1995).

To strategise the negotiation mechanism towards the agent’s decision-making process for purchasing components from suppliers, this chapter analyses the possibility and necessity measures and then reviews the linguistic variable. This chapter is organised in the following way: firstly it introduces and discusses the
purchasing behaviour of the TAC SCM environment. Thereafter, an analysis is provided on the price as a fuzzy set using possibility theory and a linguistic variable for strategy measurement.

6.2 Purchasing Behaviour of TAC SCM

Generally, most of the agents purchase their components in two ways: either, they purchase on day-0 (first day of competition) of the game, which consists of large quantities called “long-run procurement”; or, they purchase during the rest of the game, which consists of lower quantities called “short-run procurement”. The author analyses the average percentages of orders on day 0 of TAC SCM, 2004 game as illustrated in the Figures 6.1, 6.2, 6.3, and 6.4 (some analysis of TAC SCM 2003 can be found in Appendix D).

<table>
<thead>
<tr>
<th>Agent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>FreeAgent</td>
<td>51%</td>
</tr>
<tr>
<td>Jackaroo</td>
<td>75%</td>
</tr>
<tr>
<td>MrUMBC</td>
<td>77%</td>
</tr>
<tr>
<td>Boticelli</td>
<td>100%</td>
</tr>
<tr>
<td>UMTac-04:</td>
<td>98%</td>
</tr>
<tr>
<td>HarTac:</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure 6.1. The Average percentage of order on day 0 of Seeding Round

<table>
<thead>
<tr>
<th>Agent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>FreeAgent:</td>
<td>76%</td>
</tr>
<tr>
<td>SouthamptonSCM:</td>
<td>90%</td>
</tr>
<tr>
<td>Mr.UMBC:</td>
<td>86%</td>
</tr>
<tr>
<td>ScrAgent:</td>
<td>99%</td>
</tr>
<tr>
<td>KrokodilAgent:</td>
<td>99%</td>
</tr>
<tr>
<td>Socrates:</td>
<td>92%</td>
</tr>
</tbody>
</table>

Figure 6.2. The Average percentage of order on day 0 of Semi-Final (Gr-1)

<table>
<thead>
<tr>
<th>Agent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>jackaroo</td>
<td>92%</td>
</tr>
<tr>
<td>Boticelli</td>
<td>72%</td>
</tr>
<tr>
<td>UMTac-04:</td>
<td>94%</td>
</tr>
<tr>
<td>Maxon:</td>
<td>100%</td>
</tr>
<tr>
<td>Deepmaize:</td>
<td>80%</td>
</tr>
<tr>
<td>PSUTAC:</td>
<td>90%</td>
</tr>
</tbody>
</table>

Figure 6.3. The Average percentage of order on day 0 of Semi-Final (Gr-2)
Figure 6.4. The Average percentage of order on day 0 of Final

In the short-run procurement decision, an agent needs to find the output level and the associated input levels to achieve the desired objective of maximising profits. In this type of procurement, agents should either stop purchasing, or purchase components to achieve a positive level of output. The author assumes that the agents will produce a positive output because the market price of a PC is above the minimum average variable cost. The optimum short-run procurement decision will not be stopped unless the market price is below the minimum average variable cost. The problem is that an agent always calculates the price of the output at present, and probably sells it in the future when the market price of output may be comparatively cheap, and therefore decreases profit. Alternatively, if an agent wants to increase output by a small amount when the marginal cost is above the average revenue, this will also decrease profit. Here, the question arises of how the agent will tackle these problems? The following section discusses a possibility measure and a necessity measure to strategise the negotiation process.

6.3 Strategy Measurement

The result of the final round of the 2004 TAC SCM competition is different from the results of the other rounds. Free Agent is the winner of the game and purchased only 15% of components on day 0. This agent only purchased small
quantities during the whole game. In the final round, the price of the components was too expensive, and for this reason, most of the agents earned negative results.

The suppliers set component pricing in a random walk, which results in the prices sometimes being cheap, particularly on the first day of the game. However, on most of the other days prices were very expensive, reaching double the base price. So, this question arises here, how the agents will decide ‘when’ and ‘what’ price they should order? Therefore some intelligent techniques are needed where agents can find a solution in uncertain situations.

Alternatively, if agents choose the price of the component in a probabilistic way in all rounds then the agent could not maximise profit as required (for example in the final round). If the agent uses possibility theory then it could solve this problem.

### 6.3.1 Analysis of Price as Fuzzy set

Let the price of a component be *expensive*. *Expensive* does not give a clear conception about price (how *expensive* it is?). How does the agent measure this fuzzy set? In this question, the following data is expressed as propositions appearing above the horizontal line, the italicised word is the label of the fuzzy set; and the answer is expected to be in the form of a fuzzy proposition, that is, a proposition where the constituents may have a fuzzy denotation. To make a clear interpretation of this, the author analysed this example based on fuzzy logic (Bellman & Zadeh, 1977), rather than on a combination of logic and probability-based method. Specifically,

Component X is *expensive*

Y is much more *expensive* than X

How *expensive* is Y?
In this case the proposition is: 
\[ \Delta \]
\[ P = X \text{ is expensive} \] \hspace{1cm} (6.1)

This data is expressed due to the fuzziness of the denotation of *expensive*. Here we need to differentiate a term and its denotation. As the term *expensive* has its denotation a fuzzy subset, EXPENSIVE (which can be expressed in uppercase symbols) of the interval of \( U = (0, \infty) \). This subset is characterised by its membership function \( \mu_{\text{EXPENSIVE}} : U \to [0, 1] \) which associates with each price \( u \in U \) the grade of membership of \( u \) in EXPENSIVE. For example, the grade of membership of \( u = $600.00 \) in EXPENSIVE might be 0.2 while that of \$900.00 might be 0.9. To analyse this we used possibility theory in the following section.

### 6.3.2 Possibility Theory

Firstly, the author examines the difference between probability and possibility. The concept possibility is an abstraction of our intuitive perception of ease of attainment or degree of compatibility, whereas the concept of probability is rooted in the perception of likelihood (that is, chance), frequency, proportion or strength of belief (Zadeh, 1987; Higashi & Klir, 1982). The intuitive concept of possibility does not seem to add anything to the analysis of chance. The essence in the design of intelligent systems needs the ability to imitate remarkable human intelligent behaviour in decision making and control especially for TAC SCM. To arrive at this level of technology, we need to model the perception-based information of humans (Nguyen and Walker, 2006). Usually perception-based information is linguistic and for this reason we need to analyse it for processing. Linguistic analysis
is discussed later in this section. Then again, an important interpretation of possibility theory is based on the concept of similarity (Klir and Yuan, 1995). To interpret this, the possibility \( r(x) \) reflects the degree of similarity between \( x \) and an ideal prototype, \( x_i \), where the possibility degree is 1. Then \( r(x) \) is expressed by a suitable distance between \( x \) and \( x_i \) in terms of relevant attributes of the elements involved. The closer \( x \) is to \( x_i \) according to the chosen distance, the more possible we consider it in this interpretation of possibility theory. For this reason and simplicity, possibility theorem is widely used to handle uncertain situations.

Alternatively, what is the relationship, if any, between the grade of membership and probability? Basically, the grade of membership is a measure of the compatibility of an object with the concept is represented by a fuzzy set (for example, 0.6 is the compatibility of Susana with the fuzzy set of young member of Australian Young Dancer Association, AYDA). Thus, 0.6 is not the probability that Susana is a young member of AYDA. However, it is possible to establish a connection between the number 0.6 and arithmetic average of the level-sets of the fuzzy set young (Zadeh, 1976).

A basic aspect of a fuzzy proposition such as “\( X \) is expensive” is that it does not provide a precise characterisation of the value of \( X \). Instead, it defines a possibility distribution (Zadeh, 1965) of values of \( X \) which associates with each non-negative real number \( u \) a number in the interval \([0, 1]\) which represents the possibility that \( X \) could take \( u \) as a value given the proposition “\( X \) is expensive”. To express this in a symbolic form as:

\[
X \text{ is expensive } \rightarrow \Pi_X = \text{Expensive}
\] (6.2)
which signifies that the proposition “X is expensive” translates into assignment of the fuzzy set EXPENSIVE to the possibility distribution of X, \( \prod_X \).

For notational convenience we write:

\[
\text{Poss}\{X = u\} \triangleq \pi_X (u)
\]

Where the function \( \pi_X : U \rightarrow [0, 1] \) is the possibility distribution and U is the domain of X. Essentially, the possibility distribution of X is the collection of possible values of X, with the understanding that possibility is the matter of degree so that the possibility that X could take u as a value may be any number in the interval of [0, 1] or more generally, a point in a partially ordered set.

### 6.3.3 Possibility Measure

Let us suppose a variable X, which takes values in a universe of discourse U, and consider \( \prod_X \) be the possibility distribution induced by a proposition of the form (based on Zadeh, 1987)

\[
p = X \text{ is } G
\]

where G is a fuzzy subset of U, which is characterised by its membership function \( \mu_G \). In consequence of the possibility postulate, we can write

\[
\prod_X = G
\]

which implies that

\[
\pi_X (u) = \mu_G (u), \ u \in U
\]

where \( \pi_X \) is the possibility distribution function of X.
Now if $F$ is the fuzzy subset of $U$, then the possibility measure of $F$ is defined by the expression:

$$\Pi (F) = \sup ( F \cap G)$$  \hspace{1cm} (6.6)

or more explicitly,

$$\Pi (F) = \sup_U (\mu_F(u) \land \mu_G(u))$$  \hspace{1cm} (6.7)

where the supremum is taken over $u \in U$ and $\land$ represents the min operation. The number $\Pi (F)$, which ranges from 0 to 1, may be interpreted as the possibility that $X$ is $F$ given that $X$ is $G$. Thus, in symbol,

$$\Pi (F) = \mbox{Poss} \{X \text{ is } F|X \text{ is } G\} = \sup ( F \cap G)$$  \hspace{1cm} (6.8)

Specifically, if $F$ is a nonfuzzy set $A$, then:

$$\mu_A(u) = 1 \text{ if } u \in A$$
$$= 0 \text{ if } u \notin A$$

and therefore:

$$\Pi (A) = \mbox{Poss} \{X \text{ is } A|X \text{ is } G\} = \sup_A (G)$$
$$= \sup_A (\mu_A(u)), u \in U$$  \hspace{1cm} (6.9)

An important consequence of (6.6) is the $F$-additivity of possibility measure expressed by:

$$\Pi (F \cup H) = \Pi (F) \lor \Pi (H)$$  \hspace{1cm} (6.10)

where $F$ and $H$ are arbitrary fuzzy subsets of $U$ and $\lor$ is the max operation. Again this max operation is also known as plausibility measure. And 6.7, that is min operation is known as necessity measure and every necessity measure is belief function (Dubois & Prade, 1988).
By contrast the probability measure of \( F \) and \( H \) has the additive property expressed by:

\[
P(F \cup H) = P(F) + P(H) - P(F \cap H)
\]  

(6.11)

As the illustration of (6.3), our proposition is “\( X \) is expensive” has the form

\[
\Delta_p \overset{A}{=} X \text{ is expensive}
\]

(6.12)

where \( \text{EXPENSIVE} \) is fuzzy set defined by

\[
\text{EXPENSIVE} = 1/0 + 0.8/2 + 0.6/3 + 0.4/4 + 0.25
\]

(6.13)

In this case the possibility distribution induced by \( p \) is given by

\[
\Pi_X = 1/0 + 0.8/2 + 0.6/3 + 0.4/4 + 0.1/5
\]

and if the proposition \( X \) is \( F \) has the form.

Generally, the values of a linguistic variable are generated from a primary term and its antonym (for example, young and old in case of linguistic variable \( \text{Age} \)) through the use of various modifiers and connectives.

\[
\Delta_p \overset{A}{=} X \text{ is cheap}
\]

where \( \text{CHEAP} \) is defined by

\[
\text{CHEAP} = 0.2/4 + 0.4/5 + 0.6/6 + 0.8/7 + 1/8 +
\]

(6.14)

Then

\[
\text{EXPENSIVE} \cap \text{CHEAP} = 0.2/4 + 0.1/5
\]

Where a term such as 0.2/4 signifies that the possibility that \( X \) is 4, given that \( X \) is cheap, which is comparatively cheap that is 0.2.

And hence

\[
\text{Poss} \{ X \text{ is expensive} | X \text{ is cheap} \} = 0.2
\]

(6.15)
Therefore in this case the possibility of getting a cheap product from the fuzzy subset of expensive is 0.2.

Conversely, we can use linguistic form to solve this problem

### 6.3.4 Linguistic variables

It is true that most of the linguistic information that humans manipulate through an implicit use of what might be called *approximate* (or fuzzy) *reasoning* based on fuzzy, rather than traditional logic.

The concept linguistic variable plays an important role in the application of fuzzy logic (Zadeh, 1987). To make it simple as common sense reasoning this variable employs words rather than numbers to describe the values of variables.

![Hierarchical representation of the linguistic variable Age](Zadeh, 1987)

*Figure 6.6. Hierarchical representation of the linguistic variable Age (Zadeh, 1987)*

As for example, the age of an individual may be described as young, height as tall, intelligence as extremely high, health as not very good, and so on, with each linguistic value representing a fuzzy set (see Figure 6.6). Generally, the values of a linguistic variable are generated from a primary term and its antonym (for example,
young and old in the case of the linguistic variable Age, through the use of various modifiers and connectives.

A linguistic variable (Zadeh, 1976) is characterised by a quintuple \((X, T(X), U, G, M)\) where \(X\) is the name of the variable, such as, Price; \(T(X)\) is the term set of \(X\), that is, the collection of its linguistic values, \(T(X) = \{\text{expensive, not expensive, very expensive, not very expensive, ……}\}\); \(U\) is the universe of disclosure, that is Price of the component of PC, the set \(\{0, 1, 2, …500, 501, 502, ……\}\); \(G\) is a syntactic rule which generates the terms in \(T(X)\); \(M\) is a semantic rule which associates with each term, \(x\), in \(T(X)\) its meaning , \(M(x)\), where \(M(x)\) denotes a fuzzy subset of \(U\). thus, the meaning, \(M(x)\), of a linguistic value, \(x\) is defined by a compatibility – or equivalently, membership -- function \(\mu_x : U \rightarrow [0, 1]\) which associates with each \(u\) in \(U\) its compatibility with \(x\). For example, the meaning of cheap might be defined in a particular context by the compatibility function

\[
\mu_{\text{cheap}}(u) = \begin{cases} 
1 & \text{for } 0 \leq u \leq 500 \\
\frac{1}{1 + \left(\frac{u - 500}{250}\right)^2} & \text{for } u \geq 500
\end{cases}
\]

which may be viewed as membership function of the fuzzy subset cheap of the universe of discourse \(U = [0, \infty]\).

Therefore, the compatibility of the price 800 is approximately 0.41, while that of 1025 is 0.17. Here the variable \(u \in U\) is termed as base variable of \(X\). Therefore by measuring this compatibility the agent can easily make its right decision to negotiate pricing with the suppliers.
Proposition 6.1. Term set of the price of component for instance \( T(X) = \{\text{expensive, not expensive, very expensive, not very expensive, \ldots}\} \), enhance decision-making process of the agent towards negotiation to maximise its total profit.

Example: Let the agent set the term set of the price of components as expensive, not expensive, very expensive, not very expensive\ldots, when an agent receives the RFQ offer from a supplier, then the agent can evaluate the preset price as if it is very expensive or expensive then they can discard it and if it is not very expensive or not expensive then the agent can take the right decision without any hesitation/confusion. Therefore, in this way the agent can avoid an expensive component and maximise its profit. Because an agent always orders its component in the early days, which is a completely uncertain situation, and sells the product in future when the price is unknown. So, setting term set satisfies.

Proposition 6.2. Term set of the price of component narrows agent’s strategies towards its negotiation for a binding contract.

Proposition 6.3. Term set reduces the gap between strategies as well as make strategies simple, which will enhance the binding agreement.

If the price of a component is expensive which can be measured as a degree of membership in the interval of \([0, 1]\) the difference between the strategies for instant expensive is 0.6, very expensive is 0.9, not very expensive is 0.8, more or less expensive is 0.5 and so on.
**Proposition 6.4.** Delivered components are scheduled for production if \( q^{d-1} = 0 \).

Let \( q \) be the quantity of components, and \( d \) is the delivery date, so all delivered components can be scheduled for the final product production, because the day before the components are delivered are already scheduled for production, which ensures the production of PCs are in the inventory.

**Proposition 6.5.** Agent’s final product guarantee its bidding for sell if \( PC \geq 0 \).

All available PCs in the inventory guarantee which agents can sell, therefore are maximising the agent’s total profit.

The winning agent of the TAC SCM competition depends on the purchasing decision. Consequently, the supplier component pricing offer completely depends on the availability of components. The production capacity on any day is determined by a mean reverting random walk with a lower bound. For this reason some dramatic component price rises are found in the final round of the game. Then again, the agents ordering components for their daily operation directly depend on the supplier pricing offer, which can be completely uncertain. For example, the first day’s prices of the components are comparatively cheap, and on the rest of the days component prices are expensive. This expensive price also varies from day-to-day. So, in this type of uncertain condition, it is very hard to make decisions for agents on which days components should be purchased. Therefore, if agents adopt a linguistic variable as a term set for the component purchasing, then they can compare the price and can make the right decision for component ordering. Ultimately, in this way the agents will have the possibility of maximising profit.
In the TAC SCM game the agent always needs to purchase components at a low price and sell them at a higher price, and therefore, this is one way to maximise profit. Another way is to always keep available products in the inventory, which may not always be possible. Therefore if we separate the price of components in different term set as expensive, moderate, cheap then the agent might reduce uncertainty to make decision towards a negotiation mechanism.

6.4 Conclusion

In an uncertain situation, a negotiation strategy is the main issue to binding an agreement. To solve this problem, this chapter analysed the utilisation of the possibility measurement and use a term set as a linguistic variable of fuzzy logic in the automated negotiation process in the TAC SCM trading agent design. Setting term set will be reduced the gap between strategies and also make strategies simple which ultimately facilitate the agreement binding in the negotiation mechanism. The next chapter provides the analysis and discussion of the bargaining models in relation to negotiation mechanism.
CHAPTER 7

Bargaining Process

7.1 Introduction

This chapter examines the bargaining process. Bargaining is a type of negotiation that buyers and sellers engage in when there is a dispute relating to a transaction, such as the price that will be paid or the exact nature of the transaction. Eventually the buyer and seller will generally come to an agreement. Negotiation is the process whereby interested parties resolve disputes by agreeing upon courses of action, bargaining for individual or collective advantage, and/or attempting to craft outcomes that serve their mutual interests. According to Brams (2003), negotiations are exchanges between parties designed to reconcile their differences and produce a settlement and the negotiation process subsumes both bargaining and arbitration. In the bargaining process, the participating parties calculate their own gain and loss. Subsequently, arbitration involves a third party that can dictate a settlement if the bargainers cannot reach an agreement on their own. Note that arbitration is beyond the scope of this research.

Bargaining is usually regarded as a form of alternative dispute resolution and reaches mutually beneficially agreements (Dongmo, 2005). In relation to this, this chapter firstly investigates the early bargaining model, which provides necessary preliminaries for the negotiation mechanism. Next, the Nash bargaining solution and its properties is discussed. An alternative model is presented in the subsequent section. Then, the bilateral bargaining model is revisited where an extended bilateral bargaining model is developed based on OMG (1999).
7.2 Early Bargaining Model

Research on the bargaining situation has been undertaken in the areas of economics, social sciences, political sciences (Osborne, 2004, Binmore, 1992). Even computing sciences have investigated proper formalisation of bargaining for the negotiation process (Fatima et.al., 2003; Iyad et.al., 2003; Rangawamy and Shell, 1997). It usually happens between two agents, that is a bilateral exchange in a traditional situation.

For example, two agents, 1 and 2, have initial endowments:

\[ x^1 = (x^{11}, x^{12}) \in \mathbb{R}^2_+ \text{ and } x^2 = (x^{21}, x^{22}) \in \mathbb{R}^2_+ \]

of two perfectly divisible goods which defines a payoff combination \( \pi_1(x^{11}) \pi_2(x^{12}) \). According to the agents' preferences, it describes the status quo of the agents as the utility functions \( \pi_i \). Basically, this status quo can be improved by a (partial) bilateral exchange of goods. One question that arises is, what allocation will be reached if the exchange is voluntary, assuming the two agents are rational, and there is no exogenous arbitrator? This question has been researched by economists for a long time. In 1881, Anglo-Irish economist Francis Y. Edgeworth gave a formal answer firstly in *Mathematical Psychics - An Essay on the Application of Mathematics to the Moral Sciences*, where he assumed that the players' utility functions \( \pi_1 \) and \( \pi_2 \) are differentiable and sets out (Edgeworth, 1881, p. 21):

“……to find a point ... such that, in whatever direction we take an infinitely small step, \([\pi_1 \text{ and } \pi_2\] do not increase together, but that, while one increases, the other decreases”.
According to Edgeworth’s (1881) definition the concept of a player's "line of indifference" (p. 22) becomes a standard tool of economic analysis and then observes that "... the direction which [player 1] ... will prefer to move... is perpendicular to the line of indifference" (p. 22). Finally, he concludes that both players would prefer an exchange as long as they can move in a direction which is "positive... for both" (p. 22). Such a direction no longer exists if the players' indifference curves are tangential.

\[
\text{Figure. 7.1. Bilateral exchange in the Pareto box (Napel, 2002)}
\]

The situation is depicted above in Figure 7.1 with the Pareto box (Pareto, 1909) as \((x^1_1, x^1_2)\). The diagram is sketched for player 1 and a rotated diagram \((x^2_1, x^2_2)\) for player 2, which describes indifference curves in both cases. The edges of both indifference curves fall in the rectangle length \((x^1_1, x^2_1)\) and \((x^1_2, x^2_2)\) respectively. This rectangle represents the set of all feasible allocations of goods.
based on players’ initial endowments. Edgeworth’s (1881) contract curve $K$ is monotonically increasing from the origin of player 1, $0^1$, to that of player 2, $0^2$.

All points on the contract curve are Pareto-efficient, which are characterised as collectively rational. Voluntary exchange requires that allocations are also individual rational, that is result in at least as much utility to either player as the respective initial endowment. In Figure 7.1 this is considered as the only allocations in set $E$ of indifference curves of players 1 and 2 through the status quo, $I^1$ and $I^2$.

$E \cap K$ is a small set from the individual and collective rationality which is possible equilibrium allocations and this is defined as the bargaining set. It retains the multiplicity of mutually beneficial outcomes that characterises a bargaining situation. In this situation it did not specify which particular allocation would be reached by voluntary, un-arbitrated bilateral exchange. In this regard, Edgeworth (1881, p 30) quotes “Such transaction must be settled upon other than on strictly economical grounds”.

Neumann and Morgenstern (1953) were the first to consider the problem only in utility space, which the underlying problem includes trade, exchange and duopoly. These produce the immense generality of the Game Theory. This also served as a preparation for the later first solution of the bargaining problem by Nash (Nash, 1950a). Von Neumann and Morgestern (1953, p 255) believe that to reduce these bargaining set:

“*There exists precisely one solution. It consists of all those imputations where each player gets individually at least that amount which he can secure for himself, while the two get together precisely the maximum amount which they can secure together*.”
There exist two models of wage setting at the time of the Games Theory which identifies a unique outcome of bargaining.

In 1930, Zeuthen developed the first one, and argued that if two players, 1 and 2 made incompatible proposals $o^1_t \neq o^2_t$ at a given time $t$ of negotiation, then each player $i \in I = \{1, 2\}$ has as the most extreme choice to either accept the other player’s proposal, $o^{-i}_t$, and receive the payoff $\pi_i (o^{-i}_t) > 0$. Or player $i$ can insist on his proposal $o^i_t$ with the risk that, with some probability $p_i$, the other player -$i$ will leave the table and pursue an outside option. Such negotiation yields zero payoff. Harsanyi (1956) rediscovered (see Appendix B) and reappraised Zeuthen’s proposal. Zeuthen (1930) and Harsanyi (1956) argued that an expected utility maximiser $i$ will accept proposal $o^{-i}_t$ if $\pi_i (o^{-i}_t) > (1 - p_i) \pi_i (o^i_t)$. This argument provides an implicit assumption, which must reduce the set of alternatives to either full or no concession. In either cases, the utility quotient $\Delta \pi / \pi_i (t) := [\pi_i (o^i_t) - \pi_i (o^{-i}_t)] / \pi_i (o^i_t)$ measures “the utmost probability of conflict to which [player $i$] can find its advantage to expose itself” (Zeuthen, 1930, p. 115) by insisting on the better terms $o^i_t$ instead of accepting the less favourable $o^{-i}_t$. Harsanyi termed this quotient as the players’ $i$’s risk limit. Basically, the risk limits “decide the strength of each party’s ‘determination’ ” (Harsanyi, 1956, p.148).

Two distinct assumptions are then made. Firstly, player $i$ will make a concession and propose an agreement $o^{i}_{t+1}$ more favourable to -$i$ than $o^i_t$ whenever

$$\frac{\Delta \pi_i}{\pi_i (t)} < \frac{\Delta \pi^{-i}}{\pi^{-i} (t)}$$

(7.1)

That is, if player 1 is less determined than player 2, player 2 sticks to his proposal if 5.1 is satisfied, so that $o^{i}_{t+1} = o^{i}_{t}$. Without loss of generality, $i$’s concession can
be considered big enough to reverse inequality (7.1), which provides \( -i \) the player who is more vulnerable to a threat of breakdown and who is to make a concession in \( t +1 \). Secondly, if both players have the same payoff, both will make some concession. Using a small unit, or other technical or psychological lower bound to the size of a concession, the bargaining procedure will terminate within limited steps. Zeuthen’s (1930) concession rule is plausible, and it is a strong adhoc assumption which produces approximately the same outcome as the game-theoretic investigation of Nash (Nash, 1950; Rubinstein, 1982).

Another early model was proposed by Hicks (1932) who argued that each player \( i \) is ready to accept a wage proposal which is on the table, if it is less costly than a prospective labour dispute. This bargaining model specifies a crucial feature, which is the threat of strike. This threat is beyond the scope of the research.

7.3 The Nash Bargaining model

John F. Nash (1950a) invented the most important equilibrium concept in bargaining problem in relation to cooperative game theory. In his paper Nash provided the theoretical discussion of the bargaining problems. The following sections investigate the core concepts of Nash Bargaining solution.

7.3.1 Properties of bargaining set

In Nash’s terminology a bargaining problem is a pair \( \langle K, k^D \rangle \), where \( K \subset \mathbb{R}^2 \) is a compact and convex set of feasible payoff combinations. Payoffs when no agreement reached is the disagreement point, \( k^D \in K \). There is at least one element \( k \in K \) which is strictly preferred to \( k^D \) by both agents that is \( k > k^D \) which is individually rational.
All bargaining problems are denoted as the set $\beta$. Therefore for every bargaining problem $\beta = \langle K, kD \rangle$, a function is defined as $f : \beta \rightarrow \mathbb{R}^2$ with $f(\beta) \in K$. For a given bargaining problem $\langle K, kD \rangle$, $f(\langle K, kD \rangle)$ is referred to as a solution to the bargaining problem $\langle K, kD \rangle$. In 1950, Nash uses a specific function, $FN$, which is defined as Nash (bargaining) solution.

The bargaining solution $f$ selects an individually and collectively rational payoff combination. The axioms are formalised as follows:

7.3.1.1 Individual rational (IR)

Let $\langle K, kD \rangle$ be a bargaining problem. We denote that $k \in K$ is individually rational if, $k \geq k^D$. That is, each player can guarantee, by applying a best response to the opponent’s action, his highest utility is minimised (Rosenschein & Zlotkin, 1994). Alternatively, an offer is individual rational if it gives both agents a non-negative payoff.

7.3.1.2 Pareto efficiency (PAR)

For all $\langle K, k^D \rangle \in \beta$

$$k \geq f(K, k^D)$$

An offer is Pareto efficient if there does not exist another offer that dominates it (Napel 2002; Rosenschein & Zlotkin, 1994). A Pareto optimal offer cannot be improved upon for one agent without lowering the other agent’s payoff from the offer. Nash (Nash, 1950) motivated this axiom as follows. If both agents are rational, then they will not agree upon a Pareto inefficient point $k^I \in K$ because they realise that they both can do better than $k^I$ and therefore they will continue negotiations to reach a better agreement.
7.3.1.3 Invariance of equivalent utility representations (INV)

Two bargaining problems \( \langle K, k^D \rangle, \langle K', k'^D \rangle \in \beta \) should produce the same outcome if they describe the same bargaining situation, by different but the equivalent utility representations of agents’ preferences. This equivalent preference representations differ by a strictly increasing affine transformation of payoffs, that is a mapping \( \mathcal{I}_i : \mathbb{R} \rightarrow \mathbb{R} \) with \( \mathcal{I}_i(k_i) = a k_i + b \) which has a constant \( a, b \in \mathbb{R} \) and \( a > 0 \) (Napel 2002). As a result this requires:

**INV**

Given \( \mathcal{I}_i(k_i) = (\mathcal{I}_1(k_1), \mathcal{I}_2(k_2)) \) for any strictly increasing affine transformation \( \mathcal{I}_i \) and \( \mathcal{I}_2 \), and any \( \langle K, k^D \rangle \in \beta \)

\[
\mathcal{I}(f(K), \mathcal{I}(k^D)) = \mathcal{I}(f(K, k^D))
\]

7.3.1.4 Independence of irrelevant alternatives (IIA)

This axiom states that the bargaining solution does not change if alternatives other than \( f(K, k^D) \) are removed from the set \( K \). That is, if \( k^* = f(K, k^D) \) is the agreement reached by the agents given the problem \( \langle K, k^D \rangle \) and if \( k^* \) is also a feasible payoff combination for the problem \( \langle K', k'^D \rangle \) with reduced payoff opportunities \( K' \subset K \), the agent should also agree on \( k^* \) as the solution also to \( \langle K', k'^D \rangle \). This requirement supposes that all alternatives not chosen in a bargaining situation \( \langle K, k^D \rangle \) are regarded as irrelevant by the agents for finding solution \( f(K, k^D) \) except \( k^D \). The formal statement is:

For all \( \langle K, k^D \rangle \in \beta \) and all \( K' \subseteq K, k^D \in K' \)

\[
f(K, k^D) \in K' \rightarrow f(K', k^D) = f(K, k^D)
\]
The axiom (IR), (PAR), (INV) and (IIA) are consistent, that is they do not reduce the set of suitable solutions $f$ to the empty set.

The Nash solution has the following interpretation in terms of outcomes $o \in O$ underlying the payoff combination $K$. For convenience, choose both agents’ preference representations such that the utility of disagreement as zero. We consider a bargaining outcome $o^* \in O$ with the following stability property:

$$(\forall i \in I) \ (\forall o \in O) \ (\forall p \in [0, 1]) : \{ p \ \pi_i(o) > \pi_i(o^*) \Rightarrow p \ \pi_{-i}(o^*) > \pi_{-i}(o) \}$$

This means that whenever an agent $i$ strictly prefers an object $o^*$ and proposes the agreement $o \in O$ with the risk of causing final disagreement. The probability of this disagreement is $1 - p$. Then the other agent $-i$ strictly prefers to take an analogous risk and reject the proposal $o$ in favour of $o^*$ while accepting that negotiations fail with probability $1 - p$. A feasible outcome $o^*$ with the property will be called a Nash bargaining outcome (Napel 2002; Rosenschein & Zlotkin, 1994).

Any agreement $o \in O$ yielding the Nash solution vector $f(K, kD) = \pi(o)$ is a Nash bargaining outcome of the underlying bargaining situation. The reverse is also true. That is, firstly, let the case that neither agent $i \in I$ prefers any agreement $o \in O$ to $o^*$. Then clearly $\pi_1(o^*) \pi_2(o^*) \geq \pi_1(o) \pi_2(o)$, and $o^*$ maximises the Nash product. Secondly, let us consider the case in which, without loss of generality, agent 1 prefers $o$ to $o^*$, that is, $\pi_1(o) > \pi_1(o^*)$, and $\pi_1(o), \pi_2(o) > 0$. This means, the agents will offer the agreement which would give a positive outcome for both agents.
7.4 Alternating Offer Model

The ultimatum game (Napel 2002) is illustrated in Fig 7.2 (a), which shows bilateral bargaining can be considered. Player 1 and 2 can share a surplus of one unit provided they agree on a particular division of it. Consider Player 1 is the first mover by making a proposal \( x \in [0, 1] \), which represents the surplus division \((x, 1-x)\) and is referred to as the proposer. Player 2 responds to the proposal \( x \) by either accepting or rejecting it, and is then referred to as the responder (Osborne, 2004). To make it simple, the players’ utility functions can be represented as \( x \) and \( 1-x \), respectively.

The set of Player \( I = \{1, 2\} \) is used in the reduced form of the ultimatum game. The proposer’s strategy space is \( S_1 = [0, 1] \) and the responder’s strategy space:

\[
\begin{align*}
S_2 & = \{0, \infty\} \\
S_1 & = [0, 1] \\
S_2 & = \{0, \infty\}
\end{align*}
\]

\((x_0; 0)\) and \((0; \infty)\) represent the acceptance and rejection outcomes, respectively.

\[
\begin{align*}
(x_0; 0) & \rightarrow 0 & (0; \infty) & \rightarrow 1 \\
(0; \infty) & \rightarrow 0 & (x_0; 0) & \rightarrow 1
\end{align*}
\]

Figure 7.2. The ultimatum game form, 2-stage and n-stage alternating offers in bargaining situations (Napel 2002).
is $S_2 = \{ s | s : S_1 = \{ 0, 1 \} \}$ where 0 indicates rejection and 1 indicates acceptance of Player 1’s proposal. According to the Figure 7.2 (a), the Player1 proposes $x_0 \in X = [0, 1]$ corresponding to a division $(x_0, 1-x_0)$ in the initial period $t = 0$. Player 2 can make a *take-it or leave-it* response to Player 1’s proposal. The situation can change dramatically if it happens in two stages as in the Figure 7.2 (b). Consider that after rejection of the offer $x_0$, Player 2 can make a counter-offer $x_1$ which is also expressed in terms of Player1’s surplus share. The overall surplus division will then reflect Player 2’s advantage of making a credible take-it-or-leave-it offer at stage 2, while the renegotiation in stage 2 renders any commitment to a particular division by player 1 which is not credible.

Figure 7.2 (c) illustrates n-stages alternating offers in the bargaining situation. Player 1 proposes an offer like Figure 7.2 (b). Then the Player 2 can either accept or reject Player1’s proposal. If Player 2 rejects, the situation moves to the second stage $t = 1$ and Player 2 makes a counter-proposal $x_1 \in X$ corresponding to division $(x_1, 1-x_1)$. Player 1 can accept, or reject and make another proposal in the stage $t = 2$. In this way, the Players will propose and make counter-offers until one of the player accepted a division. $(x_t, 1-x_t)$ in a period $t \leq n -1$, or when the proposal $x_{n-1}$ has been rejected, that is negotiations fail.

A discrete version of the *alternating offers bargaining game with n stages* has first been considered by Ingolf Stahl (Stahl, 1972) and similar model has also been investigated by Krelle (1976).
7.5 Bilateral Bargaining Offer Model

A bilateral bargaining situation is characterised by two agents – who have a common interest in cooperating, but two have conflicting interests concerning the particular way of doing so. In economic terms, the agents can jointly produce some type of surplus, provided they agree on how to divide it. Bilateral bargaining refers to the corresponding attempt to resolve a bargaining situation, which is to determine the particular form of cooperation and corresponding payoffs for both. A lot of interaction can be happen until agreement binding or until negotiation aborted. Usually the best outcomes become a bargaining situation if it is repeated many times.

The author developed the extended bilateral negotiation model that is mainly based on TAC SCM game (see chapter 5 for full details) by using Statechart diagrams (Harel & Gery, 1996) as adopted by the UML (Rumbaugh, Jacobson, & Booch, 1999). Statecharts are well-established, widely used and are semantically rich enough to formally describe and visualise different kinds of processes. Note that Statechart Diagrams, State Machine Diagrams and State Diagrams are basically the same. (http://jdjua.com/uml.htm, (date of access – 07/01/08), Maamar et al, 2003). Different authors use these diagrams interchangeably. The author uses State Diagrams in this research.

The author developed this model by using the Negotiation Facility issued by the OMG (1999), which relies on a restricted form of Statechart. This deals with two or more parties involved in the negotiation process to make concessions until they reach a deal. It uses the full expressive power of Statechart, specifically the Event-Condition-Action string provided to focus on transitions. In the Figure 7.3, the extended model defines the main states are “Open” and “Closed”. Again it defines two states, Requested and Offered under Open state. Then it separated Requested
state into Request_For_Quote where taking RFQ and Counter_Offer-Requested. Furthermore, it has separated the state Offered as a) Co_Offer state where taking counter-offer and b) Offer_Waiting state in which offers are waiting for acceptance or rejection. On the other hand, it is divided into the Closed state as Accepted, Disagreement and Time Out state. It is assumed that this formalism is powerful enough to capture bilateral negotiation processes and will be benefited to capture negotiation process through bargaining in the electronic market for purchasing and selling purpose.

1. Request_For_Quote(buer_id, product_specification, quantity, delivery_date), /message to seller
2. Offer(seller_id, product_specification, quantity, delivery_date) / message to buyer
3. Co_Offer(buer_id, product_specification, quantity, delivery_date) /message to seller and vice versa until accept or reject.

*Figure 7.3. Extended Bilateral Negotiation Model*
The state diagram of negotiation mechanism that involve RFQ offering depicted in the following Figure 7.4.

![State Diagram of Negotiation mechanism involving RFQ offering](image)

**Figure 7.4. State Diagram of Negotiation mechanism involving RFQ offering**

The state diagram of negotiation mechanism that involves counter-offering illustrated in the Figure 7.5. In this figure it can be seen that if there is continuous disagreement then agents can enter into the compromise state if they desire and then make an agreement. Otherwise agents can withdraw their offer in the negotiation phase.
7.6 Conclusion

Some theoretical approaches to bargaining are presented in this chapter, for instance, Edgeworth’s early bargaining model, Nash bargaining model with its properties. An alternating offers model are also discussed. An Extended Bilateral Negotiation Model is developed based on TAC SCM game by using State diagrams. State diagrams of negotiation mechanism involving RFQ offering and counter-offering are also developed. As State diagrams are well-established, easy to understand, complete and can be converted into other formalisms, this model is suitable for any type of negotiation which can apply for e-commerce in either business to business or business to customer area.
In summary, an extended bargaining bilateral negotiation model and State diagrams of RFQ offering and counter-offering are developed in this chapter. The next chapter discusses the coordination and cooperation models in relation to multi-agent systems that ultimately facilitate the negotiation process.
CHAPTER 8

Coordination and Cooperation Modelling

8.1 Introduction

The main objective of this chapter is to explore the operation of a multi-agent system in supply chain management for electronic business. It focuses on the coordination and cooperation processes, and discusses a newly developed model for an enhanced and effective cooperation process for e-business. The main contribution of this research is a theoretical solution and a model for agents that adopt this strategy for their e-business transactions. Both large organisations and SMEs will benefit as it will enhance their global business by participating and sharing with other businesses to achieve common goals. As a consequence, the organisations involved will be more profitable and competitive.

The chapter is organised as follows: firstly, factors in conducting e-business are discussed. Then agent-based technology is outlined as a multi-agent system that is necessary for a supply chain system. A definition/theory of coordination is introduced, and some related work on coordination and cooperation is reviewed. The next section discusses cooperative problem-solving processes. Then a theoretical model and architecture on coordination and cooperation is explained in the context of the Trading Agent Competition Supply Chain Management (TAC SCM).
8.2 Factors in conducting e-business

The following factors are identified in conducting e-business:

8.2.1 General Problems

- **Finances:** It has been found that some SMEs do not have enough resources to conduct e-business; however, they are particularly interested in being involved (Lawson et al, 2003). Therefore, large organisations and SMEs have a good opportunity to work together to conduct global e-business.

- **Price war:** The author identified when a buyer seeks goods through an Internet catalogue, for various reasons the price of some products are too cheap, while others are too expensive. As a result, customers feel a level of confusion about making the right decision.

- **Post purchase/local customer service:** It has also been found that if somebody buys goods from the Internet the company may not have a local retailer in that city (Fawcett et al., 2007). In this case, if any problem is found with the goods post purchase, local customer service becomes a complex issue to solve. As a result, some customers are not interested in buying goods from Internet. Therefore, currently local retailers need to stock similar goods. Moreover, to conduct e-business globally, many retailers need to participate. For that reason cooperation is required for transactions with large organisations and with SMEs.

- **Lack of a pricing strategy:** In the real world, a pricing strategy is an important issue. To develop an effective pricing strategy sometimes an incentive like a discount is needed (Chopra & Meindl, 2003). This is possible when a manager thinks its time to give a discount via a special promotion or to clear old stock. It is also possible to implement a pricing strategy in the online world.
• **Lack of customer satisfaction**: From the above points, customers can feel dissatisfied.

### 8.2.2 Problems in supply chain management

• **Lack of information sharing**: Information sharing is one of the most significant issues in SCM and plays an important role (Fawcett et al., 2007; Bowon, 2005). As for example, a retailer such as K-Mart may place huge orders for a particular product for their planned promotion. If suppliers had prior knowledge of this promotion then they also can plan for a production increase.

• **Lack of information access limitation and lack of transparency**: At times users are unable to find an exact outcome due to restricted access to some information (Stadtler, 2005). This results in a lack of transparency. As a result, it obstructs making the right decision within the right time frame.

• **Lack of sharing the benefits of coordination equitably**: The coordination benefits are not being shared equitably in the supply chain, which is a challenge (Chopra & Meindl, 2003). Consequently, if agents agree to work together then it can resolve this problem accordingly.

• **Lack of agreement to work together**: Agreements are not generally found in real-world SCM. This is due to one stage of the supply chain having objectives that conflict with other stages that generally have different owners (Chopra & Meindl, 2003). For this reason, the main objective of each owner is to maximise their own profit. As a result, this diminishes the overall supply chain profit. Today, the supply chain comprises of potentially hundreds or even thousands, of independently-owned enterprises. For instance, Ford Motor Company has thousands of suppliers from Goodyear to Motorola (Hammer, 1990). To make an
overall profit for the supply chain, the partners need to reach an agreement for working together. This can lead to the overall profit being maximised. Therefore, each participant in the cooperative venture will benefit accordingly.

- **Lack of communication among business organisations/supply chains (level of product availability):** Good communication can yield good results. Companies in the supply chain often do not communicate through the various stages of the supply chain and are unwilling to share information (Fawcett et al., 2007; Schneider, 2006; Bowon, 2005). As a result, companies become frustrated with the lack of coordination.

- **Timely manner:** Sometimes some information is not accessible in a timely manner (Chopra & Meindl, 2003). Therefore, this can obstruct the right decision being made in a timely fashion.

- **Lack of use of technology to improve connectivity in the supply chain.**

- **Lack of trust:** Because of the above obstacles, trust is decreased and frustration appears at various stages of the supply chain, making coordination efforts much more difficult. High levels of trust involve the belief that each stage is interested in the other stage’s welfare, and would not take actions without considering the impact on the other stages.

   If the organisations work together electronically towards some shared common goal, then there is a possibility that the problems defined above can be fully or partially overcome.

### 8.2.3 Benefits of conducting e-business

The following are the expected benefits in conducting e-business when organisations work together:
• **Reasonable and flexible price:** If different organisations work together then they will be able to sell goods at a reasonable and levelled price. An e-business can easily alter the price of the products in one entry of the database, which is linked to its Web site. According to current inventories and demand, this type of ability allows an e-business to increase revenues by adjusting prices (Chan et al, 2001; Turban et al, 2006). Airline tickets are a good example where low-cost available tickets are shown on a Web site for flights with unsold seats. This can reduce the price war between competitors.

• **Reliable product:** By working together it is also possible to sell reliable products to customers.

• **Globally available and less transportation cost:** Because organisations can work together globally, then the goods can also be available globally (Chan et al, 2001; Chopra & Meindl, 2003). For example, a customer in Thailand can place an order on the Internet. If there is a warehouse situated in Thailand for that item, then it is easier to get the item, otherwise the seller would need to ship the item. In the case of limited stock, it might not be profitable to have an item available globally when there are high transportation costs. Consequently, by globally working together organisations can earn more profit and lower transportation costs.

• **Reduce operational cost:** Operating costs can also be decreased if a manufacturer is using e-business to sell directly to customers as there are fewer supply chain stages for the product as it makes its way to a customer (Chopra & Meindl, 2003; Krishnamurthy 2003; Turban et al, 2006).

• **Reduce delivery time:** If a warehouse exists locally, then this will also lower the delivery time, in addition to delivery costs (Chan et al, 2001; Turban et al, 2006).
• **Enhanced customer service locally:** If a problem arises for the product, then it can be serviced locally. As a result, customers will feel more confident in buying further products.

• **Fewer inventories:** E-business can reduce inventory levels and costs by improving supply chain coordination and creating a better match between supply and demand (Chopra & Meindl, 2003; Turban et al, 2006). For example, Amazon.com requires fewer inventories than local retail bookshops. As a result e-business reduces inventory cost.

• **24-hour access from any location:** Customers are able to place their order any time in a day or night and from any location through the Internet (Chan et al, 2001). Therefore, it is possible for an organisation to increase sales.

• **Maximum profit:** All of the above points have the potential to maximise profit for organisations.

• **Expansion of business:** By working together large organisations have the opportunity to expand their business with the cooperation of SMEs. Thus, SMEs also have the opportunity to share tasks with large organisations (McKay & Marsall 2004)

• **Duplication of work:** Reducing the duplication of work can save both time and money. For example, a pricing strategy for a product can be negotiated electronically, and then can be used for the collaborating organisations.

In summary, factors in conducting e-business can be categorised as general problems associated with the operation of the organisation (finances, pricing strategy
and customer service), and more specific problems in managing the supply chain (lack of information sharing and access, and lack of agreement to work together). To examine the supply chain further in an electronic context, the use of agent-based technology is investigated.

### 8.3 Agent-based Technology

Agent-based technology has emerged as the preferred technology for enabling flexible and dynamic coordination of spatially distributed entities in a supply chain. Authors have defined agents from different perspectives. The main focus of this chapter is a discussion of software intelligent agents, and the definition presented is adapted and based on (Wooldridge & Jennings, 1995). An agent is a computer system that is situated in a particular environment, and is capable of flexible autonomous actions in that environment in order to meet its design objectives. Autonomy is a complicated concept, but it can be simply explained that the system should be able to perform without the direct intervention of humans (or other agents). At the same time, it should have control over its own actions and internal state. The meaning of flexible actions is that the system must be:

- **Responsive**: Agents should be able to perceive their environment, which may include the physical world, a user, a set of agents, or the Internet and can respond timely according to changes that occur in it;

- **Proactive**: Agents cannot only perform based on their environment, but should also be able to exhibit opportunistic, goal-oriented behaviour by taking the initiative according to their intention; and

- **Social**: Agents should be able to interact with one another as humans do, based on their own problem solving ability to help others with their activities, as required.
Therefore, if the above characteristics exist in a single software entity then we can consider it is an intelligent agent that provides the capability of the agent paradigm. This paradigm is different from the software paradigm, for instance object-oriented systems, distributed systems and expert systems. Entities of the software paradigm do not have the capability of learning, proactivity, heuristic problem solving, goal-based action and communication at a time (Wooldridge, 2002). The entities of software paradigm only interact with entities within that software. In addition, objects of the software paradigm encapsulate some state on which their methods can perform actions, particularly the action of invoking another object’s method and an object has control over its behaviour. In this context Wooldridge (2002, p26) recalls the slogan “Objects do it for free; agents do it because they want to”.

**8.3.1 Multi-agent systems**

By using agent-based systems, the key abstraction used is that of an agent. It might be conceptualised in terms of an agent, but implemented without any software structures corresponding to agents at all. A situation exists with an agent-based system, which is designed and implemented in terms of agents. Again, a collection of software tools exist that allow a user to implement software systems as agents, and as societies of cooperating agents.

There is no such thing as a single agent system. Therefore we should always consider the system of agents as a multi-agent system, where the agents will need to interact with each other and cooperate as required. Jennings (1990) illustrates the typical structure of a multi-agent system (see Figure 8.1). The system consists of a collection of agents that are able to interact with each other by communication. The
agents perform their activities in the environment and different agents have different ‘spheres of influence’, and have control over, or at least are able to influence – different parts of the environment. In some cases the spheres of influence may coincide or may require dependency relationships between the agents. For instance, two robotic agents have the ability to move through the door but they may not be able to move through simultaneously. Another example might be ‘power’ relationships, where one agent is the ‘boss’ of another agent.

8.3.2 Dependency Relations in Multi-agent systems

In multi-agent systems, the agents need to be dependent in some way to be able to perform their tasks. The basic idea of such dependency was identified by Sichman and Demazeau (1995) and Sichman (1994) and there are a number of possible dependency relations as follows:

**Independence:** In this case, no dependency exists between the agents.

**Unilateral:** An agent depends on another agent, but not vice versa.

**Mutual:** Both agents depend on each other according to the same goal.

**Reciprocal:** The first agent depends on the other for a goal, while the second agent depends on the first agent for another goal. These two goals may not be same, and mutual dependency implies reciprocal dependence.

The above dependency relations may also be qualified by whether or not they are *locally believed* or *mutually believed*. The locally believed dependency is when the agent believes the dependency exists, but may not believe that the other agent is aware of it. The mutual belief is when one agent believes that the dependency exists and the other agent is aware that this dependency exists. The suppliers, manufacturers, retailers and consumers, are all in a supply chain related network,
which needs proper, efficient and timely coordination, cooperation and negotiation. Therefore, overall benefits will be achieved when applying multi-agent systems to improve efficient performance among these entities.

![Diagram of multi-agent system structure](image)

**Key:**

- ------ organisational relationship
- $\rightarrow$ interaction
- ○ agent

**Figure 8.1 Typical structure of a multi-agent system**  
(adapted from Jennings, 1990).

In summary, the use of a multi-agent system has emerged as a flexible and dynamic method for coordination of spatially distributed entities in a supply chain. Efficient performance is possible between business partners in an online environment through coordination and cooperation.

### 8.4 Definition/Theory of Coordination

We all have a common understanding about coordination and cooperation from our everyday lives. At times we need to coordinate and cooperate with others
for a variety of reasons. When we watch a winning soccer or cricket team or high-quality synchronised swimming, we notice how well the program is organised. In contrast, we could spend hours waiting to return something, or when we thought we had booked an airline ticket that had already been sold, or when a company repeatedly fails to make its expected profit, then we may become very aware of the effects of poor coordination. The Macquarie Dictionary (1998) definition of coordination is as follows:

*the act of working together harmoniously.*

It is essential that an intention to work together ‘harmoniously’ includes handling conflict as well as cooperation.

Malone and Crowston (1990) specified that computer science does not deal primarily with people, however different computational processes must certainly “work together harmoniously,” and as numerous researchers have pointed out, certain kinds of interactions among computational processes resemble interactions among people (for example, Huberman, 1988; Miller and Drexler, 1988; Hewitt, 1986; Fox, 1981; Smith and Davis, 1981). Malone and Crowston’s (1990) observation is not completely correct, due to the fact that software developers implement computational processes according to user requirements. Therefore, it is possible to develop software agents, which will perform coordination tasks for human beings in order to facilitate e-business.

**8.5 Literature Review: Cooperation And Coordination**

Finnie et. al. (2004) proposed a multi-agent architecture for cooperation and negotiation in supply networks (MCNSN), which incorporated a learning capability for some agents, and discusses the issues that need to be addressed for coordination,
cooperation and negotiation. They mainly concentrate on case-based reasoning (CBR) as a framework for learning the best strategy between buyers and suppliers and also focus on customer relationship management (CRM). They did not concentrate on B2B cooperation and coordination.

Beck and Fox (1994) developed the mediated approach to coordinate the supply chain, which has a global perspective and gathers information on commitments from other agents when there is an event disrupting supply. They conducted an experiment, which showed that the mediated approach has a better performance than the negotiation approach. Although the multi-agent approach in SCM has received considerable attention, a number of unresolved questions remain in cooperation and negotiation in supply networks (Schneider & Perry, 2001). A multi-agent system (MAS) was considered by Finnie and Sun (2003) in such a way that only some agents had the CBR capability.

Several reasons have been identified for multiple-agent coordination (Jennings, 1990); (Nwana, 1994):

- **Dependencies between agents’ actions:** Interdependencies occur when goals undertaken by individual agents are related, either because local decisions made by one agent have an impact on the decisions of other community members (selling a commodity depends on a sales person (for customer service) and customer). There is a possibility of a clash amongst the agents (for example, two cars may simultaneously attempt to pass on a narrow road, and as a result there is a risk of a collision). Ultimately, dependencies prevent anarchy or chaos and coordination is necessary among the agents to achieve common goals.

- **Meeting global constraints:** Commonly some global constraints exist that a group of agents must satisfy if they agree to participate. For instance, a system of
agents allocating components to organisations may have constraints of a predefined budget. Similarly, if one organisation fails to sell their products for some reasons, then other organisations can coordinate to minimise the problem.

- **Distributed expertise, resources or information**: All agents may not have the same capability, but have different resources and specialised knowledge in various areas. For example, treating a patient in the hospital requires different types of expertise (anaesthetists, surgeon, heart specialist, neurologist, ambulance personnel, nurse, and so on), resources (equipment like an x-ray machine and ultrasound machine) and information (different reports) to diagnose the patient. In this type of case, it is not possible to work individually. Therefore coordination and cooperation are both necessary to solve the entire problem.

- **Efficiency**: When an individual agent works independently time can be a factor. If another agent helps to finish that work then it can be completed twice as fast. For instance, if two people plant fifty seedlings each, then fifty per cent of the time is saved.

  Nwana (1996) specified that coordination may require cooperation, but it would not necessarily need that cooperation among all agents in order to get coordination. This could result in disjointed behaviour, because for agents to cooperate successfully, they must maintain models of each other as well as develop and maintain models of future interactions. If an agent thinks that other agents are not functioning correctly, then disjointed behaviour may still give a good result. Coordination may be completed without cooperation (Doran et al, 1996). For example, if somebody drives very close towards your lane, you might get out of the path, which coordinates your actions with the other person, without actually...
cooperating. To facilitate coordination agents need to cooperate with others by sending communication messages. This results in agents having the opportunity to know the goals, intentions, outcomes and states of other agents.

In summary, coordination and cooperation are practised daily in physical world transactions, and the notion of creating a similar environment in the virtual world is not a trivial problem. Electronic cooperative problem solving using a multi-agent system is a complex challenge to address.

8.6 Cooperative Problem Solving

In the context of cooperation in multi-agent systems, Franklin and Graesser (1997) offer a cooperation typology (see Figure 8.2) with a number of characteristics. If each agent pursues its own agenda independently of the others, then it is termed an independent multi-agent system. There are two types of independent multi-agent systems: a) discrete, and b) emergent cooperation.

![Multi-Agent Systems Diagram]

**Figure 8.2. Cooperation Typology (adapted from Franklin and Graesser, 1997)**

The discrete system involves agents with agendas that do not have any relation to each another. Therefore, discrete systems do not have any cooperation. Becker et. al. (1994) specified that the puck gathering robots form an independent system, each moving in a straight line until an obstacle is encountered according to its agenda, it
then backs up and goes in another direction. From an observer’s point of view, this puck gathering is an emergent behaviour of the system, as it looks like the agents are working together. However, from the agents’ point of view they are not working together. The agents only carry out their individual tasks.

On the other side of the independent system, is the agent who is cooperating to its own agenda with other agents in the system (cooperative systems). This type of cooperation can be either communicative or non-communicative. Communicative systems intentionally communicate with the other agents by sending and receiving messages or signals. The non-communicative systems are those in which the agents coordinate their cooperative activity by observing and reacting to the behaviour of the other agents. For example, lionesses on a hunt (Franklin, 1996). Intentional communicative systems are divided into two categories, a) deliberative, where agents jointly plan their actions to achieve a particular goal; and such cooperation may, or may not entail coordination; and b) negotiating, where agents act like deliberative systems, except that they have added challenge of competition.

Doran and Palmer (1995) offer a viewpoint that specifies cooperation as a property of the actions of the agents involved. Thus, given a multiple-agent system in which the individuals and the various sub-groups therein may be assigned one or more goals, possibly implicitly, then cooperation occurs when the actions of each agent satisfies either or both of the following conditions:

i) agents have an implicit common goal (cannot be achieved in isolation) and actions tend towards that goal,

ii) agents carry out actions that enable or achieve their own goals, and also the goals of the other agents.
This definition does not require that the goals be explicit within the agents. For instance, two robots carrying a large object jointly, which is an example of the definition of the variant (i) assume that both have the goal of the moving object. If two robots are building two towers separately with different coloured bricks, then if one of the robots finds coloured bricks that matches the other robot, then it passes them to the other robot, which is an example of the variant (ii). Therefore, agent developers need to know the more specific tasks and choices of actions to cooperate and achieve the intended goal.

8.6.1 The Cooperative Problem Solving Process

Wooldridge and Jennings (1999) developed a model that consists of four main stages:

a. recognition – where an agent is identified for potential cooperation;

b. team formation – where the agent applies for assistance;

c. plan formation – where the newly-formed collective agents attempt to prepare a joint contract; and

d. execution – when members of the team play out the roles they have negotiated.

Some questions arise in regard to the above stages:

1. Are the agents performing their task properly?

2. Has an agent left or decommitted in the middle of its task?

3. If it has, then who will complete that task?

4. Who will coordinate these tasks?

Gaps in the cooperation process have been recognised, and the author has identified that two more stages are necessary. The additional stages consist of:
monitoring and post-execution evaluation to support the completion of the cooperation activity. The monitoring stage will provide progress reports of the agents’ tasks, and the evaluation stage will generate the overall result of the cooperative work. These six stages, four identified by Wooldridge and Jennings (1999) and two stages identified by this research are discussed in the following section.

8.6.1.1 Recognition Stage

This stage commences when an agent in a multi-agent environment realises that it has a common goal, and identifies the potential for cooperative action. Reasons for recognition include when an agent thinks that it is not able to complete the goal in isolation, or believes that cooperative actions can achieve that goal. For example, a supplier agent has excess goods in stock, but cannot sell these without the help of proper buyers. Therefore, cooperation is needed to achieve the goal. Alternatively, a large company may be able to achieve its goal but does not want to in isolation. This large company believes that if another company works with them then it would be more beneficial. For example, a small company does not have enough capital to do business properly and a large company does, and wants to expand its business globally. This large company is looking for another company so that it can achieve its goal. Therefore, if the small company and large company work together then the cooperative actions can provide good results for both companies more quickly and more accurately.

In regard to the above situation the authors categorise the agents in the following manner:
**Definition 8.1.** types of the agents

a) *Able agent:* those agents that prefer to work with the group;

b) *Unable agent:* any agent that does not prefer to work with a group; and

c) *Partially able agent:* those agents that prefer to cooperate and commence to do work, but cannot complete the task.

If an agent has the ability to do the task in the environment then it is favourable to complete the task.

**Definition 8.2.** An Able agent finishes its task if and only if the environment (En) is favourable, which can expressed from the definition as:

\[ \text{Able}_{ag} \text{ Favourable En} \rightarrow \text{Achieve goal} \]

**Example.** Assume that an agent is going to do its task, which is possible if its surrounding environment is favourable to complete its task. Consequently, because this agent has the ability to complete its task, it can complete it successfully. In the case of an Unable agent we can introduce the following theorem:

**Definition 8.3.** An Unable agent cannot finish its task even if its environment (En) is favourable, can be expressed:

\[ \text{Unable}_{ag} \text{ Favourable En} \rightarrow \neg \text{Achieve goal} \]

In regards to cooperation, a set of able agents will complete their task.

**Definition 8.4.** A set of able agents finish their tasks if and only if the environment (En) is favourable can formalised as:

\[ \text{Able ag, Favourable En} \rightarrow \text{Achieve goal} \]
**Definition 8.5.** A set of able agents cannot finish their tasks although the environment (\(En\)) is favourable can formalised as:

\[\text{Unable agi, Favourable En} \rightarrow \neg \text{Achieve goal}\]

Therefore, it has been identified that agents are able and unable to have the potential for cooperative work. Then it needs to go to the next stage of cooperation process.

### 8.6.1.2 Team Formation Stage

After an agent identifies the potential for cooperative action with respect to one of its goal, what will the rational agent do? Wooldridge and Jennings (1999) proposed that an agent will attempt to *solicit assistance* from a group of agents that it believes can achieve the goal. If the agents are successful, then each member has a nominal commitment to collective action to achieve the goal. The agents have not undertaken any joint action in this stage, they are only aware of being able to act together. Actually, in this stage there is no guarantee for successful forming of the team; only an attempt to form a team. The able agents will attempt to do some action \(\alpha\) to achieve at least some goal. Therefore it can be formalised as:

**Definition 8.6.** Happens\{Attempt Able ag, \(\alpha\}\} \rightarrow \text{Achieve goal}

The characteristics of the team building can assume that it is mutually believed that:

1. the group can jointly achieve the goal;
2. each agent in the group is individually committed to carry out its task towards the goal or failing that, to at least cause the group to achieve the goal;
3. the individual agent has an individual goal; and
4. there is a common goal which is jointly achievable.
The main assumption about team formation is that all agents attempt to form a group, and the group believes that they will have individual commitments and can jointly complete their task. If team building is successful then it will proceeds to the next step.

**8.6.1.3 Plan Formation Stage**

In this stage, after successfully attempting to solicit assistance, a group of agents have nominal commitment to collective action. This action will not be commenced until the group agrees on what they will actually do.

From the previous section, the authors have found that to perform collective action, it is assumed that the agents have a common belief that they can achieve their desired goal. The agents believe that there is at least one action known to the group, which will take them ‘closer’ to the goal. Therefore, the possibility is many agents that know the actions of the group carry out the task in order to take them closer to the goal. In addition, in some cases it is also possible in collective actions that some agents may not agree with one or more of these actions (Doran et al, 1996). Furthermore, in collective actions, agents will not simply perform an action because another agent wants them to (Wooldridge & Jennings, 1995). Therefore it is necessary for the collective to make some agreement about what exactly needs to be done (Wooldridge & Jennings, 1999). This agreement is reached via **negotiation**.

Negotiation has long been recognised as a process of some multi-agent systems (Rosenschein & Zlotkin, 1994; Sycara, 1989). At the time of negotiation, the agents usually make reasoning arguments for and against particular courses of action, making proposals, counter proposals, suggesting modifications or amendments to plans. These continue until all the negotiators have agreed upon the final result.
Negotiation is also an extremely complex issue. But in the case of joint negotiation it is a bit simpler than self-interested individual agents.

In negotiating a plan, collective negotiation may also abort due to irrelevant circumstances. The minimum requirement to occur for negotiation is that \textit{at least one} agent will propose a course of action, which is believed will take the collective closer to the goal. Therefore, negotiation may also be successful. Like team formation we assume a group of agents also attempts to do something collectively. A group of agents, \( g \) attempt to achieve a goal after performing mutual actions \( \alpha \) which is completely or partially satisfied and can be formalised as:

\[
\{\text{Attempt } g \alpha\} \rightarrow ?; \text{Achieve goal}
\]

The minimum condition to occur in negotiation is that the group will try to bring about a state in which all agents agree to a common plan, and intends to act on it. The author assumes that if any agent shows its preference then it will attempt to bring this plan about. Similarly, if the plan has any objection, then it will attempt to prevent this plan being carried out. In this way the agents will agree on a plan to carry out their actions. If the plan formation stage is successful then the team will have a full commitment to the joint goal and will proceed to execution phase.

\textbf{8.6.1.4 Execution Stage}

When the agents have a collective plan to do something, then they are ready to move to this phase, as the group knows what to do (Wooldridge & Jennings 1999). That is, each agent has its own target and the group has its intention to perform actions to achieve the goal. The group mutually believes that the action they intend to perform in order to achieve goal can actually happen.
8.6.1.5 Monitoring Stage

How do we know that all the agents are performing their tasks according to the plans? What if an agent is unable to complete its task in the middle of the plan? Who will take this responsibility or, will another agent perform this task? How will it be solved? For these reasons the authors identified that it is necessary to have a monitoring phase when the execution stage is carried out. An agent will need to monitor the execution phase then if something unusual occurs, it can be solved accordingly. For example, if an agent cannot finish its task, then the monitoring agent will request another agent to complete this task and the agent who could not finish its task it can be defined as partially able agent.

8.6.1.6 Evaluation Stage

This research identified some additional questions:

1. Which agent completed its task?
2. Which agent did not complete its task?
3. Which agent partially completed its task?
4. Which agents did extra tasks?
5. How do we know which agent performed what action?

Therefore, the author recognises that it is also necessary to evaluate the Execution Stage, by using an agent to evaluate and allocate reward benefits. Note that, without proper cooperation, task decomposition and task accomplishment will not be successfully achieved. For this reason, it needs good cooperation to decompose and accomplish tasks and then needs to allocate to the agents who are intended to work together. Therefore, all participating agents require cordial
cooperation when they complete their tasks and if they cannot complete their tasks then they need to notify the evaluating agent immediately. Thereafter, the evaluating agent will allocate that uncompleted tasks to other agents who can accomplish the task accordingly. Therefore, from this evaluation, processes can be improved or updated according to necessity. After this stage the agent can go back to the first stage to begin a new cooperative work. Therefore, the additional stages can be considered as *enhanced and effective cooperative stages* as depicted in Figure 8.3.

![Enhanced and Effective Cooperative Processing Stages](image)

**Figure 8.3. Enhanced and Effective Cooperative Processing Stages**

In summary, the model developed by Wooldridge and Jennings (1999) has been extended by this research to include two more stages, the Monitoring Stage and the Evaluation Stage. The new model shown in Figure 8.3 is applied to the TAC SCM game as a case study to investigate its potential performance.
8.7 Product Market Performance

As we know, a pure competitor or monopolist can simply choose its price or output policy and directly calculate the resulting gain or loss. In an oligopoly market setting, the choice of a price, output, or other marketing policy does not uniquely determine profit, because the outcome for each firm depends on what its opponents decide to do. The Cournot and Chamberlin descriptions of oligopoly suggest the kind of interdependence that arises explicitly here, but do not take into account uncertainty about opponent’s decisions (Meyer, 1976).

The market price of PCs for all the agents depends on the quantity they produce. This means that the profit for each agent is linked directly to the profit of the other. Consequently, different agents have their own cost functions, which imply different payments for inputs. Therefore each agent has its own policy to bid for a customer order, which it will enhance to win the bid.

The PC market is another vital part of TAC SCM in which agents are directly involved in winning. In the TAC SCM competition, the author recognises the following critical questions to resolve or improve the agents’ performance as price competition:

- *How does the agent bid for a customer’s reserve price for a PC.*
- *What strategies need to be adopted for this?*
- *How much does the agent need to reduce the price to win the bid?*

To improve the performance of the agent, it is necessary to learn from the history of game. For example, Figure 8.4 presents the average price of PC of the competition. The agents can learn from the chart when the market price of PCs are high, medium and low. Equilibrium prices arise when supply equals demand: \( Q^i_s = Q^d_i \) for product \( i \). If \( Q^i_s \geq Q^d_i \), agents will bid price \( p_i \) lower; if \( Q^i_s \leq Q^d_i \), agents
will bid price $P_i$ higher. Usually the price of the product increases at the beginning of game due to lack of supplies. Therefore the agents who supply the product at the time of low market supply can get a higher price, and as a result can earn more market share with more profit. Consequently, the agent who can adopt this strategy of increased productivity and bids according to the market situation will have a better opportunity to maximise profit.

![Average Price of PC of the game: 942(blue line), 943(yellow), 944(magenta) and 945(Cyan)](image)

*Figure 8.4. Market price of PC of the game 942 – 945*

The author analysed the product market of the TAC SCM 2004 game and observes the lack of cooperation among agents involved in component purchasing and product selling. The average market demand for PCs in the semi-final and final round game can be depicted in Tables 8.1 and 8.2, where the second column is the average PCs delivered by the agents; the third column is the total average market demand. The author subsequently finds that the free agent bids on an average with a higher average price and a higher percentage of orders.
Table 8.1. Average Total PCs delivered in Semi-Final of Gr-1 (TAC3 and TAC4)

<table>
<thead>
<tr>
<th>Agents</th>
<th>Average Delivery</th>
<th>Total Average Price</th>
<th>% of Order</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>FreeAgent</td>
<td>46882</td>
<td>291505</td>
<td>16</td>
<td>1656</td>
</tr>
<tr>
<td>SouthamptonSCM</td>
<td>61759</td>
<td>21</td>
<td>1508</td>
<td></td>
</tr>
<tr>
<td>Mr. UMBC</td>
<td>51587</td>
<td>18</td>
<td>1527</td>
<td></td>
</tr>
<tr>
<td>ScrAgent</td>
<td>40995</td>
<td>14</td>
<td>1504</td>
<td></td>
</tr>
<tr>
<td>KrokodilAgent</td>
<td>41551</td>
<td>14</td>
<td>1538</td>
<td></td>
</tr>
<tr>
<td>Socrates</td>
<td>48732</td>
<td>17</td>
<td>1323</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.2. Average Total PCs Ordered by agents in Final Round

<table>
<thead>
<tr>
<th>Agents</th>
<th>Average PC Delivery</th>
<th>Total Average Market Demand</th>
<th>% of Order Price</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>FreeAgent</td>
<td>41659</td>
<td>201227</td>
<td>21</td>
<td>1842</td>
</tr>
<tr>
<td>SouthamptonSCM</td>
<td>45465</td>
<td>23</td>
<td>1670</td>
<td></td>
</tr>
<tr>
<td>Mr. UMBC</td>
<td>44665</td>
<td>22</td>
<td>1481</td>
<td></td>
</tr>
<tr>
<td>ScrAgent</td>
<td>13765</td>
<td>7</td>
<td>1434</td>
<td></td>
</tr>
<tr>
<td>KrokodilAgent</td>
<td>24487</td>
<td>12</td>
<td>1869</td>
<td></td>
</tr>
<tr>
<td>Socrates</td>
<td>31186</td>
<td>15</td>
<td>1764</td>
<td></td>
</tr>
</tbody>
</table>

In summary, the TAC SCM has a distinct lack of cooperation among the agents involved in component purchasing and product selling, and this led the authors to conclude that the game was a likely case study to investigate modelling coordination and cooperation.

8.8 Modelling Coordination and Cooperation of TAC SCM

According to the TAC SCM, all manufacturer agents are rational or self-interested and their main focus is to maximise profit. If we assume that the agents cannot achieve their goal in isolation or that they would prefer to work with each other, then this has the potential for cooperation. In this context, all the manufacturer agents can work together towards their goal. Subsequently, manufacturer agents will be able to increase their production capacity and sell the final products to customers. Then, suppliers will benefit by supplying more components to the manufacturers,
which will result in more profit. The following discussion proposes a theoretical model, which will be able to solve the coordination and cooperation problem of the TAC SCM game.

The author has found in the TAC SCM competition that three or four agents always dominate the market of buying components or selling the products (Keller et al, 2004). Therefore, this research characterised these agents as big agents and the other agents as small/medium agents (SMAs). Again, it was also found that SMAs could not purchase enough share of the components to produce a final product to sell. This is a technical/strategic or financial problem for the SMAs.

Consequently, if the SMAs purchase components from big agents and sell to customers, then it is possible to survive. Otherwise, the SMAs cannot compete with the big agents. In the real world, usually the intention of large organisations is to extend their business and make more profit. This increases production which ultimately leads to increased profit. Using this strategy, we assume that big agents want to extend their business, and at the same time, the SMAs would like to work with big agents. This way big agents and SMAs can work together to achieve their common goals. As a result, every agent will be benefited by participating in shared activities. Therefore, to work together the agents need to follow the stages defined in the previous section, Cooperative Problem Solving Process. In this regard the following characteristics can be defined as (see the agent types in Definition 1 of the Recognition Stage of the Cooperative Problem Solving Process):

**Definition 8.7.**

a) There exist some group of agents $g$ such that the individual agent $i$ believes that the $g$ can jointly achieve goal; and either:
b) an agent $i$ cannot achieve goal individually; or

c) an agent $i$ believes for every action that could be performed to achieve the task, it

has a goal of not performing the goal.

**Definition 8.8.** The outcomes ensure their profit, if and only if the *cooperative agents* complete their task successfully.

If the *cooperative agents* complete their task successfully then all the participating agents will share the profit, otherwise it will be considered an incomplete task.

**Definition 8.9.** The *cooperative agents* are those if, and only if, they agree to work together.

In the Cooperative Processing Stage, only those *able agents* that are determined to complete their tasks towards a common goal are considered *cooperative agents*.

A *decommitted agent* is an agent that started its task but did not complete that task, and therefore needs to be penalised.

**Definition 8.10.** Let a set of *able agents* that share their work to achieve a common goal be called *cooperative agents*, which is as follows:

$$ag_i \in A = \{ ag_1, ag_2, \ldots, ag_n \} = \phi$$  \hspace{1cm} (8.1)
**Definition 8.11.** The accumulated task of the cooperative agents $A$, the utility $u$ of that task can be considered as unique, and can be expressed as:

$$u(A) = \sum_{i=1}^{n} A_i = n \quad (8.2)$$

**Definition 8.12.** Profit allocation to the agents: The percentage of the utility of each agent can be worked out according to the contribution of each agent, which can be expressed as:

$$u(ag_i) = \frac{u(ag_i) \times 100}{u(A)} \quad (8.3)$$

**Definition 8.13.** Cooperative action takeover: If any agent fails to complete its task then other agents will need to complete that task to achieve the goal.

If any agent is unable to finish its allocated tasks due to unavoidable circumstances then in this case the other agents will take over that unfinished task enthusiastically to achieve the goal.

**Definition 8.14.** The set of cooperative agents $A$, are a finite set and said to be bounded.

The cooperative agents must be limited in number for efficiency in task allocation, as it is not possible to have an unlimited number of agents working together. The cooperative agents are bounded, for instance: a) the agent who invests or sells the greatest is called the upper bounded; and b) the agent who invests or sells the lowest is called the lower bounded.
8.9 Architecture of the cooperative processing agents

Let us consider that a number of companies in different locations have agreed to sell some products to customers within a limited timeframe. Assume that the agents are going to work together according to the Cooperative Processing Stages. A proposition for architecture of effective cooperative processing is shown in Figure 8.5. In this figure, there is a collection of manufacturer agents $n$ in the domain. When these agents have agreed to perform tasks to achieve a specific goal, then to complete the cooperative processing other agents are needed. The author argues that these agents are: Task Allocation Agent, Monitoring Agent, Evaluating Agent, Result Allocation Agent and Coordination Manager Agent (CoManager).

![Figure 8.5. Architecture of effective cooperation model]

When a problem is decomposed into smaller sub-problems, then the Task Allocation Agent is responsible for allocating tasks to the able agents in order to achieve the goal. The Monitoring Agent is responsible for monitoring the
performance of the agents’ tasks, that is, which agent is doing its task and which is not. Finally, this agent will produce a report to the CoManager Agent. According to this report the CoManager Agent will reallocate the unfinished task to the agent that is willing to undertake that task.

The Evaluating Agent will evaluate all tasks from the Monitoring Agent. The Evaluating Agent will provide analytical and objective feedback on efficiency, effectiveness of the performance of agents. Finally, it will produce an overall final report including benefits of each agent to the Result Allocation Agent. Eventually, this final report allows the agents to learn lessons. The Result Allocation Agent then processes the benefits deserved by each agent, and finally produces a benefit report to the agents.

The contribution made by this research is the addition of the monitoring and evaluation stages for the Cooperative Problem Solving Process, and the results described in this section. The TAC SCM was used as a case study to illustrate the concepts outlined in the theorems and definitions.

8.10 Future Trends

As the projected growth of B2B e-commerce is growing faster (see detail in Figure1.1 at Chapter 1), so, we can predict that the growing trend in e-business utilisation will increase into the future. As described in the previous sections both large organisations and SMEs will be able to work together to conduct e-business on a global basis. In regards to implementing cooperative work utilising multi-agent systems, the agents need to follow the stages defined in this chapter. As a result, all the participant organisations will benefit in overall performance outcomes. In conclusion, the author argues that team effort, rather than individual effort, will give
more robust and sustainable results. The cooperation and coordination protocol, and information sharing among various agents can be future research areas, which will facilitate in building the software that enables coordination and cooperation activities.

8.11 Conclusion

This chapter identifies problems in conducting e-business and managing the supply chain. It also identifies expected benefits for supply chains with agents working together in coordinated and cooperative processes. The utilisation of a multi-agent system in supply chain management and the Cooperative Problem Solving Stages are presented and discussed. To apply these stages the proposition for architecture of effective cooperative processing for agents, and some characteristics in modelling coordination and cooperation for TAC SCM are outlined. The ultimate goal is to develop the capability of organisations to work effectively together in online e-business transactions. In addition to this, large organisations can expand their businesses, and SMEs can work with large organisations. Finally, time for selling and buying activities can be reduced, and increase the total profits of the supply chain. In addition, it will facilitate the ability to cooperate and coordinate among multi-agents in e-commerce. Further, customer satisfaction can be enhanced and streamline B2B transactions by reducing transaction costs of tasks at every stage of the supply chain. Therefore, trust and confidence will be increase in the component market and product market.

The next chapter provides the overall discussion of this research and its implications that also includes recommendations and limitations.
CHAPTER 9

Discussion and Implication of Research Outcomes

9.1 Introduction

This concluding chapter discusses the contributions made by the research detailed in this thesis. Recommendations and limitations of the research are also discussed. The studies of this research were undertaken based on the broad question identified: How can the negotiation process in business-to-business (B2B) transactions be formulated and applied in multi-agent based e-business? A negotiation mechanism comprises of space, protocol, and strategies. It is also realised that cooperation and coordination will enhance and facilitate negotiation in some circumstances. Therefore, this research investigated the negotiation protocol, strategies and coordination and cooperation model as applied to the negotiation mechanism.

In the real world, the negotiation process is one of the most complicated and time consuming processes. To conduct negotiation in multi-agent based electronic business, a more flexible approach is needed to allow implementation in an electronic environment. Certainly, ‘Simplicity’ is one of the most essential criteria for automated systems. Therefore, to simplify the automated negotiation process, the contributions of this research include:

a) A non-monotonic negotiation protocol and extended and flexible iterated negotiation process. This will ultimately fabricate the system so uncomplicated that
businesses will be attracted to these automated facilities. Furthermore, it will also be sustainable for future generations due to its simplicity.

b) *Negotiation strategies in which agents will be able to find what strategy will be best* in making an agreement by following the negotiation mechanism (that is, an overall negotiation system or method).

c) *Some theoretical solutions developed*, such as theories and definitions to understand the complex issues regarding the negotiation mechanism. These will also be of benefit to academics and practitioners for their teaching and learning process, and for practice in general. Meyer (1976, p.6) commented, “Empirical observation, theories, and predictions are ways of enhancing our knowledge and improving decision making….”. In 2004, M. J. Osborne noted that “…if a model enhances our understanding of the world, and then it serves its purpose” (p. 7)

The following section discusses the overall results of the research findings in detail.

**9.2 Discussion of contributions**

To implement automated negotiation in multi-agent based e-business, firstly the protocol that should be followed needs to be discovered. If we want to implement a bargaining process, involving interaction with offers and counter-offers, into the TAC SCM then we need to use a non-monotonic protocol. This is because, in a dynamic situation it is not possible to use a monotonic protocol as the agents are not allowed to offer higher than a previous offer. The reason for this is that the prices of the components depend on the availability and production of the components. Figure 9.1 depicts the average price for some of the game of TAC SCM on a daily basis. The
author found that the price varies every day. Therefore, it makes more sense to implement a non-monotonic protocol for automated negotiation in electronic business.

Even though a non-monotonic protocol facilitates uncertain situations, it will also enhance the agreement-binding rate due to the flexible price of components. Consequently, the negotiation process will end quickly with the binding of an agreement or aborting of the negotiation process.

![Figure 9.1. Market price of PC of the game 942 – 945](image)

(Note: Figure 8.4 is reproduced here for easy reference and discussion)

According to the theoretical result of the non-monotonic protocol, the price will be either lower or higher than a previous offer price, which is due to the availability and production of the components. This protocol can be used in any bargaining procedures in multi-agent based e-business. This situation is very much similar to real world business, which can be implemented in the software world to make it effortless and
sustainable. The comparison between monotonic and non-monotonic protocols is highlighted in Table 9.1.

**Table 9.1 Comparison of monotonic protocol and non-monotonic protocol**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Monotonic protocol</th>
<th>Non-monotonic protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seller’s offer</td>
<td>High to decreasing trend to expected value (up to reserved price)</td>
<td>No decreasing or increasing trend. Price is determined on the basis of seller pricing formula</td>
</tr>
<tr>
<td>Buyer’s offer</td>
<td>Counter-offer should be less than seller’s offer</td>
<td>Counter-offer must be less than seller’s offer but this offer varies from a monotonic protocol as different times can have different offers.</td>
</tr>
<tr>
<td>Offer trend</td>
<td>Agents are not allowed to offer greater than the last offer. For instance if a seller agent offers $10.00 for a good, the buyer agent can Co-offer $6.00 which is lower than seller’s offer.</td>
<td>No restriction</td>
</tr>
<tr>
<td>Price assurance</td>
<td>Ensures lower price</td>
<td>Do not ensures either lower or higher price which becomes uncertain</td>
</tr>
<tr>
<td>Produced line in a graph</td>
<td>Produce linear line</td>
<td>Produce non-linear line</td>
</tr>
</tbody>
</table>

The proposed definitions and theorems (in chapter 5) will be helpful to utilise the protocol as it makes it clear to understand.

The existing protocol of the TAC SCM game only provides fixed priced components. In this game, the manufacturing agents do not have any alternative options to purchase these components; they can only take it or leave it. To facilitate alternative options this research developed the *extended and flexible iterated negotiation processes for TAC SCM*. This will allow time to think and judge the situation when moving
towards binding an agreement, aborting the negotiation process, or waiting for a future time when agents can again enter into the same negotiation process. As a result, this process will diminish the total negotiation time, rather than entering into a new negotiation process. This process can be used in any electronic market to conduct an automated negotiation process. Finally, this iterated process will provide an efficient, economic and effective negotiation process in which business organisations will be attracted to enter into, and thereby avoid complex processes.

In addition to this, it is possible to generate economic business processes by implementing the extended and flexible iterated negotiation process. Because agents are all individually rational, that is, self interested, then the agents cannot be forced to participate in the negotiation process. If agents find they have an opportunity, then it will attract more agents to participate. More participation will enhance the negotiation process. As a result, it will increase the agreement-binding rate.

The negotiation mechanism is a very complex issue particularly in the case of business-to-business (B2B) transactions. The following features need to be concentrated on to implement sustainable digital negotiation mechanism on a “long term” basis in an electronic B2B transaction:

- The order,
- Satisfied customers,
- Long-term relationships,
- Repeat business, and
- Strong referrals.
The implementation of a negotiation mechanism in an automated environment needs to establish all of these features on behalf of business organisations. Furthermore, the strategies that need to be applied should be flexible and iterated to enhance the negotiation rate. In relation to this, the following questions arise:

1. Does the agent really want to negotiate?
2. How much will each agent need to concede to make an agreement?
3. How do both agents proceed to negotiate?
4. What are the reasonable steps that need to be followed by each agent?

To address these questions, each agent will need to consider the desired amount of payoff in which the agent will guarantee the maximum of the minimum payoff, or the minimum of the maximum payoff. Therefore if both agents adopt this strategy at the time of negotiation then it will enhance the binding of an agreement.

In relation to the issue of cooperation and coordination, which includes buying, selling, servicing, an obvious problem arises that is reaching agreement in a society of self-interested agents. We all reside in a society (as in a multi-agent world) where every day we need to cooperate, coordinate, and finally reach agreements when moving towards some kind of negotiation with others. This reaching agreement may be complex, as participants may not share common goals. Sometimes we may only be interested in profit at the expense of our opponents, or alternatively we may be interested in mutually beneficial outcomes where common interests exist. The ability to reach agreements (which will not be dictated by the intervention of a third party) is a fundamental capability of intelligent autonomous agents. In the absence of this capability, it is
impossible to function as an electronic society to perform tasks effectively. In reaching agreements, negotiation is the central issue to the ability of potential agents.

The supply chain consists of a number of intelligent software agents in which agents are required to coordinate, cooperate and negotiate with each other, typically by exchanging messages through some computer network infrastructure. These types of integrated operations in an electronic environment are termed multi-agent systems. In most of the general cases, the agents in a multi-agent system will be representing, or acting on behalf of, users or owners who have a variety of goals and motivations. To interact successfully, these agents will require the ability to cooperate, coordinate and negotiate with each other, in much the same way that we cooperate, coordinate, and negotiate with other people in our everyday lives (Wooldridge, 2002). In a multi-agent system (MAS), negotiation does not have sufficient support for a ‘binding agreement’. The meaning of the ‘binding agreement’ is when one or more agents jointly search a space for a possible solution through interaction with the goal of reaching consensus.

In the game theoretical model, it is assumed that the players are perfectly rational, that is, self-interested and this rationality is common knowledge. Consequently, game theory does not need to apply to human behaviours, since in practice humans do not always behave as the theory suggests (Roth, 1995). Therefore, if a software agent is rational then it will always find its maximum utility or profit. But in real life, humans are not always rational and can be changeable according to the situation. Generally, businesses also follow this to ensure their existence. According to this assumption, agents can also follow this at the time of the negotiation process. Thus agents can find the equilibrium strategy from the analysis of their offers and counter-offers in the negotiation process.
If we can develop an environment in which the agents can make offers and counter-offers moving towards a negotiation process, then they will be able to find the most feasible strategies for making decisions to reach agreements. This research simulated this type of mechanism to discover the points in which the agents can choose the best strategy to make a decision towards negotiation, just as we do in real life when negotiating something. This research identified a *reasonable positive intention* of agents in the negotiation strategy. If each agent adopts this reasonable positive intention then they will be able to reach an agreement for their intended deal.

The reasonable position intention works in the following ways. If the system has a type of environment where agents can make offers and counter-offers and after some time they can find a possible deal, that is, can find Nash equilibrium (NE) points, then they can make an agreement at that point. Otherwise, they can make an agreement on the most conservative points, that is, if both agents have maximum of minimum utility, then they can make an agreement easily with low utility, which will guarantee the satisfaction of both sides. As with the maxmin principle, the agent can ensure its maximum of minimum utility. For this reason, the agents will not loose anything. According to this principle, various definitions and theory are introduced in Chapter 4. These definitions and theory increase knowledge for academics, practitioners, and application programmers and will be applicable in the software world.

Now return to the features for a “long term” basis that are identified above. Here long term means an integrated outcome of the above defined features. These features are:
a) suppliers always expect reasonable orders from customers (the manufacturers);

b) customers must be satisfied with the suppliers and as a result good long term relationships will be developed among suppliers and their customers;

c) selling and procurement of parts/components will increase accordingly, that is, repeated business will develop; and

d) ultimately, all these features will work as an excellent reference to other buyers.

Generally, the supplier organisations expect frequent orders from their customer organisations, that is, the manufacturer agent. If both organisations adopt the positive intention strategy, that is, to take the maximum of their minimum of each action then they can easily reach the agreement towards negotiation. This maximum of the minimum strategy will satisfy both the organisations, and at the same time, it will lead to establishing good and long-term relationships. Moreover, the organisations will attract repeated business and will bring strong referrals from other organisations.

In addition to the above, let us answer the predefined questions of the intention of agents to negotiate, how much each agent will-concede, how they proceed to negotiate and the reasonable steps to be followed by each agent. If agents want to enter into the negotiation process then those agents firstly need a positive intention; otherwise they cannot make any agreement binding. Secondly, the agents can adopt strategies from defined simulation learning and steps to reach the agreement for negotiation.
Furthermore, these problems can be solved by utilising a non-monotonic negotiation process, and extended and flexible iterated negotiation process.

Another problem was identified in the TAC SCM game that involved how the agents would select which offer is best to reach an agreement. In this uncertain situation, a negotiation strategy is the main issue to reach an agreement. This research measured and analysed the negotiation strategy in the TAC SCM by fuzzy logic using possibility theory and a linguistic variable, which will aid in binding the agreement to achieve the agent’s expected profit. Theoretical solutions were developed such as definitions and setting a term set that would solve the problem involving uncertainty. These will make strategies uncomplicated and easier to reach an agreement from the negotiation process. Generally, systems need to develop in straightforward ways, rather than more complex ways of doing things. Subsequently, setting a term set will be suitable for any type of negotiation mechanism in e-commerce especially where the situation is completely uncertain. Electronic business transactions along the supply chain can benefit from adopting strategies that automate the process of negotiation and lead to an acceptable agreement. In addition, automated negotiations based on fuzzy logic can reduce costs and increase economic benefit, and therefore contribute to competitive advantage in a global environment.

An alternating offers bargaining model has been used for computationally limited negotiations (Larson and Sandholm, 2002; Kraus, 1996). It has been reported that the equilibrium strategies for the model results in a single shot take-it or leave-it strategy. The agents wait without exchanging offers until one of the agent’s deadlines arrives and then the agent with the earlier deadline concedes and makes an offer that the other agent may accept. This limited negotiation can be extended and enhanced for
iterative negotiation until agreement reached. An extended bilateral negotiation model is
developed, which is an extension of OMG (1999). In addition, State Diagram models
involving offers and counter-offers in the negotiation process have also been developed
in this research. These models will be useful to understand how an agent performs a task
by making offers and counter-offers in the negotiation process. The models will also be
useful to develop a negotiation mechanism in an electronic environment for the future
generation.

When negotiation fails then the agents can coordinate and cooperate with each
other to work together to achieve maximum profit. As for example in the final round of
the TAC SCM game (2003 and 2004) most of the agents earned negative results due to
high price of components. A few agents received positive results. Therefore, if agents
can cooperate and coordinate then they can achieve positive results. In relation to this,
an extended model, enhanced and effective cooperative processing stages is developed
based on the model by Wooldridge and Jennings (1999). The extended model can be
utilised in the TAC SCM and agents can cooperate with each other to have a positive
result. In addition, each agent can gain an appropriate benefit from cooperation.
Subsequently, large organisations and small to medium organisations can work together
by applying the enhanced and effective cooperative processing stages. In addition to
this, architecture of effective cooperation model has developed for TAC SCM.

The model developed for coordination and cooperation can improve the TAC
SCM game. It is not only to improve TAC SCM, but also to improve any type of
business process, which involves cooperation and coordination. Osborne (2004, p. 2)
argued that models cannot be judged by an absolute criterion: they are neither “right”
nor “wrong”. Whether a model is useful or not depends, in part, on the purpose for which it is used. The reason for improving our understanding of the world is to enhance out the ability to mould it to our desires.

Generally, the procedure makes negotiation a time-consuming process. Sandholm (2000) argued that the software agents not only save labour time of human negotiators, they can also find solutions that are as beneficial as possible for all parties. Therefore, negotiation in an electronic environment will increase the overall efficiency of negotiations through the assistance and automation of decision-making tasks. Finally, the results will be able to reduce the complexity and uncertainty of traditional decisions, total cost, and time for negotiation. It can also provide more flexible options, and facilitates transparency that will attract more efficient agreements which leads to negotiation.

Finally, the dynamic system will act as a catalyst for the business community. Subsequently it will create a stable situation for binding agreements based on negotiations. Development of the flexible iterated negotiation process will be one of the achievements of automated negotiation process.

9.3 Summary of research

The research outcomes are achieved from the analysis of Game Theory, Decision Theory, and Fuzzy logic. In addition some of the analysis was undertaken by using TAC SCM as a case study. The overall outcomes are based on theoretical analysis that contains theory, definitions, and some models.
Firstly this research analysed the negotiation mechanism with the combination of game theory with the concept of Nash equilibrium, and a maxmin/minmax strategy. Agents can adopt this mechanism to find feasible strategies for reaching agreements. This means that the agents will not always look for their maximum utility. The author assumed the maxmin/minmax strategy in the negotiation process will enhance the agreement-binding rate among agents and proposed it by using a *reasonable positive intention approach* of agents when moving towards negotiation. It is also assumed that the adoption of the strategy will ensure that the agents have positive intention behaviour.

Secondly, this research developed a non-monotonic negotiation protocol, which will provide for up and down trends for pricing offers. Ultimately this protocol will end quickly and that will enhance either binding an agreement or aborting the negotiation process.

Thirdly, an extended and flexible iterated negotiation process is developed where the agents will have an opportunity to reach agreements in the future. That means if the agents cannot currently make any agreement, then they will be able to enter into the same negotiation process in future rather than entering into a new negotiation process. As a result, they can save their total time and also can avoid complex process.

Fourthly, fuzzy logic was used to solve some decision making problems that are involved in uncertain situations. This study analysed the strategy measurement by using possibility theory. Setting a term set will be useful to binding an agreement in uncertain situations. Various definitions are developed, which will make it easier to understand the system.

An enhanced and extended bargaining model is developed based on OMG (1999) with the help of a State Chart model. A RFQ offering and counter-offering State
Diagram is also developed. These State Diagram models provide a clear understanding of the activities of the bargaining situation.

Finally, this research developed an extended and enhanced cooperation processing model and architecture of that model that can be used in TAC SCM. It is assumed that this model will facilitate the overall negotiation mechanism, or when the present system fails to negotiate. The following section outlines the contribution to new knowledge including relevant chapters.

9.3.1 Contribution to new knowledge

The main research question is: How can the negotiation process in business-to-business (B2B) transactions be formulated and applied in multi-agent based e-business?, and related sub-questions are as follows:

1. What protocols and strategies are needed for the negotiation process?
2. What is the way that makes agents enter into negotiation process, which will reduce cost and time?
3. What bargaining procedure can be followed?
4. How would a coordination and cooperation model be developed, which will facilitate the negotiation process in multi-agent based e-commerce?

Therefore, based on the above sub-questions, the outcomes of this research that addressed the main research question include the development of:

a) Answers for sub-questions 1 and 2 are as follows:
   - definitions and theory to formulate negotiation strategies with a positive intention.
• a negotiation protocol from monotonic to non-monotonic.
• an extended and flexible iterated negotiation process.
• definitions for negotiation strategies using a linguistic variable as fuzzy logic.

b) Answers for sub-questions 2, 3 and 4 are as follows:
• an enhanced bargaining model to assist the bargaining operation in a negotiation mechanism.
• coordination and cooperation model for B2B transactions in multi-agent e-commerce.

It is noted that most of the above outcomes provide the answer to sub-question 2, which is that the ultimate result is to reduce cost and time.

The research contributions include in the chapters is listed in the Table 9.2.

Table 9.2 Research contribution in relation to chapter

<table>
<thead>
<tr>
<th>No.</th>
<th>Summary</th>
<th>Related Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Developed some definitions and theory to formulate negotiation strategies with a positive intention</td>
<td>Chapter 4. Negotiation Analysis by Decision theory and Game theory</td>
</tr>
<tr>
<td>2</td>
<td>Developed negotiation protocol from monotonic to non-monotonic.</td>
<td>Chapter 5. Negotiation Analysis based on Trading Agent Competition Supply Chain Management (TAC/SCM)</td>
</tr>
<tr>
<td>3</td>
<td>Extended and flexible iterated negotiation process</td>
<td>Chapter 5. Negotiation Analysis based on Trading Agent Competition Supply Chain Management (TAC/SCM)</td>
</tr>
<tr>
<td>4</td>
<td>Developed definitions for negotiation strategies using linguistic variable as fuzzy logic</td>
<td>Chapter 6. Negotiation Analysis based on Fuzzy Logic on (TAC/SCM)</td>
</tr>
</tbody>
</table>
In summary, the research outcomes will facilitate electronic negotiation, coordination, and cooperation within the supply chain especially in B2B transactions that involves multi-agent systems, and enable more complex e-business transactions using the defined outcomes.

The Interpretive Research Philosophy is adopted for the investigation, as this research focuses on understanding real-world business problems in an electronic environment that involves negotiation as well as coordination and cooperation. Accordingly, the research concentrates on interpretation of data and sources. Results are produced by different methods for gathering and analysis of data, namely, Decision Theory, Game Theory, and Fuzzy Logic. These theories are well established tools for analysis, particularly negotiation analysis.

### 9.4 Recommendations

Researchers always look for current problems and try to find their probable solutions by developing various methods and models. In addition to this, researchers provide appropriate guidance on these new methods and models to software developers. Academics will use the theoretical solutions and model for teaching future IT professionals. Developers will use the solutions and model for building software
development tools. Ultimately, practitioners will utilise those tools in day-to-day operations in the workplace. Therefore academics, software developers, practitioners can use the results of this research.

The implementation of the Negotiation Strategy was the most difficult and challenging part of the research. For that reason it needs further investigation and implementation.

There are many researchers conducting studies on automated negotiation in distributed systems, however, not much research has been done in the area involving the B2B electronic environment. Therefore the contributions of this research would be useful to enable complex negotiation procedures in B2B transactions in electronic environment.

9.5 Limitations of the Research

This research comprises of the negotiation mechanism, and includes the negotiation strategy, protocol and also analysis of cooperation and coordination, to enhance the negotiation mechanism to proceed effectively. The studies of this research have mainly focused on the theoretical analysis and development of models involving the negotiation, and cooperation and coordination processes.

The case “Trading Agent Competition Supply Chain Management” (TAC SCM) was used for the analysis, which is the only one international simulation implemented involving automated performances including negotiation. The competition involving TAC SCM commenced in 2003 and is ongoing for research purposes. Most of the data used was from the game in 2003 and some of the data was also collected from the game
in 2004. The games in 2005 and 2006 were not utilised due to the limited timeframe. However, it is worth noting that the specification of the game has not changed, and still is far from reality. For that reason it needs some improvements and enhancements of some of the processes involving negotiation for the scenario to represent business reality in the real world. Therefore, it is considered as that this is the initial stage of the research involving negotiation mechanism in software world. Implementation, testing will be the future research work. Again, this research is limited to B2B transaction rather than B2C.

To investigate the negotiation mechanism this research also analysed some procurement processes of TAC SCM as it directly relates to the negotiation mechanism.

9.6 Directions for Future Research

Negotiation strategies need to be further explored and implemented for sustainable situations, which will be a focus for the future generation of electronic business. Negotiation protocols and cooperation and coordination models also need to be implemented. Therefore the research detailed in this thesis provides the basis for what is undertaken in the future. Negotiation involving compromise can also be undertaken in future research. This compromise is one of the important characteristics of the negotiation process that relates to real world problems.

Further investigations will be conducted in a broad implementation level to find the overall effect of behaviours of the agents from the relation/comparison of maximin/minimax and Nash equilibrium points.
9.7 Conclusion

This concluding chapter of this dissertation firstly provided a brief discussion of the results of the studies that was undertaken in this research. It also presented the research contributions with an indication to the related chapters. The research limitations, future directions have also been discussed in this chapter.

Finally, the author believes that the outcome of this research will be useful for the next generation electronic world. It will provide economic, efficient, effective environment to conduct business globally involving complex negotiation process for B2B transactions.

The end
REFERENCES:


Sun, Z. (2000). *Towards understanding CBR and intelligent agents in e-commerce*: School of Information Technology, Bond University, Gold Coast, Australia.


   Routledge and Sons.
   Paper presented at the 9th International Joint Conference on Artificial
   Intelligence, Edinburgh, Scotland, UK
   Protocols for E-commerce Applications* (No. SEN -R0417), Centre for
   Mathematics and Computer Science, Amsterdam, Netherland.
**APPENDICES:**

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<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
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<tbody>
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Appendix A

Action Profiles:

If an object is associated with each member of a set of players, sometimes it needs to refer to the action chosen by each player, and then it can describe the correspondence between players and actions by specifying the functions that associates each player with the action taken. For example, if the players are John, whose action is $R$, and David, whose action is $S$, then it can be describe the correspondence between players and actions by the functions $a$ defined by $a(\text{John})=R$ and $a(\text{David})=S$. Alternatively, it can represent the function $a$ by writing $(a_{\text{John}}, a_{\text{David}}) = (R, S)$. The function $a$ is a profile. This can be written in a different order, for example, the profile $(a_{\text{David}}, a_{\text{John}}) = (S, R)$.

Therefore, for convenience of this thesis, the players are named as 1, 2, 3 and so on. As a result, a profile of actions can be written as a list such as $(R, S)$, without saying explicitly which action belongs to which player: the convention is that the first action is that of player 1, and the second action is that of player 2.
Appendix B

Harsanyi (1956) proposed a few simpler and more general postulates for Zeuthen’s assumption that each bargaining player will be prepared to make a concession to his opponent, whenever he finds that the latter’s readiness to risk a conflict is at least as great as his own. For this Harsanyi (1956) proposed the following postulates:

I. Symmetry. Both players follow identical (symmetric) rules of behaviour (because they follow the same principles of rational behaviour).

II. Perfect knowledge. Each player can estimate correctly the probability that the other player will definitely reject a certain offer.

III. Monotony. Let us consider, player 1 has received the offer $O_2$ from the player 2. then the probability $p_1$ of player 1’s rejecting $O_2$ and insisting on the more favourable terms $O_1$ is a monotone nondecreasing function of the utility of the difference of player 1 and player 2 if all other independent variables are kept constant.

IV. Expected-utility maximisation. Unless both players agree to make simultaneous concessions, each player will make a concession if and only if his making this concession will give him a prospect with higher expected utility than his refusing the concession would.

V. Efficiency. However, the two players will agree to make simultaneous concessions if this policy gives both of them higher expected utilities than they would obtain otherwise.
Appendix C

Source Code for Analysis of Negotiation Strategy by Simulation

```cpp
#include <iostream>
using std::cout;
using std::endl;
using std::cin;
using std::string;
#include <cstdlib>
#include <string>
#include <iomanip>
#include <cmath>
using std::setw;
double x,z,max,min,count,minj,mini,temp;
double arraya[100][100];
double arrayb[100][100];
string ans;
string nasha[100][100];
string nashb[100][100];
double maxa[100],mina[100];
double maxb[100],minb[100];
int i,j,row,col,y,r,c,loop,addi,addj;
int main()
{
    start:  //label
        x,y,z=0;
        y=1;
        z=1;
        cout<<"How many actions does agentI have?"<<"\t";
        cin >> row;
        cout<<"How many actions does agentJ have?"<<"\t";
        cin >> col;

        for (i=0;i<row;i++)
            {
            
        for (j=0;j<col;j++)
            {

                cout<<"agentI does action"<<y+i<<" and agentJ does action"<<y+j<<"\n";
                cout<<"agentI get"<<"\t";
```
cin>>arraya[i][j];
    cout<"agentJ get"<<"\t";
    cin>>arrayb[i][j];
}
}

cout<<"Payoff Matrix"<"\n"; //heading
x=(col*10/2)+15;
cout<<setw(x)<<"agentJ"<"\n"<<"-------------";
for (i=0;i<col;i++) //print line
    cout<"--------";
    cout<<endl;
    cout<"\t";
for (i=0;i<col;i++) //heading for action
    cout<"\t"<"action"<<i+1;
    cout<<endl;
for (i=0;i<row;i++) //print data
{
    cout<"agentI/action"<<i+1<<"| ";
    for (j=0;j<col;j++)
    {
        cout<arraya[i][j]<<","<<arrayb[i][j]<<(i+1)||"\t";
    }
    cout<<endl;
}

for (i=0;i<row;i++) //find maximum for agentI for Nash equilibrium
{
    max=arraya[0][j];
    for (j=0;j<col;j++)
    {
        if(max<=arraya[i][j])
        {
            max=arraya[i][j];
        }
    }
    //cout<<max; //print max
    //maxa[j]=max;
    for (j=0;j<col;j++)
    {

if(max==arraya[i][j])
    nasha[i][j]="y";
else nasha[i][j]="n";
}
}
cout<<endl;
for (j=0;j<col;j++) //find maximum for agentj for Nash equilibrium
{
    max=arrayb[i][0];
    for (i=0;i<row;i++)
    {
        if(max<=arrayb[i][j])
        {
            max=arrayb[i][j];
        }
    }
    //cout<<max; //print max
    //maxb[i]=max;
    for (i=0;i<row;i++)
    {
        if(max==arrayb[i][j])
            nashb[i][j]="y";
        else nashb[i][j]="n";
    }
}
cout<<endl;
for (j=0;j<col;j++) //find maximum for agentj for negotiaion
{
    max=arrayb[0][j];
    for (i=0;i<row;i++)
    {
        if(max<=arrayb[i][j])
        {
            max=arrayb[i][j];
        }
    }
    //cout<<max; //print max
    maxb[j]=max;
}
cout<<endl;
for (i=0;i<row;i++) //find maximum for agentj for negotiation
{
max=arraya[i][0];
for (j=0; j<col; j++)
{
    if(max<=arraya[i][j])
    {
        max=arraya[i][j];
    }
}
//cout<<max; //print max
maxa[i]=max;
}
cout<<endl;
for (j=0; j<col-1; j++) //desending maximum for agentj
{
    i=1;
    for (i=i+j; i<col; i++)
    {
        if(maxb[j]<maxb[i])
        {
            temp=maxb[i];
            maxb[i]=maxb[j];
            maxb[j]=temp;
        }
    }
}
for (j=0; j<row-1; j++) //desending maximum for agentI
{
    i=1;
    for (i=i+j; i<row; i++)
    {
        if(maxa[j]<maxa[i])
        {
            temp=maxa[i];
            maxa[i]=maxa[j];
            maxa[j]=temp;
        }
    }
}

cout<"maximum for agentI (desending order) = "<"\t";
for(i=0; i<row; i++)  //show max data
    cout<maxa[i]<"\t";
cout<endl;
cout << "maximum for agentJ (descending order) = " << "\t";
for (j = 0; j < col; j++) // show max data
    cout << maxb[j] << "\t";
    cout << endl;
for (i = 0; i < row; i++) // print data Y/N testing nash
{
    for (j = 0; j < col; j++)
    {
        cout << nasha[i][j] << "," << nashb[i][j] << "\t";
    }
    cout << endl;
}
for (i = 0; i < row; i++) // print nash
{
    for (j = 0; j < col; j++)
    {
        if (nasha[i][j] == "y" && nashb[i][j] == "y")
        {
            addi = i; addj = j;
            count = count + 1;
        }
    }
}
if (count == 1)
{
    cout << "Nash Equilibrium: ";
    cout << arraya[addi][addj] << "," << arrayb[addi][addj] << "\n";
    cout << "agentI takes action" << addi + 1 << " and agentJ takes action" << addj + 1 << "\n";
    // exit (EXIT_SUCCESS);
    goto final;
}
else if (count > 1)
    cout << "No unique Nash Equilibrium\n";
else if (count == 0)
    cout << "No Nash Equilibrium\n";

for (j = 0; j < col; j++) // find minimum for agentJ
{
min = arrayb[0][j];
for (i=0; i<row; i++)
{
    if (min >= arrayb[i][j])
    {
        min = arrayb[i][j];
    }
}
//cout<<min;
minb[j] = min;

//cout<<endl;

for (i=0; i<row; i++) // find minimum for agent I
{
    min = arraya[i][0];
    for (j=0; j<col; j++)
    {
        if (min >= arraya[i][j])
        {
            min = arraya[i][j];
        }
    }
    //cout<<min;
    mina[i] = min;
}
//cout<<endl;
mini = mina[0]; // show max data minimum I
for (i=0; i<row; i++)
{
    if (mina[i] >= mini)
    {
        mini = mina[i];
    }
}
cout << "maximum for agent I minimum = " << mini << endl;

minj = minb[0]; // show max data minimum J
for (j=0; j<col; j++)
{
    if (minb[j] >= minj)
minj=\text{minb}[j];\\
}\\
cout<<"maximum for agentJ minimum = "<"\t";\\
cout<<minj<<endl;\\
y=0;\\
//if (\text{maxa}[0]<\text{maxb}[0]) ///in case that agentJ starts offering**********\\
{  goto agentJoffer;\\
  //  loop=1;\\
  //}\\
//if (\text{maxb}[0]<=\text{maxa}[0]) ///in case that agentI starts offering**********\\
{  agentIoffer://label\\
  if (r<row && c<col)\\
  {\\
    for(i=0;i<row;i++)\\
    {\\
      for(j=0;j<col;j++)\\
      {\\
        //cout<<\text{maxa}[y]<<\text{arraya}[i][j]<<\text{arrayb}[i][j]<<\text{minj}<<\text{loop}<<endl;\\

        if(\text{maxa}[y]==\text{arraya}[i][j] && \text{arrayb}[i][j]>=\text{minj})\\
        {\\
          cout<<"Taking its highest utility strategy for agentI's \\
          "<"y+1"<<"highest value =";\\
          cout<<\text{arraya}[i][j]<<","<\text{arrayb}[i][j]<<\"n";\\
          cout<<"agentI performs action"<"j+1"<<end;\\
          y=row;i=row;j=col;z=1;goto final;//exit(EXIT_SUCCESS);\\
        }\\
      }\\
    }\\
  }\\

agentJoffer:  //label\\
for(i=0;i<row;i++)\\
{\\
  for(j=0;j<col;j++)
{
    //cout<<maxb[y]<<arrayb[i][j]<<arraya[i][j]<<mini<<loop<<endl;
    if(maxb[y]==arrayb[i][j] && arraya[i][j]>=mini)
    {
        cout<<"Taking its highest utility strategy for agentJ's "<<y+1<<"highest value = ";
        cout<<arraya[i][j]<<","<<arrayb[i][j]<<endl;
        cout<<"agentI performs action"<<i+1<<" and agentJ performs action"<<j+1<<endl;
        y=col;i=row;j=col;z=1;goto final;
    }
}
}

r=r+1;c=c+1;y=y+1;
//if(loop==1)
//{y=y-1;r=r-1;c=c-1;}
goto agentIoffer;
//}

if(z>0) //take most conservative strategy
{
    for(i=0;i<row;i++)
    {
        for(j=0;j<col;j++)
        {
            if(arraya[i][j]>=mini && arrayb[i][j]==minj)
            {
                cout<<endl;
                cout<<"Most conservation strategy = ";
                cout<<arraya[i][j]<<","<<arrayb[i][j]<<endl;
                cout<<"agentI performs action"<<i+1<<" and agentJ performs action"<<j+1<<endl;
                y=col;i=row;j=col;
            }
        }
    }
}

final: //label
    cout<<"Press enter to exit program";
cin>>ans;
if(ans=="") goto start;
else goto end;
}

return 0;

agentI does action3 and agentJ does action2
agentI get 4
agentJ get 2
agentI does action3 and agentJ does action3
agentI get 0
agentJ get 1
Payoff Matrix
-------------------------------------
agentJ
--------------
action1| action2| action3
agentI/action1| 2| 1| 0.2
agentI/action2| 4| 1| 1.2
agentI/action3| 2| 4| 0.1

maximum for agentI (descending order) = 4 4 2
maximum for agentJ (descending order) = 4 2 2
y.n n.n y.n
n.n y.n n.y
n.y y.y n.n
Nash Equilibrium 4.2
agentI takes action3 and agentJ takes action2
Press enter to exit program.
Appendix D

1. TAC SCM Scenario and Games

There are three entities, namely, suppliers, agents and customers in the TAC SCM scenario. Full specification can be found at [http://www.sics.se/tac/TAC’03_spec.PDF](http://www.sics.se/tac/TAC’03_spec.PDF). The agents are the manufacturers who assemble components to produce personal computers (PC) and finally sell them to customers. The agents purchase four types of components (CPUs, Motherboards, Memory, and Hard drives) from eight different suppliers and after assembly, sell sixteen differently configured PCs to customers according to their orders. Each agent sends RFQs (request for quotes) by stating the expected quantities of components and due dates to suppliers. Thereafter, suppliers respond to the agents with offers containing an offer id, RFQ-Id, Quantity, due date and price.

If suppliers are unable to deliver some components by the specified due date, they can also offer an alternative delivery date. If agents are satisfied with the offers, they can place an order with the suppliers for the components that need to be delivered. Alternatively, each day customers also send RFQs to the agents, specified with a RFQ-Id, desired quantity of PC, delivery due date, penalty and reserve price. The agents must bid to satisfy the entire order (both quantity and due date) for the customers with regard to the bid. The customers will not consider any bids for prices greater than the reserve price (Arunachalam et. al., 2003). Then the agents make bids against the quotes. The agent wins who offers the lowest price against the reserve price for the entire quantity and exact due date for delivery of the PCs, and consequently all other agents bids are rejected. But if that winning agent fails to deliver the PC on the due date, then it will be penalized as mentioned in their RFQs. Alternatively, at the beginning of the game the agents that do not have money in their account, can borrow money from the bank with a fixed interest rate.

There are six agents competing in each game for 220 days for a period of 55 minutes, that is, each day lasts for fifteen seconds. At the end of the game the agent with the highest bank balance wins.
2. The Trading Agent Competition 2003

The TAC SCM competition was organised in such a way that it had different phases as follows: i) qualifying round; ii) seeding round: a) seeding round 1, and, b) seeding round 2; iii) semi final; and finally, iv) the final round. The qualifying round took place from 16th June to 17th June 2003. In the qualifying round there were twenty participating agents. Each agent played 135 games on average in the qualifying round. No agents were discarded from the qualifying round. Therefore, all twenty agents were entered to compete in seeding round 1.

Seeding round 1 commenced on 1st July and ended on 11th July 2003. Sixty games were played by each agent for seeding round 1. From this round only the two last positioned agents were dropped and the remaining eighteen agents entered seeding round 2. Seeding round 2 lasted for five days from 14th July to 18th July 2003. There were 66 games played by each agent in this round. The semi-finals and the final game were played in Acapulo, Mexico at the Eighteenth International Joint Conference on Artificial Intelligence (IJCAI’03) from 11th to 13th August 2003.

The semi final game was subdivided into two rounds: semi final round 1 and semi final round 2. In semi final round 1, again it was structured into two groups. These two groups were constructed from seeding round 2 in such a way that the top six ranked agents, and the three last positioned agents were put together in group 1. Consequently, the remaining nine middle agents were put together in group 2. Each agent played nine games for semi final round 1. Semi final round 2 was structured as the three top ranked agents from group 1 of semi final round 1, and the three last ranked agents from group 2 in semi final round 1 were again placed into group 1. Subsequently, the last three ranked agents from group1 and the top three ranked agents from group 2 of semi final round 1 were put together into group 2. As a result, these two groups played in semi final round 2 and nine games were played by each agent. Finally, the top three ranked agents from each group of semi final round 2, competed in the final round. Each agent played 16 games for the final round. The agents that competed in the final round were: Red Agent (top ranked), deepmaize, TacTex,
Boticelli, PackaTAC and whitebear (listed according to the rank). The results can be found in the [http://www.sics.se/tac/page.php?id=1](http://www.sics.se/tac/page.php?id=1). Some networking problems occurred in the semi final round, and the organiser mentioned that because of the network failures at the conference some teams executing their agents from there had difficulties. It is likely that they would have scored better otherwise. The teams were jackaroo, HarTac, and NNN (3). The author worked with the agent jackaroo.

3. Components ordered on the first day of the competition

In the competition, generally all agents ordered components by the lot quantity of components at a time. But these ordering components defer in the different rounds. Figure 1, Figure 2 and Figure 3 show the mean components ordered on the first day of the Qualifying Round, Seeding Round 2 and Final Round respectively. The results expressed that each agent changed their strategy: ordering components on the first day of the game in different rounds. Most of the agents gradually increased their ordering quantity on the first day from the Qualification Round up to before the Final Round and then they dropped ordering in the Final Round. The ANOVA (analysis of variance) table visualised in Table 1, Table 2 and Table 3 for the Qualifying Round, Seeding Round 2 and the Final Round respectively. After statistical analysis of the data, the F-value of the result from the ANOVA table is highly significant in both the Qualifying Round and Seeding Round 2. However, in the Final Round the F-value of the ANOVA table is not significant.

Thereafter, the significant F-values were tested with Duncan’s New Multiple Range Test (DMRT) (Dowdy and Wearden 1991) to make a specific comparison of the performance of the agents that are depicted in Figure 4 and Figure 5 for the Qualifying Round and Seeding Round 2 respectively. Figure 4 indicates that the performance of ordering a quantity of components on the first day of the competition is highest with agent TacTex ranked at a. The performance of the two agents, PackaTAC and Boticelli, are statistically similar and therefore ranked at b. Then, agent Mertacor ordered in a different way and ranked at c. Agents RedAgent and jackaroo ordered similarly, and therefore ranked at d. Agents HarTac and DummyAgent performed in a similar way and ranked at e. Agent PSUTAC and Mertacor ordered statistically the
same way, and are ranked at f. Subsequently, the rest of the other agents (whitebear, UMBCTAC, deepmaize, Sirish, RonaX, Socretes, TAC-o-matic, zepp, argos, DAI-hard) did not order any components on the first day of the competition and are therefore ranked at g. Figure 5 represents the performance of ordering quantities of components on the first day of the competition, and these are statistically similar for two agents, PSUTAC and RedAgent. These agents ordered the highest amount of components. Therefore, they are ranked at a. Then the five agents, namely, HarTac, UMBCTAC, TacTex, Boticelli, jackaroo ordered in the similar way, and are ranked at b. While the rest of the eight agents like whitebear (rank c), PackaTac (rank d), MinneTac (rank e), Sirish (rank f), Mertacor (rank g), deepmaize (rank h), Ronax (rank i), Socretes (rank j) ordered components differently. Consequently, the last three agents TAC-o-matic, zepp, and argos did not order any components on the first day of the game. Therefore these agents are ranked last.
Figure D-1. Mean components ordered on the first day of the Qualifying Round

Table D-1. ANOVA for Qualifying Round

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-Groups</td>
<td>19</td>
<td>84197532233</td>
<td>4431449065</td>
<td>74.673 **</td>
</tr>
<tr>
<td>Within-Groups</td>
<td>80</td>
<td>4747554163</td>
<td>59344427.04</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>88945086396</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Calculated value of F is greater than tabulated value at 1% level, hence the ordering of components of the agents on the first day of the game is highly significant.
Figure D-2. Mean components ordered on first day of the game of Seeding Round 2

Table D-2. ANOVA for Seeding Round 2

<table>
<thead>
<tr>
<th></th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-Groups</td>
<td>17</td>
<td>10931200000000</td>
<td>64301176471</td>
<td>213.448 **</td>
</tr>
<tr>
<td>Within-Groups</td>
<td>72</td>
<td>216900000000</td>
<td>301250000</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>11148100000000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Calculated value of F is greater than tabulated value at 1% level, hence the ordering of components of the agents on the first day of the game is highly significant.
Mean Component Ordered on the First Day of the Game of Final Round

**Figure D-3. Mean components ordered on the first day of the Final Round**

**Table D-3 ANOVA for Final Round**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-Groups</td>
<td>5</td>
<td>28265128278</td>
<td>5653025656</td>
<td>1.537</td>
</tr>
<tr>
<td>Within-Groups</td>
<td>42</td>
<td>154435000000</td>
<td>3677020755</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>182700000000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Calculated value of F is less than tabulated value at 1% and 5% level, hence the ordering of components of the agents on the first day of the game is insignificant.**
Duncan's New Multiple Range Test of the Qualifying Round

![Bar graph showing quantity of components ordered on the first day of the game for different agents.]

**Figure D-4. DMRT test for Qualifying Round 2**

Duncan's New Multiple Range Test of Seeding Round 2

![Bar graph showing mean quantity of components ordered on the first day for different agents.]

**Figure D-5. DMRT test for Seeding Round 2**
The author also analysed the percentage of the components ordered on the first day of the competition of the Qualifying Round, Seeding round 2 and the Final Round shown in Table 4. In the Qualifying Round, agent TacTex ordered thirty-six per cent, and agent PackaTAC ordered twelve percent, Boticelli ordered ten percent, jackaroo ordered seven per cent, RedAgent ordered six per cent, deepmaize ordered five per cent, HarTac and DummerAgent ordered four per cent, PSUTAC ordered one per cent, the rest of the agents did not order.

In the Seeding Round, agent HarTac ordered components hundred percent, PSUTAC, whitebear, UMBCTAC, Redagent ordered ninety percent, jackaroo ordered eighty four percent, Boticelli – seventy-eight percent, TacTex – forty-six percent, PackaTac twenty-nine percent, Sirish twenty-five percent and the rest of the other less than ten percent or zero percent. In the Final Round, the percentage of the components ordered on day zero of the game were: RedAgent ordered thirty five per cent deepmaize: twenty four per cent, TacTex: thirty three per cent, Boticelli: thirty six percent, PackaTAC: twenty per cent, and whitebear ordered hundred per cent, which defers a lot from the Qualifying Round and Seeding Rounds.
Table D-4. The percentage of the components ordered on the first day of the competition of Qualifying Round, Seeding Round 2 and Final Round.

<table>
<thead>
<tr>
<th>Name of Agent</th>
<th>Qualifying Round %</th>
<th>Seeding Round 2 %</th>
<th>Final Round %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TACTex</td>
<td>36</td>
<td>46</td>
<td>33</td>
</tr>
<tr>
<td>RedAgent</td>
<td>6</td>
<td>90</td>
<td>35</td>
</tr>
<tr>
<td>Boticelli</td>
<td>10</td>
<td>78</td>
<td>36</td>
</tr>
<tr>
<td>jackaroo</td>
<td>7</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>deepmaize</td>
<td>5</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>HarTac</td>
<td>4</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PSUTAC</td>
<td>1</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>PackaTAC</td>
<td>12</td>
<td>29</td>
<td>20</td>
</tr>
<tr>
<td>whitebear</td>
<td>0</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>MinneTac</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>UMBCTAC</td>
<td>0</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Sirish</td>
<td>0</td>
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