An Investigation of the Trading Agent Competition

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Preface

This thesis is for my Master of Science study at the Department of Information and Mathematic Science, Massey University. I have faced many challenges to finish it.

Conquering the difficulties gave me great pleasure, for it pushed back boundary-lines and promoted my personal growth.

In the first place I would like to thank Dr. Chris Messom for his support in starting this research. He showed more patience and help with me than I could have ever wished for.

I want to thank Professor Robert McKibbin for encouraging me to finish my thesis.

Tong Liu

2005

Abstract

The Internet has swept over the whole world. It is influencing almost every aspect of society. The blooming of electronic commerce on the back of the Internet further increases globalisation and free trade. However, the Internet will never reach its full potential as a new electronic media or marketplace unless agents are developed. The trading Agent Competition (TAC), which simulates online auctions, was designed to create a standard problem in the complex domain of electronic marketplaces and to inspire researchers from all over the world to develop distinctive software agents to a common exercise. In this thesis, a detailed study of intelligent software agents and a comprehensive investigation of the Trading Agent Competition will be presented. The design of the RiskerWise agent and a fuzzy logic system predicting the bid increase of the hotel auction in the TAC game will be discussed in detail.

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Chapter 1: Introduction

In this chapter, the motivation behind this research will be introduced, the definitions of relative terms will be provided and the literature review of TAC game and TAC agents will be given. The overview of following chapters will be listed in the end of this chapter.

1.1 Background

Because of division of labour, most of people couldn't be self-sufficient anymore. In order to survive, people need to exchange goods and/or services. A market is a mechanism which allows people to trade. The traditional market is where traders set up stalls and buyers look around the merchandise. Extending the concept of the traditional market, the modern shopping malls, shopping centres or shopping arcades are built. It is a building or set of buildings that contain many stores/shops, which is easy for people to walk from store to store.

With the terrific developments of communication and information technologies, the Internet is experiencing an exponential growth. In 2000, there were 304 million people having Internet access and ten million domain names were registered (Anderberg, 2003). The Internet Society data shows that there were approx 285,139,107 host computers on the Internet (Internet Domain Survey, 2004) and there were 46,067,743 web sites by the year 2003 (Zakon, 2004).

The Millions of people are assembled by the Internet. Internet has become a world-wide medium for collaboration and interaction between individuals without regard for geographic location. Markets do not have to always locate in a physical space. People can exchange goods and/or services on the Internet. The physical limitations of traditional auctions such as time, space and presence have disappeared.

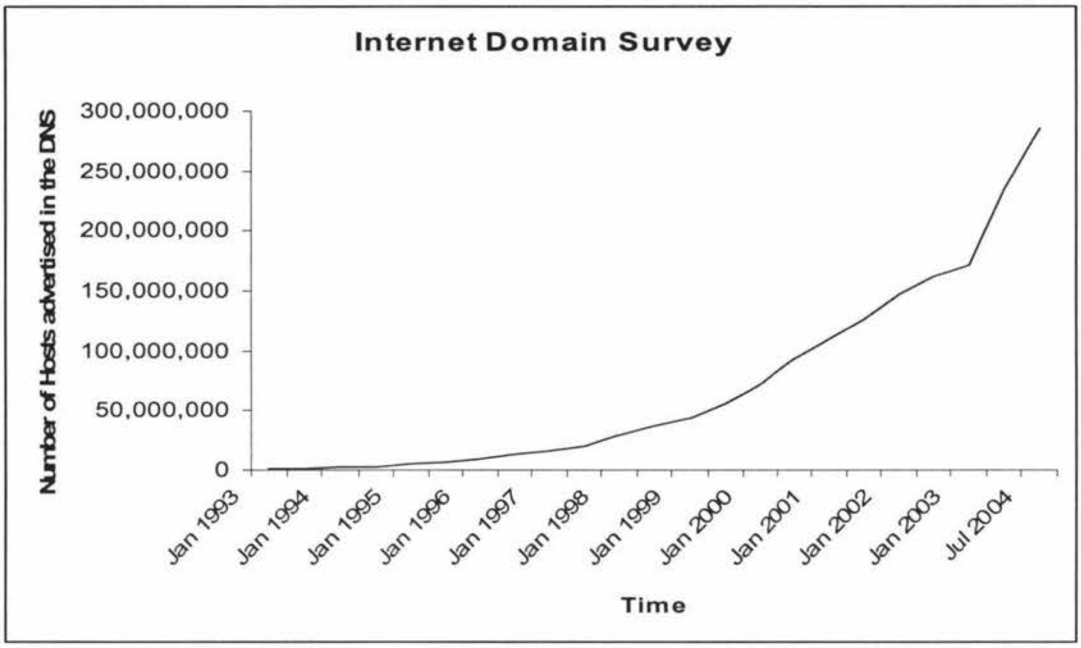

Figure 1: Number of Hosts advertised in the DNS (Internet Domain Survey, 2004)

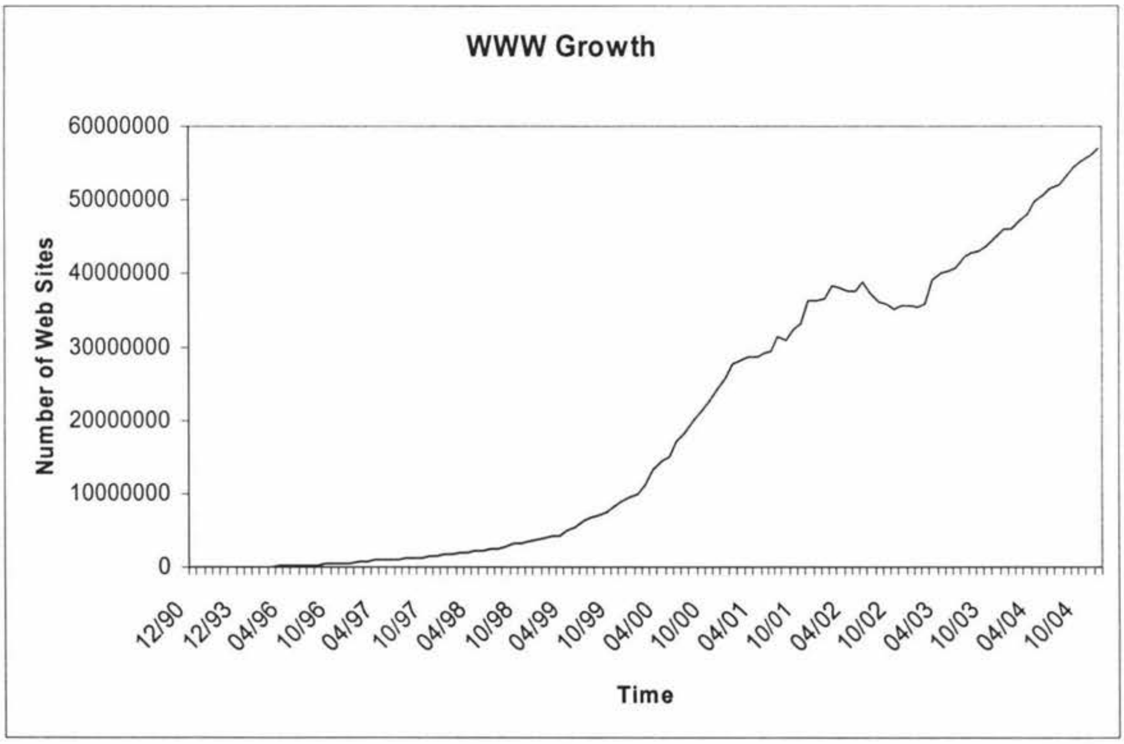

Figure 2: WWW Growth (Zakon, 2004)

The development and success of electronic commerce has dramatically increased the opportunities for automated trading agents because searching, accessing, filtering and integrating information is hard for a person or current computer systems especially when decisions are based on a massive amount of factors, using complex strategies. One of the few studies comparing human and computer traders did not reflect very favourably on the humans (Das et al, 2001). Compared to human negotiation, automated trading agents can be faster, cheapter, more convenient (He 2004). Automated trading agents have the advantages of being able to work continuously and repetitively without losing concentration. Automated trading agents can also remove the human sensibilities that are often associated with bargaining (He 2004).

Once the agent is realized, many of the obstacles that currently limit how people use computers will disappear. It will make users' lives easier. People would like to delegate more functions to the agent (Negroponte, 1997).

There are many different trading methods. Auction is one of them. An auction is the process of buying and selling things by offering them up for bid, taking bids, and then selling the item. Internet auctions have become very popular. In the Internet Auction List there were more than 2500 auction company listings in 2003 (He 2004). eBay, an on-line auction, has 100 million registered users around the world (eBay, 2004).

In order to understand the effectiveness of agent strategies, the possible influences of automated traders to electronic markets and also to stimulate research in trading agents with an emphasis on developing a successful strategy for maximizing profits in a constrained environment, the Trading Agent Competition (TAC) game was designed (Strother 2000).

The TAC is a game simulating an electronic auction market. It was proposed by Wellman and Wurman. The first competition was held in July 2000 in Boston (Stone and Greenwald, 2001). TAC attracted 18 participants from six countries. Based on the success of the first event, the second competition was held in October 2001 in Tampa. The third TACs (Wellman et al., 2002; Greenwald, 2003), which were held in the following year had minor modifications. The fourth competition introduced new supply chain management research subject (Raghu et al., 2002).

To play TAC, software agents need to be designed. The goal of an agent is to satisfy its client. The agent will play the role of a travel agent with the goal of putting travel packages together for its clients. Each agent has eight clients who would like to take a trip and also have their preferences for various aspects of the trip. The travel packages include airline tickets, reserve hotel rooms, and entertainment events. All these items are traded in different kind of on-line auctions.

The objective of this thesis is to investigate the TAC game and TAC agents. A trading agent is designed and implemented. A fuzzy logic module used to predict the price is also designed.

1.2 Definitions

1.2.1 Software agent

Before the agent definitions are given, one needs to be aware that there is not only one definition of agents. There are some widely accepted concepts characterizing agent systems and the definitions of agents with their own significances. They are described as follows:

- "The agent is an autonomous, self-contained, reactive, pro-active computer system with central locus of control that is able to communicate with other agents by an Agent Communication Language" (Wooldridge and Jeannins, 1994).
- Agent-Oriented Programming - An approach to building agents with mentality such as beliefs, desire and intentions (Franklin, 1996).
- An autonomous agent is a system which situated and is a part of the environment that senses that environment and acts in it to pursue its own agenda and to influence the future (Worldridge and Jeannins, 1995).
- An agent is an entity or object, which is able to execute symbolic external tasks, and reacts autonomously on the changes of its environment (Gadomski 1998).
- A Software agent is a computer program which functions as a user's personal assistant by performing tasks autonomously or semi autonomously. It is more than a passive task receiver and execution program (Harmon, 1995).

- The general functional definitions of software agent and intelligent agent are given below:

  A. "A software agent is a functional software module that is able to execute some predefined class of external tasks and has autonomy during these task realizations. It reacts on the predefined states of its own environment according to acquired information, its own built-in preferences and knowledge" (Gadomski 1998).
  B. "An intelligent agent is an agent with capability to change and evaluate its own preferences and knowledge" (Gadomski 1998). For example, it can learn or change goals if the original objectives are not reachable.

Researchers have offered a variety of agent definitions. The next section lists some of these definitions.

Virdhagriswaran, a researcher of MuBot Agent, an acronym for "Mobile Unstructured Business Object", defined that the agent has the ability for autonomous execution and domain oriented reasoning (Virdhagriswaran n.d.).

Russell and Norvig, researchers of the AIMA (Artificial Intelligence: a Modern Approach) Agent, stated that: "An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors" (Russell and Norvig 1995).

Pattie Maes, researcher from MIT's Media Lab, described that Autonomous agents are computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed" (Maes 1995).

Smith, Cypher and Spohrer, researchers of the KidSim Agent defined an agent as a persistent software entity dedicated to a specific purpose. (Smith, Cypher and Spohrer 1994)

Hayes-Roth thought that the intelligent agents need continuously perform three functions: "perception of dynamic conditions in the environment; action to affect conditions in the environment; and reasoning to interpret perceptions, solve problems, draw inferences, and determine actions" (Hayes-Roth 1996).

Wooldridge and Jennings defined an agent as a hardware or (more usually) software-based computer system that has the following properties:

- Autonomy: an agent makes its own decisions about its actions and state rather than being influenced by others (Wooldridge and Jennings 1995)
- Social ability: an agent communicates with other agents or humans (Wooldridge and Jennings 1995)
- Reactivity: an agent perceives its environment and responds to it. It may make changes due to the environment (Wooldridge and Jennings 1995)
- Pro-activeness: an agent takes the initiative instead of only responding to its environment (Wooldridge and Jennings 1995)

Michael Coen, the researcher of the SodaBot Agent, defined: "Software agents are programs that engage in dialogs and negotiate and coordinate transfer of information" (Coen, 1995).

Brustoloni claimed that "Autonomous agents are systems capable of autonomous, purposeful action in the real world" (Brustoloni 1991).

Having these definitions given above, it is clear that there is no general definition for an agent. It could simply be described as a piece of software assisting users in the computers and computer networks.

1.2.2 General properties of an agent

The following sets are some agent attributes and properties. The list below is not complete and exhaustive.

- Reactivity: An agent has the ability to sense and act according to its environment.

- Knowledgeable: An agent has the ability to reason its goals; acquire knowledge and information from its environment.

- Inferential capability: An agent has the ability to make decision based on knowledge and information already have. It may choose best methods from itself, users, or other agents.

- Autonomous: An agent has the ability to independently act for its users. It is proactive not reactive.

- Adaptable: An agent has the ability to change its behaviour by learning, user preferences, or new capabilities.

- Collaborative: An agent has the ability to communicate, co-operate or collaborate with other agents in multi-agent societies.

- Communication ability: An agent has the ability to communicate with humans and other agents with suitable language.

- Mobile: An agent has the ability to move from one executing environment to another and continuing execution in a new environment.

- Persistent: An agent has the ability to keep its identity, knowledge and state over a long period of time even system failures.

- Personality: An agent has the human characters such as emotion, humour, etc.

1.2.3 Auction types

The following is a list of some basic types of auction:

- One-sided: a single seller accepts bids from multiple buyers or a single buyer accepts bids from multiple sellers.
- Two-sided or double auctions: multiple buyers and sellers to bid to trade goods.
- Continuous double auction (CDA): buyers and sellers match immediately on compatible bids.
- Sealed bid - No bids are visible to other bidders before auction closes. It clears only once and does not generate and publish price quotes.
- Open-outcry - Bids are made public at time of bidding.
- English (ascending) - Start at low price, increase amount until no further bidders, item goes to last bidder
- Dutch (descending) - Start at high price, decrease price til price accepted, e.g. tulips.
- First price - Pay amount of bid
- Second price - Pay amount of next highest bid
- Uniform-price auction: All the successful bidders pay the same price, which is decided by the auction.
- Common/Objective value - Item has identical value to all bidders, but each bidder has imprecise estimate.

- Private/Subjective Value - Each bidder knows and places different values on item according to the bidder's own information, but the bidder's value is private information to the bidder themselves.

Auctions can use any combination of the above types as long as they make sense. From the sellers' (auctioneer's) point of view, a good auction design gives the highest return to the seller.

1.3 Literature review

The TAC game and the strategies used in the TAC game will be introduced.

1.3.1 General information of TAC game

In each TAC game, eight trading agents compete for travel goods, with each agent representing eight clients. One customer can only have one agent. The duration of each game is 12 minutes.

Travel packages consist of the following (Game Overview, n.d.):

1. A round-trip flight,
2. A hotel reservation, and
3. Tickets to some of the following entertainment events
    - Alligator wrestling
    - Amusement park
    - Museum

Each customer will be given a set of preference for wishing to purchase travel arrangements. Preferences include the desired travel days; bonus for hotel quality; values for entertainment events.

A client's preference is characterized by

- Ideal arrival and departure dates.
- Bonus value for staying in the better hotel
- Bonus values for each of the three types of entertainment events

Agents must participate in auctions to try to acquire necessary resources. TAC has three different auction types bind together. Different auctions have different rules for matching the bids and recording the transactions. This increases the complexity of the TAC auction compare the real on-line auction. The three different kinds of auction in the TAC game are flight, hotel and entertainment auction. The flight auction is a continuously clearing one-sided auction with the changing price. The entertainment ticket auction is a standard continuous double auction. The most interesting auction is the hotel auction, which is a 16th price English ascending auction.

All of the auctions follow the high-level protocol below:

- Agents submit bids to the TAC server.
- The TAC server updates its price quote, publishing the current going prices.

Accepting bids, updating and publishing bids are most common tasks for an auction site server.

1.3.2 TAC auction rules

Different types of goods (flight tickets, hotel rooms and entertainment tickets) are traded at separate auctions with different rules. Agents can only buy air tickets and accommodation. Agents can buy and sell entertainment tickets. The following sections introduce the goods and auctions in the TAC market.

1.3.2.1 Flight auctions

1.3.2.1.1 Flight tickets

There is only one auction for each day and direction (arrival or departure). All the flight tickets are sold by the TAC server. There are two auctions in day 2, 3, 4. There is only one in flight auction in day 1 and out flight auction in day 5. (There will be no in flights on the last day, nor out flights on the first day.) There are 8 auctions in total.

Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
in flight	in flight **out flight**	in flight **out flight**	in flight **out flight**	**out flight**

Table 1: The available flight tickets

The TAC server offers an infinite supply of flight tickets. The details of the TAC flight price are described as follows. The TAC server sells the flight tickets based on a stochastic function. The method used to update flight prices is a random walk method.

$$X(t) = 10 + (t/720) * (x - 10)$$

where t is the number of seconds since the game starts and x is a random variable chosen from a uniform distribution on [10, 90] for each flight separately (Game Overview, n.d.).

In order to find the relationship between flight price and game time, an experiment was designed. After 100,000 experiments, it is found that the flight ticket prices increase linear over the time, and its difference is fairly large.

Figure 3 is based on the result of the 100,000 experiments. The price starts from $10. The C++ program designed for the experiment is in Appendix 1.

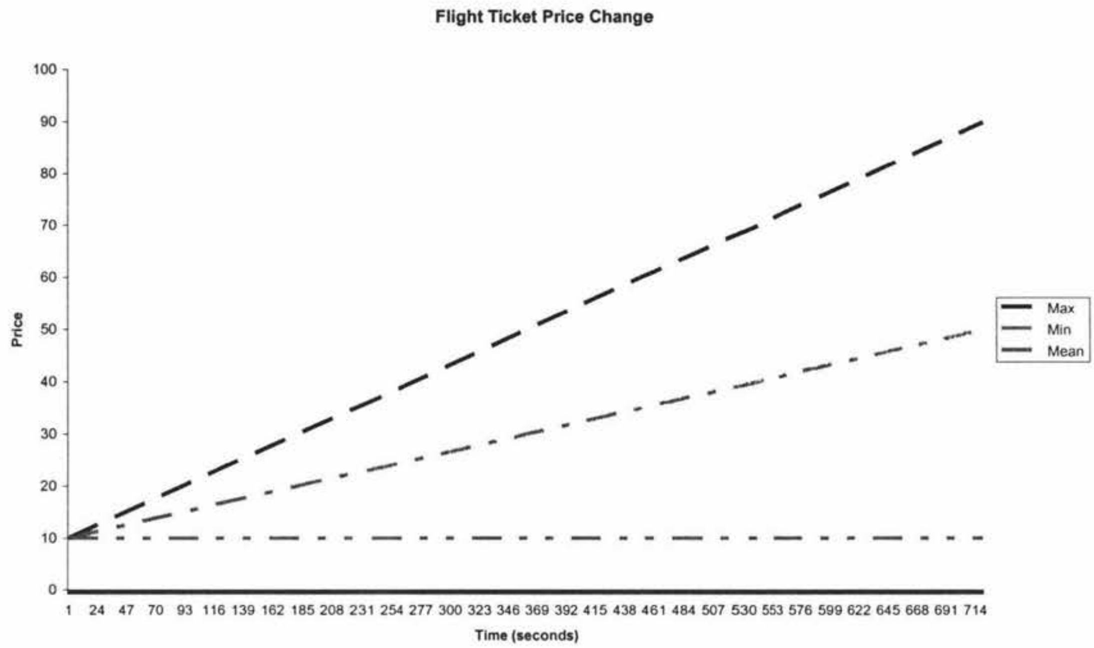

Figure 3: The flight prices are biased to drift upwards.

1.3.2.1.2 Flights auction

Flight auctions are continuously clearing one-sided auctions (TAC Server is a single seller, who accepts bids from multiple buyers), and clear continually (Once the action matches buyers and sellers, the transaction complete).

Agents can only buy the flight tickets but cannot sell or exchange their flight tickets. TAC server only accepts bids for buying flight tickets from agents.

If the price of buy bid point is equal to or higher than the current ask price, it will be matched immediately at the ask price. In other words, if the price of agent's buy bid is higher or equal to the TAC seller's sell price, the agent gets the ticket immediately and the agent has to pay for that.

If the price of buy bid point is less than the current ask price, it cannot be matched. The bid remains in the TAC auction as a standing bid. A standing buy bid remains in the TAC auction unless it can be matched by a sell bid which price drops to the same as or below the price of the standing buy bid. Because the flight price increases over the time, the chance for the standing buy bid to be matched is not good.

For example, TAC seller submits a sell bid of ((-50 450)) while an agent submits a bid of ((5 580) (6 385)). There are five units at $450 each would be matched. Since the whole bid could not match, the remaining part, ((6 385)), would remain in the auction.

1.3.2.2 Hotel auctions

1.3.2.2.1 Hotel rooms

There are only two hotels: one is Tampa Towers and another one is Shoreline Shanties. Clients must stay at least one night at one of the hotels. Tampa Towers hotel costs more compare with the Shoreline Shanties hotel. There are 16 rooms available per hotel per night. A client cannot change the hotels during the trip.

1.3.2.2.2 Hotel auction

Hotel auctions are Standard English ascending, multi-unit and sixteenth-price auctions (price increase, bidders pay amount of 16th highest bid), except that they all close at randomly determined times (Game Overview, n.d.). All of the bids whose price is higher than 16th price pay for the 16th price. Only the TAC servers can sell hotel rooms. There is no minimum bid price for either type of hotel. The TAC server sells 64 hotel rooms in total.

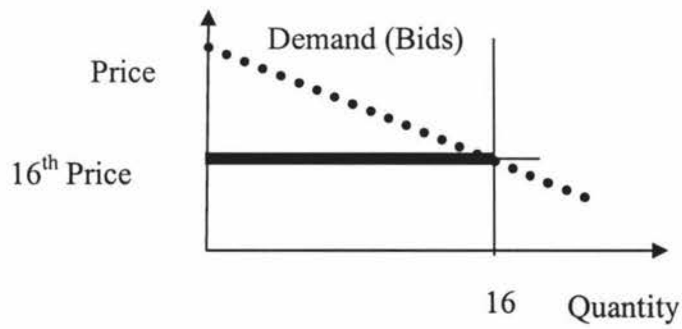

Figure 4: The illustration of 16th Hotel Auction.

Since clients only need hotels from the first day of their arrival and through the last day before their departure, there are no hotels available on the last day. There are 8 hotel auctions.

Day 1	Day 2	Day 3	Day 4	Day 5
TT Auction	TT Auction	TT Auction	TT Auction	
SS Auction	SS Auction	SS Auction	SS Auction	

Table 2: The hotel room auctions

Hotel auctions all close at randomly determined times. Specifically, one randomly chosen hotel auction will be closed at four minutes after the game starts. Then one randomly chosen hotel auction will be closed each one minute thereafter until 11 minutes when the last hotel auction is closed. The TAC server matches and clears hotel auction bids only once on the minute when it is closed (Game Overview, n.d.).

The agents don't know in advance when and which hotel auction will be closed and what the price of the hotel. TAC server only generates price quotes once per minute, on the minute when the hotel auction is closed. In most of the real on-line auctions, humans instead of software agents make decision. The uncertainty of the hotel auctions increases the difficulties for making decision. The type of TAC hotel auction could be adopted in the future as the software agent technology develops.

Agents can only submit buy bids instead of sell bids. The TAC seller submits sell bids to provide 16 rooms of two hotel types on each day for a minimum price above $0. The price quote is calculated as the 16th highest price between all buy and sell bid units. Second-price auction is more common than 16th auction. There is no big difference. To encourage bidders bid high is the same motivation behind 16th auction and Second-price auction. The optimistic bidders would hope that the 16th price or 2th price will lower than the price their bid. Maskin and Riley (1999) show that "strong" buyers prefer the second-price auction.

Any new buy bid must satisfy the following conditions to be admitted to the auction: ASK be the current ask quote (16th highest price).

- It must offer to buy at least one room at a price greater than 16th highest price. It is not practical for a bid buying nothing. If the price is less than 16th highest price, the bid couldn't win anyway.

- If the agent has already submitted its bids to the hotel auction. It can not withdraw its bid. In the real on-line auction, withdrawing bid is also not encouraged. For example, it may be allowed to retract (cancel) bid in some cases if the retraction meets the requirements of eBay strict bid retraction policy.

- If the agent has a current buy bid, which could get m rooms in the current state, then the new bid must offer to buy at least m rooms a price greater than 16th highest price. This policy also encourage bidder bid high, which benefits the auctioneer.

When the TAC server clears and closes the hotel auction, the 16th highest price buy bids will be matched and the agents will pay their ask price for the hotel rooms.

For example, if the following hotel auction bids were submitted to TAC server:

If the following hotel auction bids were submitted to TAC server:

- Sell bid: ((-16 0)),
- Agent 1: ((3 3) (5 5) (9 8))
- Agent 2: ((4 1))

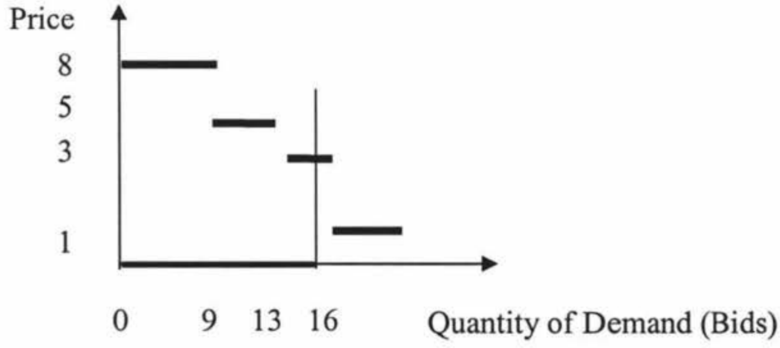

Figure 5: Example of Hotel Auction

In this example, if the TAC closed the hotel auction on the minute, Agent 1 would get 9 rooms at price 8, 5 rooms at price 5 and 2 rooms at price 3. Agent 1 asked for 17 rooms. It only got 16 rooms and Agent 2 did not get any rooms.

1.3.2.3 Entertainment ticket auctions

1.3.2.3.1 Entertainment tickets

All the travel agents receive allocation of entertainment tickets at the beginning of the game.

There are 8 entertainment tickets available for each entertainment type on each day in total. Each agent gets 12 entertainment tickets split as follows:

- On day 1 or day 4: One package of four of a specific entertainment type and one package of two of another different type.
- On day 2 or day 3: One package of four of a specific entertainment type and one package of two of another different type.

1.3.2.3.2 Entertainment auction

Agents buy or sell entertainment tickets through a continuous double auction (CDA), which all the agents can be buyers or sellers to bid to trade goods. Buyers and sellers match immediately for the compatible bids. There is one auction for each entertainment event on each day. Entertainment tickets are bought and sold on TAC auctions at prices the agents decide to bid.

- Tickets owned from the initial allocation are free.
- The score for selling entertainment tickets can be positive or negative because it is equal to the amount earned from selling entertainment tickets deduct the amount spent buying entertainment tickets.

Same as the hotel rooms, clients cannot use entertainment tickets on the day of departure (day 5).

Day 1	Day 2	Day 3	Day 4	Day 5
Alligator Wrestling	Alligator Wrestling	Alligator Wrestling	Alligator Wrestling	
Amusement Park	Amusement Park	Amusement Park	Amusement Park	
Museum	Museum	Museum	Museum	

Table 3: The available entertainment tickets auctions

Agents can submit bids with buy and/or sell points as long as a bid does not sell to itself. If the sell bid points prices are the same or below the price of the buy bid, the buy bid points will immediately match the lowest price sell bid points. Auctions clear continuously once the bids match. If the buy bid points prices are the same or above the price of the sell bid, the sell bid points will immediately match the highest price buy bid points. A bid point which does not completely match remains in the entertainment tickets auction.

Once new bids are submitted, price quotes are published immediately. The price quote includes the bid price and ask price. The price of the highest standing buy point will be the bid price. The price of the lowest standing sell point will be the ask price.

For example, if the standing bids in an entertainment ticket auction were:

- ((-2 101))
- ((-3 92) (-1 53))
- ((-5 63))
- ((2 44) (4 27))
- ((1 36))

Figure 6: Example of Entertainment Auction

- The bid price would become $44.
- The ask price would become $53.

1.3.3 TAC bid format and protocols

A bid represents an agent's willingness to sell and buy the goods in the auctions. A bid contains a bid string, which consists of a list of bid points in the following form:

"((q_1 p_1) (q_2 p_2) (q_3 p_3) ... (q_i p_j))"

where q_i is a quantity of the goods an agent wants to buy or sell

p_i is a price of the goods an agent wants to buy or sell

If $q_i > 0$, it means that the agent wants to buy q_i amount of the good at the auction for less than or equal to p_i price per unit of that goods.

If $q_i < 0$, it means that the agent wants to sell q_i amount of the good at the auction for greater than or equal to p_j price per unit of the good.

The prices should always be nonnegative. None of the agents would like to sell goods and pay the money. If prices were negative, agents could buy goods and get money.

It is not acceptable in TAC for an agent submitting a bid to sell goods to itself. For example if an agent placed the bid "((-2 5) (2 10))", it could likely sell 2 units to itself at a price between $5 and $10. Agents sell goods to themselves would not get any benefit. It is waste of resources and time. It is sensible for an agent want to sell goods to itself. This TAC rule just prevents the agent make careless mistakes.

If a bid is matched at the TAC server, the bid string will change after the match. For example, if an agent submits the bid "((-3 5) (-4 30))" and sells two units of the good for $5, then the bid string becomes "((-1 5) (-4 30))". The remains of bid string stay in the server waiting to be match.

1.3.4 Final score of an TAC agent

The TAC server computes and reports each agent's optimal allocation. It calculates the score for all the agents at the end of each TAC game.

The final score of an agent is composed of:

+ The value of the allocation of the goods to clients,
- The penalty for changing clients' preference,
- The cost of buying flight tickets, hotel rooms and entertainment tickets,
- The penalty for negative entertainment balances

1.3.5 Characteristics of TAC game

- First, there are contests between agents. For exmple, the hotel rooms are finite and the price is unpredictable and the order of auctions closing was unknown and unpredictable).

- Second, there are interdependencies (He and Jennings, 2004). These are relations between different types of auctions (e.g. flight tickets will be wasted if the same hotel rooms are not available from arrival day to the day before departure); between different dates in the same type of auction (e.g. customers must stay in the same hotel during their trip. Customers cannot get extra utility for attending the same type of entertainment more than once during their trip); between the same kind counterpart auctions in the same day (e.g. if the price of good hotel is high, the customer can change to cheap hotel at the same day).

- Third, the bidding involves uncertainty (He and Jennings, 2004). For example, flight ticket prices start and change randomly; one randomly chosen hotel room auction closes from the 4^{th} to 11^{th} minutes after game starts; the customers' preferences are assigned randomly and the way players bid for their hotel rooms is unpredictable if they are new players.

- Fourth, a trade-off exists (He and Jennings, 2004). For instance, the prices of flight tickets in flight ticket auctions rise over the time as shown in the figure 3. But, if the agent buys cheap flight tickets very early, it might not be able to buy the necessary hotel rooms. This leads to some invalid travel packages. The flight tickets might be wasted. Hence, a trade-off exists between buying flights tickets earlier at lower prices and buying them later at higher prices to make sure they match with the hotel rooms that have been bought.

1.3.6 Strategies of TAC agents

The high-level bidding decisions of most previous games had the following structure:

- Analyse the game environment and history data
- Decide at what time to bid
- Predict the prices
- Decide on what goods to bid for

1.3.6.1 Analysis of competition environments

The success of an agent not only depends on its own strategies, but also depends on the strategies of the other competitors. The best solution is relative to other players' strategy (Vetsikas and Selman, 2003). Peter Stone stated:

> The success of agent strategies depends a great deal on the strategies of the other competition (Stone, 2002).

In both TAC-00 and TAC-01, the competitors learned about each other's strategies and made many adjustments. In TAC-00, only 14% of the agents were using a particularly effective (in isolation) high-bidding strategy during the qualifying round; by the finals 58% of the agents were using this strategy (Stone, 2002).

Before each game, ATTac downloads a published list of agents from the TAC website to identify known high-bidders. If there are more than two, it factors the information into bidding strategy.

The agent SouthamptonTAC designed by He, Minghua and Jennings, Nick observed the TAC game market environment and categorized the TAC game market environment into three kinds of environments according to the different risk attitudes of other agents and decided different strategies correspond to different environments (He and Jennings, 2004).

- Non-competitive environment: there is no price war in the hotel room auctions. Agents can easily obtain the hotel rooms at very low prices. In this environment, the agent doesn't change the travel plan for each client. It buys almost all the flight tickets at the beginning of the game and all the rest of the tickets at the end of 4th minute (He and Jennings, 2004).

- Semi-competitive environment: the competition of most hotel room auctions is reasonable. The hotel room prices are moderate e.g. the price of a good hotel room is 120 and the price of a cheap hotel room is 60. In this environment, the agent predicts the closing prices of the hotels and changes the travel plans for its clients if new plans could make the clients' utilities higher enough. It buys almost all the flight tickets at the beginning of the game and all the rest tickets at the end of 4th minute (He and Jennings, 2004).

- Competitive environment: there are price wars in the hotel room auctions. The prices of some hotel rooms are very high, e.g. the price of a good hotel room is 300. In this environment, the agent uses the fuzzy reasoning methods to predict the hotel room closing prices and bid adaptively. It buys most flight tickets at the beginning of the game and the rest of the flight tickets based on the flight category (He and Jennings, 2004).

The environments are decided by the past games history before a game starts. In the TAC semi-final, general seeding round data was used to predict the environment because there was not enough past data.

After the 4th minutes of the game start, one of the hotel room auctions will be closed. The agent then can use the current hotel prices to decide if it needs to change its strategy. For example, the agent may change its strategy from Non-competitive environment to Competitive environment.

1.3.6.2 Time to bid flight tickets: early bird and deliberate buyer

The flight price in general is going up all the time as shown in figure 3. There is a dilemma, which is bidding *early* could get the cheap tickets but may waste the tickets (travel plan changes); or bidding *late* the agent can pay a high price for the tickets after the hotel auctions (accommodation secured not to waste the tickets).

Bidding for all the flight tickets late is not very wise strategy (the price difference may be over $650). Vetsikas and Selman did experiment on the performance of different bidding times:

- Late Bidder: Buy at the beginning only tickets that are "certain" to be used
- Early Bidder: Buy all tickets at the beginning

High aggressive bidder bids for all rooms progressively closer to the marginal utility. Medium bidders bid for critical rooms close to marginal utility and the rest of the rooms an increment above the current price.

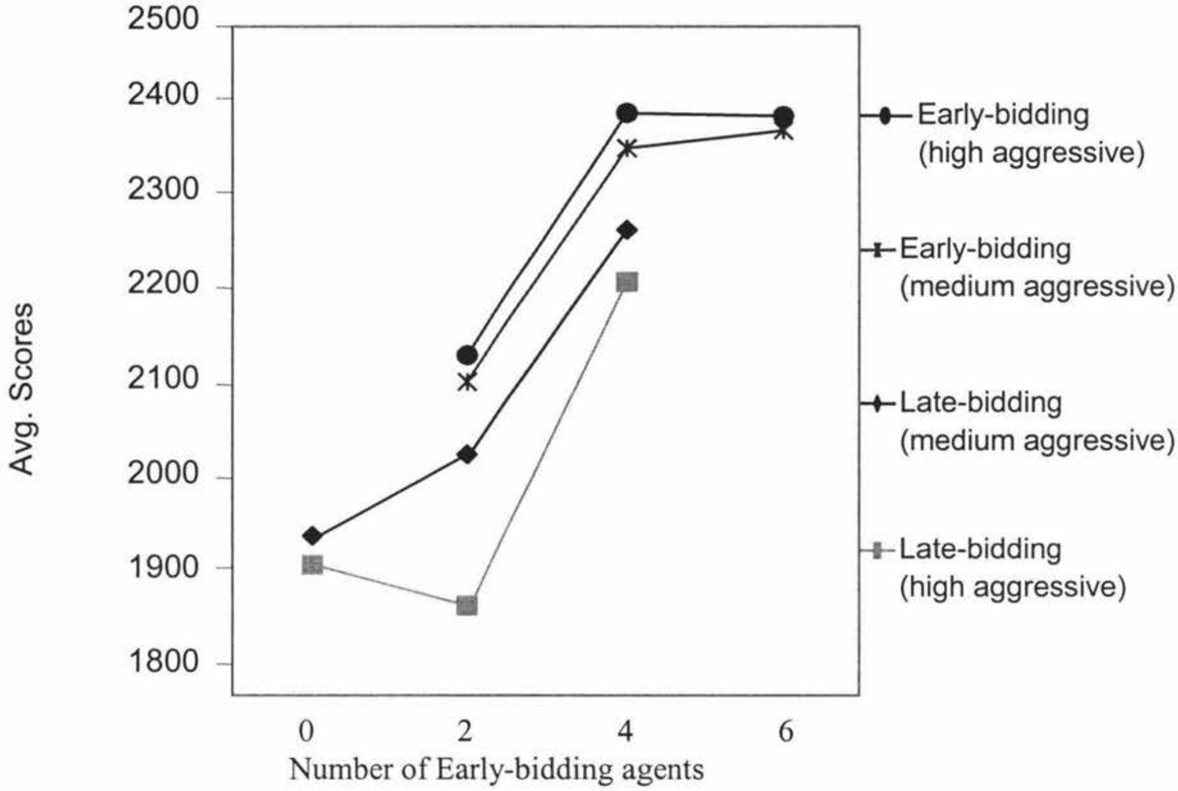

Figure 7: The performance of agents with four different strategies against different number of early-bidding agents (Vetsikas and Selman, 2003)

Figure 7 shows that Early-bidding is better than late bidding.

In TAC'01, there are two main candidate heuristics – early bird and deliberate buyer (they are also called "open-loop" and "closed-loop" by Stone et al. 2003 respectively). A trading agent using the early bird heuristic makes decisions at the very beginning of game and does not change them. This early bird heuristic was recognized as the reason to the success of LivingAgent (Fritschi and Dorer, 2002). LivingAgent was the winner of TAC'01. The early bird heuristic is based on perfect prediction assumption, which means that an agent could accurately predict the clearing prices for the auctions at the beginning of a game. This assumption is supposed to guarantee the optimality of static resource allocation (Ding *et al.* 2003).

The open-loop strategy has the advantage of buying a minimal set of goods. That is, it never buys more than it can use. On the other hand, it is susceptible to unexpected prices in that it can get stuck paying arbitrarily high prices for the hotel rooms it has decided to buy. In particular, if all eight agents are open loop and place very high bids for the goods they want, many of the prices will skyrocket, eliminating any potential profit. Thus, a set of open-loop agents would tend to get negative scores (Stone, Schapire, Littman, and McAllester, 2003).

The agent like ATTac used a deliberate buyer bidding decision based on a cost-benefit analysis: ATTac analyses the costs of postponing bids on auctions, if the cost exceeds the benefit of winning that good under multiple scenarios, then decide to bid or not.

Theoretically, the deliberate buyer should have a better performance compared to the early bird. But practically, its performance is very sensitive to its implementation. The difference of hotel room auction clearing prices and the ensemble of game participants also affect the performance of agents (Stone *et al.* 2002). Some experiments on open-loop vs. closed-loop (deliberate buyer and early bird) strategies were completed. The results are shown in the table 4.

Agent	Score	Utility
EarlyBidder	2869 $\pm$ 69	10079 $\pm$ 55
ATTac-2001(2)	2614 $\pm$ 38	9671 $\pm$ 32
ATTac-2001(3)	2570 $\pm$ 39	9641 $\pm$ 32
ATTac-2001(4)	2494 $\pm$ 68	9613 $\pm$ 55

Table 4: The results of one EarlyBidder against three different versions of deliberate buyer over 197 games (Stone, *et al*, 2003)

According to Stone, Schapire, Littman, and McAllester, the results in the table 4 suggest that the variation of the closing prices is the major decisive factor between the effectiveness of the open-loop and closed-loop strategies. They think that the closed-loop strategy could do better in large price variance situation, while the open-loop strategy should do better in the small price variance situation (Stone, *et al*, 2003).

In TAC'02, the winners used both heuristics. "the most successful agents were primarily heuristic-based and domain-specific" (Greenwald, 2003). The originally NP-complete optimisation problem became more tractable when the domain-specific heuristics are used.

- Compose travel plans earlier: buy most flight tickets earlier but postpone purchasing "risky" flight tickets to allow change resource allocation later (e.g. ATTAC (Stone *et al.*, 2002) and Whitebear (Vetsikas and Selman, 2003));

- Change among different heuristics strategies according to the prediction of competitiveness environment of the TAC game (e.g. SouthamptonTAC (He and Jennings, 2004));

- Use early bird heuristic in the hotel and flight auctions, and bidder heuristic in the entertainment auctions (e.g. UMBCTAC (Ding *et al.*, 2002)).

The success of these strategies is based not only by the ability of predicting accurately, but also by the ability to avoid and handle risk, especially avoid buying hotel rooms at a very high price.

Vetsikas and Selman (2003) did experiment on six different bidding strategies: high aggressive late Bidder; median aggressive late Bidder; high aggressive early Bidder; median aggressive early Bidder; high aggressive strategic Bidder; median aggressive strategic Bidder.

Bidding Strategies for Hotels:

- Low aggressiveness: Bids higher than the current ask price by an increment.

- High aggressiveness: Bids for all rooms progressively closer to the marginal utility.

- Medium aggressiveness: Combines two previous strategies

- ✓ For critical rooms (rooms with high marginal utility) the bid is close to the marginal utility

- ✓ For all other rooms it bids an increment above the current price (the increment increases as time passes)

Bidding time for Plane Tickets

- ➢ Late Bidder: (boundary str.): Buy at the beginning only tickets that are "certain" to be used

- ➢ Early Bidder: (boundary str.): Buy all tickets at the beginning

- ➢ Strategic Bidder: (intermediate str.)

  - ✓ Uses "Strategic Demand Reduction"
  - ✓ Buy all tickets at the beginning, except the ones that are "highly likely not to be used"

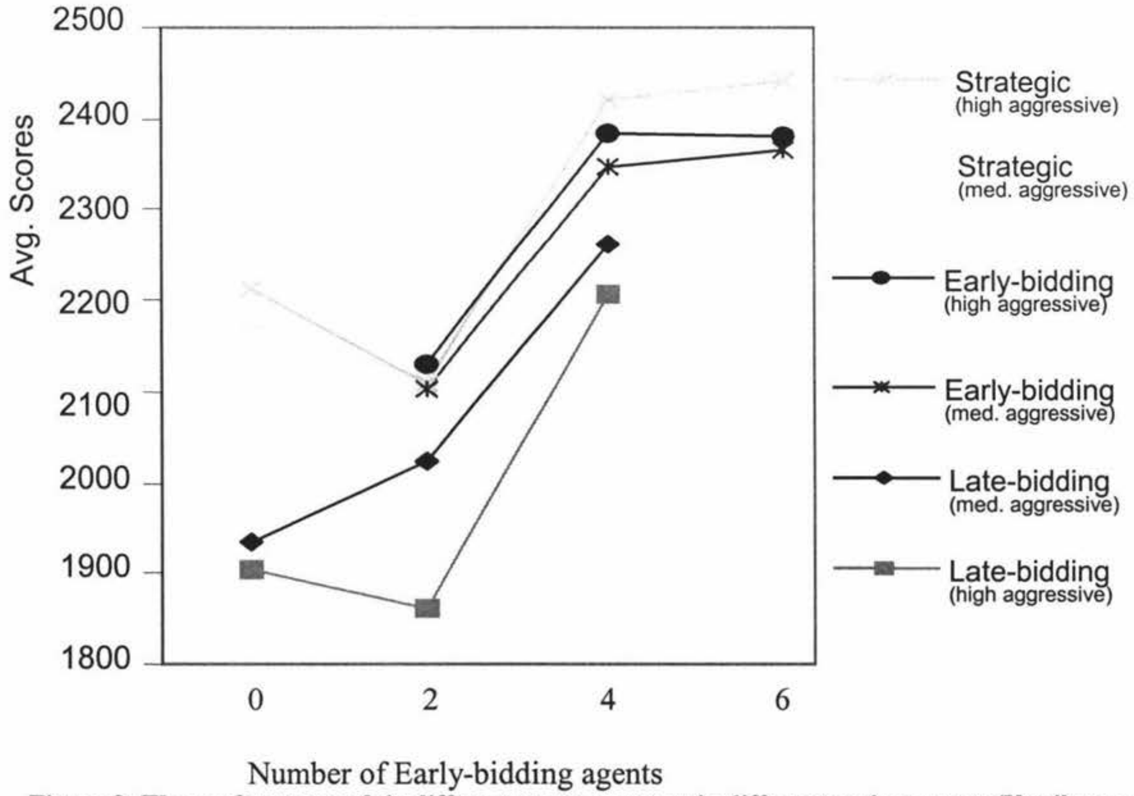

Figure 8: The performance of six different strategy agents in different environments (Vetsikas and Selman, 2003).

Figure 8 shows that the strategically bidding agents perform best overall.

1.3.6.3 Analysis of the hotel combinations

The success of an agent not only depends on its own strategies, but also depends on the preferences assigned by the server. There are 20 possible hotel combinations for a customer. Table 5 lists the 20 possible travel schedules.

Number	AD	DD	Hotel		Number	AD	DD	Hotel
1	1	2	SS		11	1	2	TT
2	2	3	SS		12	2	3	TT
3	3	4	SS		13	3	4	TT
4	4	5	SS		14	4	5	TT
5	1	3	SS		15	1	3	TT
6	2	4	SS		16	2	4	TT
7	3	5	SS		17	3	5	TT
8	1	4	SS		18	1	4	TT
9	2	5	SS		19	2	5	TT
10	1	5	SS		20	1	5	TT

Table 5: A customer's possible travel schedules

AD means Arrival Day, DD represents Departure Day. The number in AD, DD column corresponds to a weekday, e.g. 1 means Day 1. In the hotel column, TT means Tampa Towers and SS means Shoreline Shanties.

Researchers from University of Maryland computed the estimated price for each hotel combination. Hotel price was based on 1000 games in the 2002 seeding round. The mean is denoted by a solid line, and the median is denoted by a circle (Ding, *et al.* 2003).

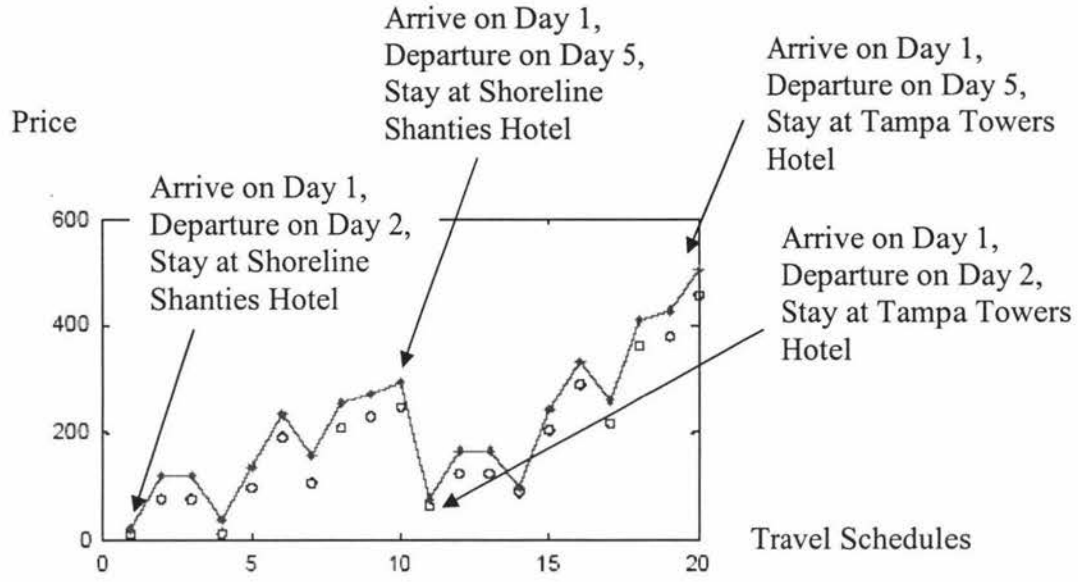

Figure 9: The estimated price for each hotel combination (Ding, *et al.* 2003)

For the same arrival day and departure day, it costs more for the agents to satisfy the clients who want to stay at Tampa Towers hotel than to satisfy the clients who want to stay at Shoreline Shanties hotel.

For both Shoreline Shanties hotel and Tampa Towers hotel, it costs less for the agents to satisfy the clients whose arrival day is day 1 and departure day is day 2 than to satisfy the clients whose arrival day is day 1 and departure day is day 5.

They found that (Ding, *et al.* 2003):

- Shorter hotel combinations cost less
- Short trips will always have better performance
- Shoreline Shanties hotels cost less

1.3.6.4 Price prediction

Hotel auctions are important in securing feasible travel packages and the most contested items during the TAC competition. Because of the random nature of the customers'

preferences and the way other agents deal with their hotel bidding, there are risks and uncertainty associated with the hotel auctions.
However, general price trends cannot be captured completely because they depend on the identity of the participating agents. The uncertainty of hotel price significantly influence the relative cost of assembling trips for clients.

There are several approaches predicting hotel clearing price (Wellman *et al.* 2004):

- Use the current price quote
- Adjust the current price quote by the difference between clearing price and the price at current time
- Predict by fitting a curve to the price points seen in the current game.
- Predict based on closing price data for that hotel in the past games or also used extrapolation from current prices.
- Similar approach as above, but condition on hotel closing time, awareness that the closing sequence will influence relative prices.
- Similar approach as above, but condition on full ordering of hotel closings, or what hotels are open or close at a particular point.
- Learn a mapping of the features of the current game to closing prices based on historic data.
- Use Fuzzy logic rules based on observation about associations between abstract features.
- Use a moving average technique

The team from the Artificial Intelligence laboratory, University of Michigan surveyed the price prediction approaches employed in TAC-02 game. Based on the survey responses and other strategies used in previous game, prediction techniques used in the TAC includes (Wellman, et al, 2004):

- Historical Averaging: Agent harami; agent UMBCTAC; Agent SouthamptonTAC (He & Jennings, 2004); Agent ROXYBOT (Greenwald, 2002); Agent cuhk (Wellman *et al.*, 2002)
- Machine Learning: Agent ATTac (Stone et al., 2003), Agent kavayaH (Putchala et al., 2002)
- Competitive Analysis: Agent Walverine (Cheng et al., 2005) (Greenwald, 2003)
- Fuzzy reasoning techniques: Agent SouthamptonTAC (He and Jennings, 2004)
- A Partially Observable Markov Decision Process Approach: Agent TOMAHACK (Braziunas, *et al,* 2002)
- Branch-and-Bound Optimization: Agent SICS (Boyan and Greenwald 2001)

1.3.6.5 What price to bid?

In the first price auction, most of the buyers would like to bid low or the actual price because the winner pays her/his winning bid price. But in the second-price auction, the buyer may take the risk to bid high because the winner only pays the second highest price. What is the best strategy: to bid high or low or actual price in the second-price auction? Paup Klemperer states:

> A little reflection shows that in a second-price sealed-bid private-values auction it is optimal for a player to bid her/his true value, whatever other players do. In other words "truth telling" is a dominant strategy equilibrium (and so also a

Nash equilibrium), so here, too, the person with the highest value will win at a price equal to the value of the second-highest bidder (Klemperer, 1999).

This is also applied to the TAC auctions. Each bidder places their own private values on the TAC items such as hotel rooms. The hotel auction is a 16th English ascending auction, which means the agent with the highest value will win at a price equal to the value of the 16th highest bidder.

Assume that Bidder1 and Bidder2 have the following price arrangement:

- Bidder1 high price: $ 600
- Bidder1 actual price: $ 200
- Bidder1 low price: $ 100
- Bidder2 high price: $ 500
- Bidder2 actual price: $ 150
- Bidder2 low price: $ 50

Assume that Bidder2 holds the 16th highest price in the 16th price auction. Bidder1 enters the auction with different prices. Table 6 shows a simple example of how the equilibrium occurs. The description is from the Bidder1's point of view.

Bidder1 / **Bidder2**	**Bid high Price (b1) $600**	**Bid Actual Price (b1) $200**	**Bid Low Price (b1) $100**
Bid high Price (b2) $500	Win but lose. Have to pay high price $500. (Unhappy)	**Happy** to give up	Lose but **happy**
Bid Actual Price (b2) $150	Win with profit $50 **(Happy)**	Win with profit $50 **(Happy)**	Lose (unhappy)
Bid Low Price (b2) $50	Win with profit $550 **(Happy)**	**Win with profit $150 (Happy)**	Win with profit $150 (**Happy**)

Table 6: The bidder price matrix 1

This example shows that if the bidder1 bids the true value, it never loses. It only pays her/his acceptable price or makes profit when she wins.

This time, assume that Bidder1 holds the 16th highest price in the 16th price auction. Bidder2 enter the auction with different prices. The description is from the Bidder2's point of view.

Bidder1 / Bidder2	Bid high Price (b1) $600	Bid Actual Price (b1) $200	Bid Low Price (b1) $100
Bid high Price (b2) $500	Lose but **happy**. Don't have to pay high price $600.	Win but lose $50 (Unhappy)	Win with $50 profit **happy**
Bid Actual Price (b2) $150	Lose but **happy**. Don't have to pay high price $600.	Lose but **happy**. Don't have to pay price $200.	Win with $50 profit **happy**
Bid Low Price (b2) $50	Lose but **happy**. Don't have to pay high price $600.	Lose but **happy**. Don't have to pay price $200.	Lose but unhappy. Could have $50 profit.

Table 7: The bidder price matrix 2

This example shows that if the bidder2 bids the true value, it never loses. It only pays her/his acceptable price or makes profit when she wins.
Vetsikas and Selman talked about the bid price dilemma in their presentation (Vetsikas and Selman, 2003):

- If not aggressive, could get outbid and lose rooms needed.
- If too aggressive, prices will skyrocket and the agent's score will be reduced.

Peter R. Wurman also pointed out that:

> "Truth telling is a dominant strategy because it is optimal regardless of the other agents' strategies" (Wurman *et al.*, 1998).

If all the agents use the same strategy, for example all bids low price or all bids true value. Which strategy is better? Wellman and other researchers did experiments on those two different bid strategies: shading (an agent bids at a lower price than its marginal values), non-shading (agents bid true marginal values). They found that if the agents bid their true values this would improve social welfare, but sacrifice individual profits. The average client-adjusted payoffs for all shading, all non-shading are 3339 and 3155, respectively. The corresponding market efficiencies are 88.5% and 89.4% (Wellman, *et al.,* 2003).

If the agent knows the other agents' strategies, there is another tactic that could be applied, which is "against the tide". There is an interesting observation of going "against the tide". Vetsikas and Selman stated:

> In general an agent wins when the agent is going against the tide. i.g. being aggressive when most other agents are not (Vetsikas and Selman, 2003).

Experiments made by ATTac show that: When one ATTac played with seven Early Bidders, ATTac is against the tide. ATTac won.

Agent	Score	Utility
ATTac	2431 ± 464	8909 ± 264
EarlyBidder	-4880 ± 337	9870 ± 34

Table 8: One ATTac played with seven Early Bidders (Stone, *et al.*, 2002).

When seven ATTac played with one Early Bidder, Early Bidder is against the tide. Early Bidder won.

Agent	Score	Utility
ATTac	2578 ± 25	9650 ± 21
EarlyBidder	2869 ± 69	10079 ± 55

Table 9: Seven ATTac played with one Early Bidder (Stone, *et al.*, 2002).

If in the unknown situation, the best strategy is to bid at true valuation.

1.3.7.6 Completion problem

Given the current holdings, and given (expected) prices, what goods should be chosen to buy or sell at these prices?

There are two general approaches in TAC-01:

- Global optimisation: Agents like whitebear solved the completion problem using global optimisation techniques used by TAC-00 agents, including integer linear programming (Stone et al. 2001) and heuristic search (Greenwald & Boyan 2001).

- Local optimisation: Agents like TacsMan constructed travel packages by optimising utility client-by-client (Porter, *et al,* n.d.).

Local optimisation completion strategy is a kind of greedy strategy for allocation. It is computationally feasible to quickly determine the maximum utility achievable by one client given a set of purchased goods, move on to another client with the remaining goods, etc. However, this strategy can lead to sub-optimal solutions.

A different approach is a heuristic approach that implements the greedy strategy over a number of random client orderings and chooses the most profitable resulting allocation. Empirically, the resulting allocation is often optimal. ATTac chose 100 random client orderings to implement the heuristic approach. In a set of seven games from just before the tournament, ATTac's greedy allocator was run approximately 600 times and produced allocations that averaged 99.5% of the optimal value (Stone, *et al.*, 2001).

1.3.6.6.1 Linear Programming Approach

In the competition, Agent ATTac implemented integer linear programming approach, an allocation strategy to find the optimal allocation of goods (Stone, *et al.*, 2001). The integer linear programming approach works by defining a set of variables, constraints on these variables, and an objective function. Agent ATTac defined 272 variables and 188 constraints (Stone, *et al.*, 2001).

1.3.6.6.2 A Genetic Algorithm-Based Optimisation Technique

Agent PaininNEC used a combination of heuristics, including a genetic algorithm-based optimization technique to find the optimal requirements of hotel rooms (Greenwald, 2003). Genetic Algorithms are useful and efficient when the search space is large, complex or poorly understood, the domain knowledge is scarce or expert knowledge is difficult to encode to narrow the search space. The advantages of the GA approach are intrinsically parallel; able to manipulate many parameters simultaneously and handle arbitrary kinds of constraints and objectives. Their major disadvantage is that they are relatively slow, being very computationally intensive compared to other methods, such as random optimization.

1.3.6.6.3 Generate domain-specific heuristics approach

Agent WHITEBEAR generates domain-specific heuristics and experiment with these heuristics to determine which are the most effective. Sometimes, the most effective heuristic is a combination of two or more heuristics (Vetsikas and Selman 2002).

1.4 Summary

In this chapter, the motivation behind this research was explained. The definitions of relative terms including softare agent were provided and the literature review of TAC game and TAC agents were given.

The purpose of this study is to investigate the TAC game and the TAC agents. As shown in the literature review, there has no article evaluating the TAC game from auctioneer's point of view. There is no article listing the changes of TAC game. There is no article describe about how to play against 7 aggressive open loop agents in TAC game. This thesis will address these issues. A fuzzy logic model for predicting the TAC hotel price change will be designed. A short overview of following sections in the thesis is presented below.

Chapter 2: Is TAC game a good design?

In this chapter, the design of the TAC game will be evaluated from an auctioneer's point of view. The changes of TAC game will also be listed.

Chapter 3: The RiskerWise agent

In this chapter, the design and performance of the RiskerWise agent playing against seven open-loop EarlyBidder DummyAgents will be presented in detail. And the relationships among score, utility and cost will be discussed.

Chapter 4: Using Fuzzy Logic to Predict the Hotel Price Increase

In this chapter, basic concepts of Fuzzy Logic are introduced and the design of fuzzy logic system for predicting hotel auction price change in TAC is explained.

Chapter 5: Conclusion and future development

This Chapter gives conclusions of the thesis and future development of the Fuzzy Logic hotel price change prediction System.