UNIVERSITÉ DU QUÉBEC À CHICOUTIMI

THE URBAN REAL-TIME TRAFFIC CONTROL (URTC) SYSTEM : A STUDY OF DESIGNING THE CONTROLLER AND ITS SIMULATION

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PAR
WANG-LEI

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Abstract

The growth of the number of automobiles on the roads in China has put higher demands on the traffic control system that needs to efficiently reduce the level of congestion occurrence, which increases travel delay, fuel consumption, and air pollution.

The traffic control system, urban real-time traffic control system based on multi-agent (MA-URTC) is presented in this thesis. According to the present situation and the traffic's future development in China, the researches on intelligent traffic control strategy and simulation based on agent lays a foundation for the realization of the system.

The thesis is organized as follows: The first part focuses on the intersection' real-time signal control strategy. It contains the limitations of current traffic control systems, application of artificial intelligence in the research, how to bring the dynamic traffic flow forecast into effect by combining the neural network with the genetic arithmetic, and traffic signal real-time control strategy based on fuzzy control. The author uses some simple simulation results to testify its superiority. We adopt the latest agent technology in designing the logical structure of the MA-URTC system. By exchanging traffic flows information among the relative agents, MA-URTC provides a new concept in urban traffic control. With a global coordination and cooperation on autonomy-based view of the traffic in cities, MA-URTC anticipates the congestion and control traffic flows. It is designed to support the real-time dynamic selection of intelligent traffic control strategy and the real-time communication requirements, together with a sufficient level of fault-tolerance.

Due to the complexity and levity of urban traffic, none strategy can be universally applicable. The agent can independently choose the best scheme according to the real-time situation. To develop an advanced traffic simulation system it can be helpful for us to find the best scheme and the best switch-point of different schemes. Thus we can better deal with the different real-time traffic situations.

The second part discusses the architecture and function of the intelligent traffic control simulation based on agent. Meanwhile the author discusses the design model of the vehicle-agent, road agent in traffic network and the intersection-agent so that we can better simulate the real-time environment. The vehicle-agent carries out the intelligent simulation based on the characteristics of the drivers in the actual traffic condition to avoid the disadvantage of the traditional traffic simulation system, simple-functioned algorithm of the vehicles model and unfeasible forecasting hypothesis. It improves the practicability of the whole simulation system greatly. The road agent's significance lies in its guidance of the traffic participants. It avoids the urban traffic control that depends on only the traffic signal control at intersection. It gives the traffic participants the most comfortable and direct guidance in traveling. It can also make a real-time and dynamic adjustment on the urban traffic flow, thus greatly lighten the pressure of signal control in intersection area. To

some extent, the road agent is equal to the pre-caution mechanism. In the future, the construction of urban roads tends to be more intelligent. Therefore, the research on road agent is very important. All kinds of agents in MA-URTC are interconnected through a computer network.

In the end, the author discusses the direction of future research. As the whole system is a multi-agent system, the intersection, the road and the vehicle belongs to multi-agent system respectively. So the emphasis should be put on the structure design and communication of all kinds of traffic agents in the system. Meanwhile, as an open and flexible real-time traffic control system, it is also concerned with how to collaborate with other related systems effectively, how to conform the resources and how to make the traffic participants anywhere throughout the city be in the best traffic guidance at all times and places. To actualize the genuine ITS will be our final goal.

Keywords: Artificial Intelligence, Computer simulation, Fuzzy control, Genetic Algorithm, Intelligent traffic control, ITS, Multi-agent, Neural Network, Real-time.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AI	Artificial Intelligence
ACL	Agent Communication Language
ANN	Artificial Neural Network
ANN-FC	Artificial Neural Network- Fuzzy Control
AOP	Agent Oriented Programming
BP	Back Propagation
C/S	Client/Server
COMET	Concurrent Object Modeling and architectural design Method
CPS	Cooperative Problem Solving
DAI	Distributed Artificial Intelligence
D/A	Digital analog
DTDS	Distributed Transportation Dispatch System
DVMS	Distributed Vehicle Monitor System
FC	Fuzzy Control
FIPA	Foundation for Intelligent Physical Agent
GA	Genetic Algorithm
GDP	Gross Domestic Product

GPS	Global Positioning System
ITS	Intelligent Transportation System
KQML	Knowledge Query Manipulation Language
MAS	Multi-agent System
OO	Object-Oriented
OOP	Object-Oriented Programming
P2P	Peer-to-Peer
PNP	Plug and Play
RPC	Remote Procedure Calls
RMI	Remote Method Invocation
RRT	Rail Rapid Transit
USS	Urgent Succor System
UTFGS	Urban Traffic Flow Guidance System

CHAPTER 1

INTRODUCTION

1.1 Research Background and Objectives

In the large cities with a population over a million in China, the annual direct and indirect economic loss caused by traffic congestion is about 160 billion Yuan, approximately 3.2% of GDP. Moreover, the other negative influences are unimaginable [68]. However, the possibility to rebuild or enlarge roads in these large cities becomes less and less because of the limited space. So the major method of solving traffic problem is to organize and control the traffic flow by use of modern computer, communication and control, etc. making full use of present traffic network, to let it flow in order.

Now, intelligent transportation system is put forward, that is using the latest research products in fields such as modern computer, electron, communication, artificial intelligence, automobile, etc. to reform the traditional traffic system, achieving intelligent vehicle and road, that is, making intelligent driver drives intelligent vehicle on intelligent road, finally letting the most vehicles pass and present traffic situation improve. ITS mainly contains: intelligent traffic control system, intelligent vehicle driving system, traffic guidance system, traffic information management system and urgent succor system, etc.

Setting up ITS needs a lot of manpower, material and financial resources and it cannot produce obvious effect in short period. Meanwhile, because of the different traffic condition in each country, though ITS theory can be used for reference, universal ITS products cannot be achieved. Thus the goal of this thesis is to make out a real-time traffic control plan, which is better than reconstructing roads and meets present urban traffic demands.

In urban traffic control, intersection is a basic unit of traffic network, so its research is the prerequisite and basis of urban traffic research. At present, one intersection takes large quantity of traffic flow. Signal control is generally adopted. However, this thesis intends to start with real-time signal control strategy to optimize signal intersection and comment its operating condition by simulation mode, thus to reduce traffic delay. Later, it gradually improve the whole real-time traffic control system and realize ITS.

1.2 Research Significance of the Thesis

This thesis is mainly on real-time traffic control and simulation of intersections, which helps make full use of intersection resources, reduce or eliminate its bottleneck influence in traffic network, improve the traveling capability and the service level in the whole traffic network.

Traffic engineers from all countries carrying out research on intersection are widespread and thorough. They have collected more basic database than researching on other traffic facilities. But its operating analysis is still the most difficult with different analysis methods, which is caused by the complex traffic-operating mode in intersection's area. Chinese traffic operating has its special characteristics from such angles as facility, vehicle performance, traffic content and the drivers, etc. which is different from other countries, so the operational analysis formulas of data model from other countries don't fit for Chinese traffic analysis either on accuracy or precision. However, we think their research products is good for reference, basing of which seek out Chinese intersections in road system and put forward a set of practical operational analysis.

1.3 Thesis Method

This thesis seeks real-time traffic control strategy from artificial intelligence theory. Intelligent control is superior to traditional one which is characterized in setting D/A (digital analog) of controlled objects, however, because of complexity, variability and high non-linearity of the traffic objects, it is difficult to set up accurate D/A to describe them in addition to uncertainty, so it is impossible to solve traffic control problem of complex objects using traditional methods. However, intelligent control, a kind of nonlinear model control method, can do. It imitates human intelligent decision. So it is better in solving complex and uncertain problems. Intelligent control contains: fuzzy control, neural networks, genetic algorithm and expert system, etc.

The thesis discusses the traffic control strategy from these aspects. Needs to pay attention that no technology can be called an absolute plan. They have different applicable ranges and gradation. What we shall do is to make full use of these technologies, comparing their merits and demerits, aim at the special details, selected composition, so as to let them work optimally for urban traffic control. It is the so-called synthesis intelligence out of which an intelligent traffic control strategy based on agent is drawn. Agent is generally believed to be cognitive, rational, deliberative and cooperating. [17][52][53] It has three differences at least with the traditional object-oriented viewpoint.

Agent has a stronger autonomy than object, specially, which decides and carries out actions requested by other agents by it.

Agent has flexibility, reactivity, pro-activeness and social ability, however standard object model doesn't have.

Multi-agent has innate multithread. Each agent has at least one control thread.

All the above characters are fit for solving complex traffic control problems. As we study on real-time traffic control of the whole city, the research on multi-agent systems in distributed artificial intelligence (DAI) meets the actual demands. Multi-agent system is a loose cooperative one, which is made up of autonomous intelligent agents. For an overall goal or other different aims, they share in relative problems and the solving methods to cooperative Problem Solving (CPS).

In the process of solving traffic problem, communication is the base of cooperation. There are mainly two communication models in DAI: shared memory and message passing. We use message passing to communicate based on distribution and parallel of traffic agents.

Distributed problem solving system is generally divided into two kinds: task sharing and information sharing. They are shown respectively in Figure 1.1 and 1.2. Number in the figure refers to order of incidents. In task sharing system, nodes cooperate with each other by undertaking sub-assignment. Control in the system takes goal as the reference. Goal of each node is a part of the overall assignment. In information sharing system, nodes cooperate by sharing partial outcomes. Control in the system takes data as reference. So solving of each node at any time depends on the data and knowledge it owns or received from other nodes at that time. [42][58][59]

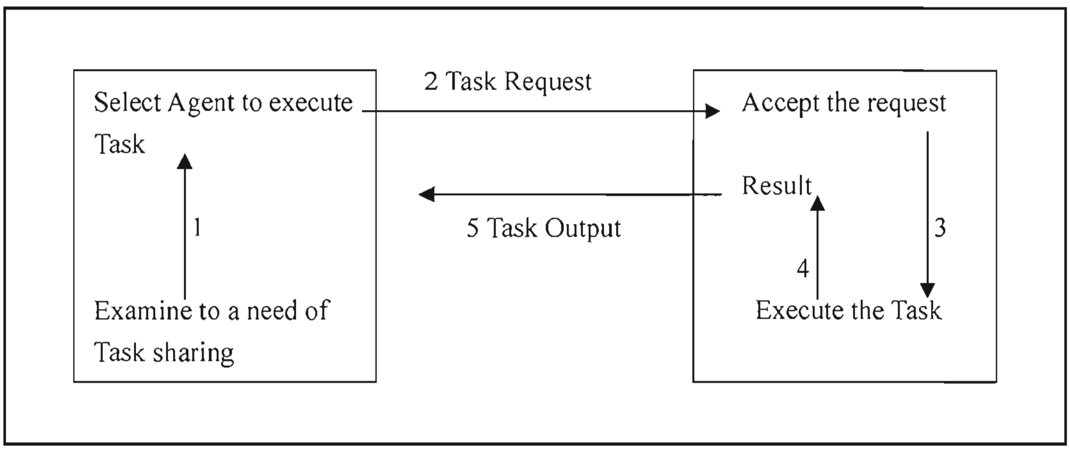

Figure 1.1 Task Sharing

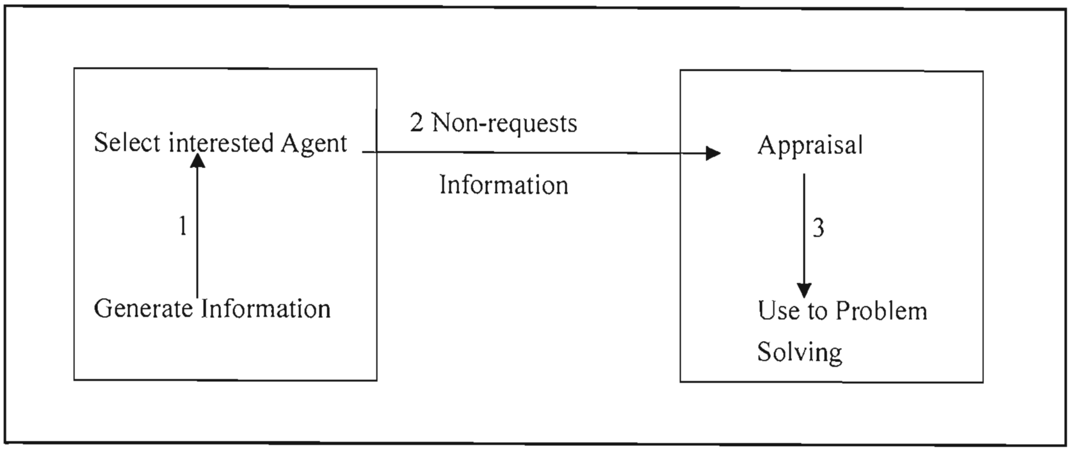

Figure 1.2 Information Sharing

Task sharing fits for solving tasks with gradations, while information sharing fits for solving problems whose results of either sub-task interact with each other and part of which needs multi-purposing. Actually, these two methods are essentially compatible. They put emphasis on how to solve problem in different solving stages. In our design, task sharing fits for distributed intersection signal control while information sharing fits for distributed transportation dispatch system (DTDS) and distributed vehicle monitor system (DVMS) to be developed later. It is necessary to evaluate these methods before putting them into use.

It is very complex to realize modern control and management of urban traffic. Using computer, we can simulate actual traffic flow from different gradations and angles; we can understand in advance the practical effects of traffic management measures and avoid on-the-spot experiment that cost expensively in a long term. We obtain a lot of data with low cost that could meet conveniently different researchers' needs. Simulation model in this thesis uses agent in a certain degree in order to adjust to further development.

Shoham puts forward AOP (agent oriented programming) based on OOP (object-oriented programming). [52] It is an enlargement of OOP. Shoham takes AO P as a special OOP. AOP allows each agent to own relative environment, knowledge and belief of other agents. AOP allows these models to own capacity and make promise, etc. An operation is made up of the informant, request, negotiation and help among each agent. Nowadays, as instruments for developing relative agent are not mature, we still use OOP to realize simulation system. In the actual simulation design, we use active object to embody agent as an autonomous entity. So some models in simulation system use agent's theory although it is based on object-oriented technology. We hope this simulation system to meet such demands as scalability, versatility, reusability and robustness to solving complex practical traffic problems.

1.4 Thesis Organization

The rest of this thesis is organized into the following chapters:

Chapter 2 generally introduces relative knowledge on signal control and reviews its optimization design process. An intelligent traffic system based on agent using real-time traffic control is put forward to solve traffic problem.

Chapter 3 mainly research on agent-based intelligent real-time traffic signal control strategy. At present traffic control model is generally made by traffic control center. But there exist some problems with it, such as slow response, bad adjustment, etc. Therefore according to agent's characteristics and combining developing trend of distributed intelligent control system. This chapter first discusses how to set up intelligent traffic control system based on agent theory. Secondly, the chapter discusses the core of traffic signal control strategy by using artificial intelligence in intersection-agent, as well as neural network, genetic algorithm, fuzzy control and expert system. Besides it uses simple simulation to test the control effects. We have to use proper real-time traffic signal control strategy according to actual situation, because condition of each urban intersection is different (for example, isolate intersection and correlative "intersection-group", different intersection of geometry design and intersection having on different traffic function's shoulder, etc). Finally, although Chinese real-time traffic control focuses on urban intersection so far, traffic control in roads cannot be overlooked. As public traffic is the main cause, how to cooperate with intelligent control of public traffic becomes the next research key issue.

Chapter 4 elaborates agent-based intelligent traffic control simulation and explains the necessity to set up traffic simulation system and the advance of traffic simulation based on agent theory. In traffic simulation system, it is very important to simulate macroscopic traffic flow and the microscopic single vehicle. In our simulations, we take vehicle-agent as an intelligent body of driver and vehicle whose decision style is the actual traffic behavior, embodying a driver's decision.

So combining characteristics of fuzzy intelligent control, we discuss vehicle-agent's fuzzy decision and enlarge the factors that influence it. It differs from former simulation research based on fixed D/A vehicles. Driving on urban roads differs from driving on highways. Traffic flow on highway embodies a collective behavior, while vehicles on urban roads embody individual behavior. So we must make them have autonomous intelligence in traffic network. We believe that more vehicle modes resemble actual traffic driving more simulation value they embody. At the same time, In order to meet the future traffic control need to develop, road agent in traffic network design model is also mentioned.

Chapter 5 points out that although agent software is superior, at present, there does not exist good environment for the development of agent commodity software. However, AOP as a software development method, we can develop agent using other software environment. In this chapter, we discuss using OOP to realize MA-URTC simulation system. Traffic simulation based on agent is a massive and long-term process, which needs huge manpower and material resources. Java and MATLAB are used to set up a prototype intelligent traffic simulation environment, meanwhile carry out simple emulation to lay a foundation for further research.

Chapter 6 reviews main contents and conclusions of this thesis, and discusses relative technological characteristics and puts forward further research direction.

CHAPTER 2

COMMENT ON THE PROGRESS OF THE TRAFFIC SIGNAL CONTROL SYSTEM

In China, the traffic jam phenomenon of the level intersection is becoming more and more serious. Vehicles shunt, meet and cross repeatedly in intersection area where traffic condition is complicated. The intersection is a bottleneck that restricts the urban road function. To any city, it is essential to strengthen the infrastructure construction of urban road, and improve the fast arterial highway system of the city, but doing well of the control management of the intersection undoubtedly has realistic benefits.

2.1 Introduction of the Intersection

The central lines crossing at the same height is called the level crossing. According to the shape of level crossings, we divide them into T-shaped crossing, Y-shaped crossing, cross crossing, and loop crossing, etc. The function of level crossing is to commit road network by joining road together. There are multi-direction traffic flows at the crossing, and the traffic flow is guided by the traffic light to form the traffic bottleneck. Moreover, any left-turning or direct driving vehicle, either motor vehicles or non-motor vehicles interlock here, where traffic accident is likely to happen. Traffic control model at intersection can be divided into signal control and parking control. Signal control is to control the traffic flow with the traffic semaphore while parking control can also be called priority control, which has priority for the traffic flow on main roads, lets other traffic flows stop and wait temporarily. [69]

2.2Traffic Signal Terms and Control Evaluation Indexes

The following is the introduction of some special-purpose terms of the traffic signal control:

- Cycle — the whole process that the signal displays.
- Cycle length — the total time that the signal needs to finish one cycle expressing with seconds, and using C as the symbol.
- Phases the signal — there are several control states of a traffic semaphore within one cycle, and each kind of control state is called the signal phase. That is, send signals with the same color simultaneously to show time sequence towards one or several rates of traffic flow in order within one cycle and open circularly signal lamps in this order, and each different compounding signal is called a phase.
- Intervals — the continuous unchanging time that all signals display.
- Time of green lights — the time that the phase of green lights last, using G_i (refers to the phase of i) as the symbol and unit: Sec.

- Effective green light time — the time that the vehicles granted the right-of-way can use effectively in a given phase. We use second as the unit, and g_i as the symbol (to the phase of i).
- The traffic light of green signal ratio — the ratio between the effective green light time and the cycle. g_i/C is used as the symbol (to i phase).
- Effective red light time — the continuous time that forbid a vehicle to run effectively. We use second as the unit. It means that cycle deducts the effective green light time that regulates the phase. The symbol: r_i.

The basic goal of using signal control at level crossing is: assign entry lane right-of-way rationally with light color signals, so as to keep crossing in a good order, to reduce or dispel conflicts totally which may cause traffic accidents, and keep operation of crossing targets best. The major indexes are as follows:

- Delay time –it refers to the subtraction between the necessary time a vehicle needs to pass by the leading way of crossing entry in a forbidden position and the time a vehicle needs to use while be in no hindering position. There are two appraisal yardsticks: one is average delay time, and the other total delay time.
- Average queuing length — Refers to the average value of the longest length that every lane needs to queue within one cycle of the signal. The longest length of each lane of queuing refers to the length when the phase of green lights starts in the driveway.

- Numbers of average starts and stops — It refers to times that vehicles stop and restart at the intersection because of restraint of traffic signal light. The times of stopping and starting are not only closely related to control parameter, but it is one of the indexes used to weigh the degree of saturation.
- Traffic capacity — Refers to the total sum of vehicles passing by an intersection way in entry way in stop line within a given period of time. The traffic intersection capacity is not merely related to control strategy, but closely related to conditions of the real road (including the width of leading way, number of driveway, radius of turn, length of turn, and leading way slope) and traffic conditions (rate of traffic flow, vehicle types, the proportions of turn round vehicles, speed, non-motor vehicles, pedestrian interference, and the division of roadway functions, etc). The traffic capacity is an important evaluation index of the degree of saturation at the intersection. Besides above-mentioned evaluation indexes, there are others such as traveling time, crowded time, oil consumption, waste gas discharge, etc. As all these are not in common use when appraising the isolated level crossing, we do not mention them.

The one that needs pointing out is that these evaluation indexes cannot reach best at the same time in a traffic control system. For example if we want to improve traffic capacity and reduce the times of starting and stopping, we have to strengthen signal cycle, but once signal cycle exceeds the optimum cycle, delay index would turn ineffective. So for the signal control system with many goals we have to introduce the integrated target. [21] The overall target is expressed with the weighted sum of above-mentioned indexes. The most frequently used overall target is expressed as follows:

$$f(G) = k_1 D + k_2 S + k_3 Q$$

Among them: k_i is weighting coefficient, $\sum_{i=1}^{3} k_i = 1$, D, S, Q refer to delay times, parking times and traffic capacity respectively. The weight of the three indexes is not fixed, which is adjustable in line with the change of the traffic flow for the sake of sufficient precedence of certain index, and adapts to the requirements of real-time traffic.

2.3Control Types of Traffic Signal

Modern traffic control has many kinds of methods for signal timing. It diversifies from simple two-phase fixed cycle to complicated multi-phases control. According to the difference of the control devices adopted, the traffic signal generally has three types.

- Fixed cycle signal control: The cycle length, phase, green-light time and changing intervals, etc. are confirmed in advance. Signal runs according to the fixed time, and the time and phase of each cycle is invariable. Depending on the equipment offered, we could use some kinds of timing plans, each kind of which changes alternately within the stipulated time. This kind of method is relatively suitable for the road with more steady traffic flows, and its fabrication cost is lower and realistic, however because of the complexity and time variation of the traffic flow, the effect of this signal control is relatively bad.

- Half-responsive signal control: this signal control guarantees the main arterial highway keeping green light until the detection installed at the sub-highway detects that there are vehicles to reach at this moment. The signal displays green light for sub-highway at once after a proper interval of conversion. Green light time will continue until all vehicles on the sub-highway get through the intersection or sustain the biggest green light time in arterial control system. Rationed times of green light of sub-highway must be confined to the pre-booked time.
- Whole-responsive signal control: All phase of this signal are controlled by the detection. Each phase generally stipulates the minimum and the maximum green time, the same as the order of phase. The cycle length and green light time of this method can make great changes as requested. Some phases of cycle can be used freely. When detector detects the existence of traffic flow, it distributes the phase for the traffic flow automatically.

2.4The Types of Urban Traffic Control

Urban traffic control has many ways and classifications. Considering the convenience of choosing the control method, we divide them according to the span of control. The following is a brief introduction:

- Point control method: Point control method refers to the way that the signal light at the intersection runs independently. It is suitable for the far-distance adjacent intersection or the place where arterial control has no effect or the traffic needs to change apparently because of each phase. It controls independently the cycle and the green signal ratio at intersection respectively is more effective than others.
- Arterial control method: As the traffic flow characterized in moving successively. When several nearer intersections on arterial is independent of signal control with each other, the vehicles from the upstream are likely to meet the red light at the intersection of downstream. Isolated control method among intersections unavoidably causes stopping frequently. At this time, if link and control the semaphores of these intersections on the basis of time, it can form a "green wave belt", thus reduce the stopping times and delay time on the arterial. The main characteristic of the arterial control is to establish the same cycle and the relative phase difference of several semaphores. Arterial control is suitable for the intersections that the distance is not far away, and the traffic flow is heavy. Since the traffic flow will not disperse at this moment, the control performs more effectively. Arterial control on the basis of control time can be divided into: simultaneity control, priority control and interaction control; cable control and non-cable control according to whether it has cable to connect or not; according to the control strategy, it can be divided into: fixed cycle control, scheme choosing responsive control and scheme production responsive control.

- Area control method: It can also be called coordinated regional control. It adopts coordinated control to many sets of semaphores on the large area of road network. Because these semaphores are interrelated, and the timing change of each intersection is more or less related to other intersection. Area control method is the expansion of the arterial control. It is generally divided into several sub-regions, which refer to the region that can control with the same cycle. It is made up hierarchically of central controlling machine, sub-region controlling machine and intersection controlling machine. Central control machine provides with each sub-region the best cycle. Each sub-region machine is responsible for the optimized computation of the phase difference and the green signal ratio , intersection control machine adjusts optimally it again. Area control system is suitable for the structure that many arterial highways interlock together. Traffic control cannot achieve the anticipated result if the arterial control is adopted. Area control method can be divided into fixed timing control system and adaptive control system according to the control method.

2.5The Summary of the Signal Intersection Control System

The signal control system at intersection can be roughly divided into three research stages: Early stage refers to the period from 1868, at Westminster crossing of London, when the earliest traffic signal light appeared, to the 1960s when the countries all over the world began to study the coordinated signal linkage and set up simulated mathematics model for different traffic flow situations at each intersection to solve the optimized problem of signal timing. The second stage, Britain traffic and traffic road research institute (TRRL) in 1966 began to research and develop the system TRANSYT (Traffic Network Study Tool), SCATS that Australia began to develop since the seventies last century (Sydney Coordinated Adaptive Traffic System) and SCOOT (Split-Cycle-Offset Optimization Technique) system that the system and Britain TRRL began to study and develop in 1973, etc. Having put forward the concept of " intellectual transportation system ", that is ITS (Intelligent Transportation System) from 1994 to the present, namely use such latest research results in the field as modern computer, electron, communication, artificial intelligence, automobile, etc., to transform the traditional traffic system, to reach the intellectual faculties on the vehicles and road, its main content includes the following several respects: Intelligent traffic control system, intelligent vehicle driving the system, USS, UTFGS and traffic information service system, etc..

2.6Intelligent Traffic System Based on Agent

In the course of research on the intelligent traffic system, software is the kernel and soul of the whole system. How to use software to carry out the design development of the traffic engineering, to make each system cooperate with each other, is the weak point of carrying out intelligent traffic research at present. The appearance of agent technology offers a new concept for the settlement of this problem. As the latest software development approach and the results in the artificial intelligence field, agent is a leap on people's concept. Agent is relatively suitable for the settlement of the problem on the big complicated system, and has already been applied to the simulation of battle field of intelligence fields, the operation management of the airport, internet individualized information service, production of intelligent chemical plant and simulation of the eco-system, etc.

As an entity of intelligence, agent has all kinds of abstract levels. Figure 2.1 illustrates it. As to traffic field, we can regard each subsystem in the intelligent transportation system as an agent, meanwhile within each agent; different small granular agents can be included. Cooperating with each other will make the whole traffic system achieve the goal of optimization soundly.

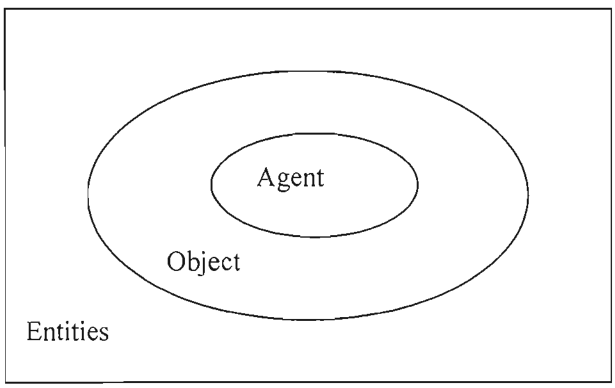

Figure 2.1 Agent-Object-Entities relation

2.7Summary

The chapter mainly introduces something about the Traffic Control Technology at intersections and the development of it. We claim that we should adopt some new techniques rather than use the old ones in traffic control so as to solve the increasingly serious problems on traffic. As a new technology for developing software, agent technology is the development of OO technology. Its autonomy, activity and collaboration make it convenient for people to describe all kinds of traffic conditions, and it is further revolution of software developing in computer science. The great effects that the agent technology has brought are to influence our software developing methods greatly. To make greater progress in promoting the computer's intelligence, reliability, portability, interaction, expansibility, etc. are the main software developing purpose in the future. We hope that we can solve the bottleneck in real-time traffic control in the city by using the agent technology in our system.

CHAPTER 3

AGENT-BASED INTELLIGENT TRAFFIC SIGNAL CONTROL STRATEGY

3.1 Synopsis of Agent

3.1.1 Advantage of Intelligent Agent

Agent technique is the key in software engineering study and artificial intelligence field. It is a branch of distributed artificial intelligence and also a development of expert system at unit intellectualization. Although different groups have different interpretations of Agent, however as a high-intelligent program, agent may be a module even or a sentence. From the angle of software engineering, it is a new development of OO. It contains further understanding about software development, which makes up for the shortcoming on the development of OO. It describes the active object, human being, social organization and biological existence, etc. Figure 3.1 describes it.

Agent has the following advantages:

- Autonomy: Agent will automatically adjust its behavior and status in line with outside circumstance. It has self-management and self-adjustment capability.

- Proactive: Agent will take active response to satisfy the outside changes based on its self-internal status.
- Reasoning: Agent can reason rationally according to the knowledge and the experience it already has. Agent intelligence has mainly three components: internal knowledge database, auto-adapted ability and reasoning capacity based on knowledge database.
- Character: Agent requests consideration of social factors such as security, risk, and good faith, etc.

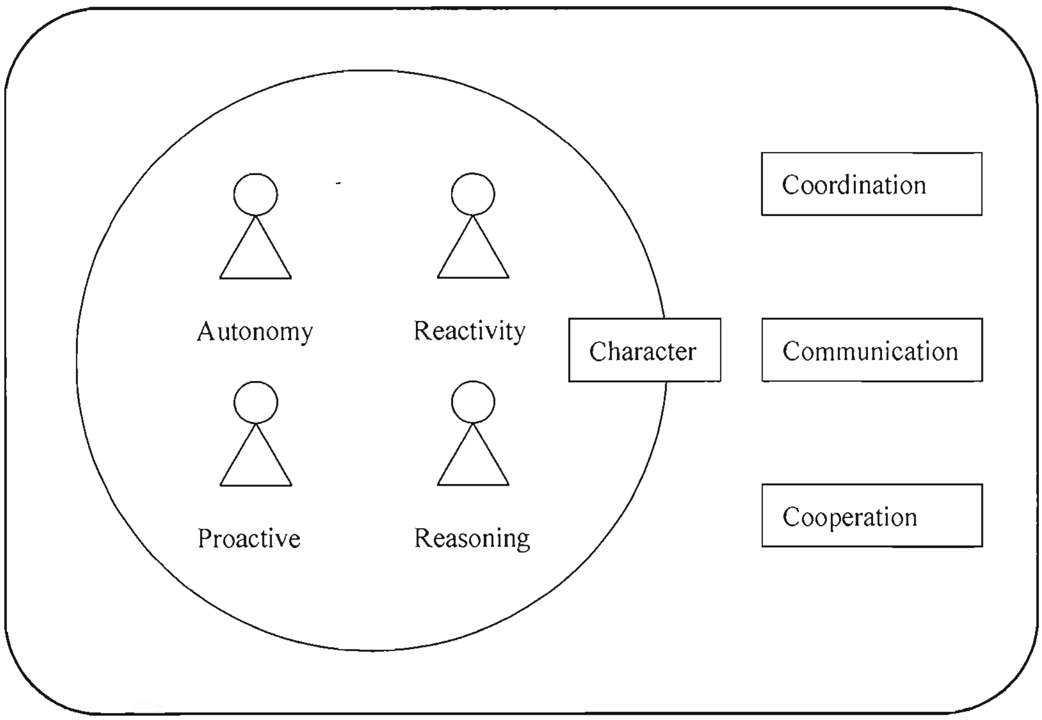

Figure 3.1 Description of Agent

- Social: Agent is characterized in owing the capability of Communication/Cooperation/Coordination with other Agent or human being. While considering the limited power of single Agent, multi-agent system is applied in practice. Different-functioned Agent works together to solve one problem. Traffic system is a classical multi-agent system.

3.1.2 Structure of Traffic Agent Model

Agent's being a rapidly developing technique; there are different kinds of advices on Agent model. But in spite of different individual structure, its Autonomy remains the same. Agent model applied in engineering is composed of Head, Body and Communicator. Head controls the decision-making; Body owns the function or capability of Agent and Communicator is the channel corresponding with the outside. Fig. 3.2 and 3.3 describe the abstract structures of Agent.

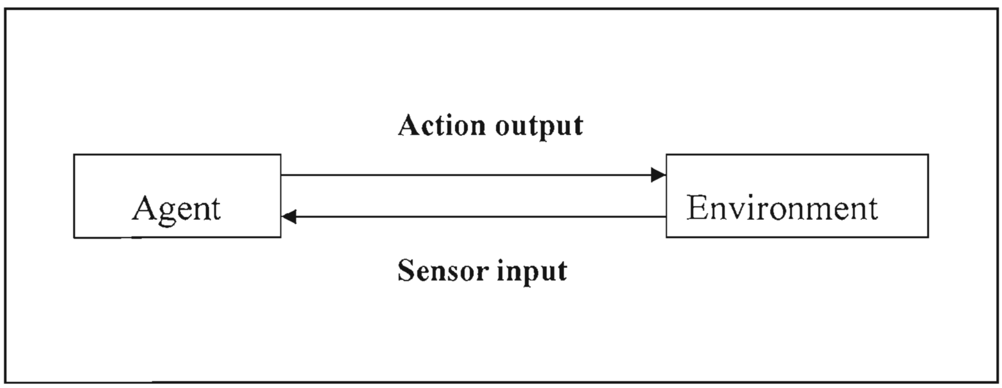

Figure 3.2 Interactions of Agent and Environment

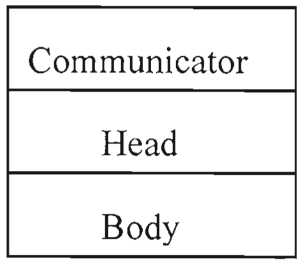

Figure 3.3 Structure of Agent model

By applying Multi-Agent System (MAS) in traffic control system, a group of self-managed agents can be well organized to perform certain intelligent activities, sharing information and working for a common purpose or different purposes and capability of problem settlement will be improved.

3.2Intelligent Real-Time Traffic Signal Control System Based on Agent

In intelligent transportation system, traffic control is the key in the whole system. How to better control traffic has been studied for a long time. The traffic control system has been changed from fixed time control to traffic-responsive control, which leads to great improvement in control effects. Currently the main traffic-responsive control system includes SCATS in British, SCOOT in Australia, and some used in France and Japan. Structure of all these systems is central control whose traffic control plans are managed by control center and controller at each intersection is not authorized with active adjustment capability except for collection of traffic data and execution of control plan. Since the development of the control plan is based on the data from the key intersections of the designated area, there is no effective consideration of undulation of the traffic flow at local area. And, as control plan is developed by control center, which causes a complicated optimization algorithm, huge operand, and low efficiency; along with its inability to adapt the changeable traffic environments. Therefore, intelligent real-time traffic signal control system based on agent is put forward in this thesis.

3.2.1 Analysis of the Control Characteristic at Traffic Intersection

Seen from the macroscopic angle, traffic system has characteristics of fluid and wave transferring, which means what is happening at one intersection will take place at nearby intersections too after a certain time. One intersection's traffic condition is determined not only by the traffic flow situation of itself but also by its nearby intersections. Based on this, it is more practical and closer to the fact if traffic control strategies are developed based on the traffic condition of itself and the nearby, so the traffic control strategies made by traffic control center are not suitable. Another advantage is that control algorithms and control rules will be much more simplified and data transmit is going to be reduced. It leads to higher control efficiency of the whole system.

3.2.2 Architecture of Intelligent Real-Time Traffic Control System

Nowadays, we need to design the new traffic control system according to the characteristics of the transportation system, which enables it to achieve intelligent control purpose no matter the macroeconomic regulation or the microscopic adjustment. To satisfy the requirement, we develop firstly multi-agent urban real-time traffic signal control system that is subsystem of MA-URTC. This system is designed with three-level architecture. The initial control strategy is going to be completed by the intersection-agent. Figure 3.4 illustrates it. It mainly includes:

- General Agent: Its responsibility is not center control. It has data warehouse only. It monitors the overall urban traffic environment and makes the traffic control system cooperate with outside relative system. It has the highest decision-making right.
- Region Agent: Mid-level of the control system. Be responsible for monitoring traffic at intersections within designated area and force to setup execution model (while sectional priority control impact overall traffic flow and leading to traffic jam in region); also take care of emergent issue in the area. Communication between individual regional agents is setup based on the requirement to exchange information and cooperation.
- Intersection-agent: Located at the bottom level of the control system, it is stored with data information such as geometry shape of self-intersection, connected road and adjacent intersection, whose responsibility includes traffic signal control at its intersection, setup on-line

communication with nearby intersection and adjust its traffic signal in accordant with local traffic flow as well as nearby situation to reach the best efficiency. When exception occurs, intersection-agent is able to become real-time interaction of the relative agents such as region agent, adjacent agent and road agent, etc. It is the main executor of the traffic control work.

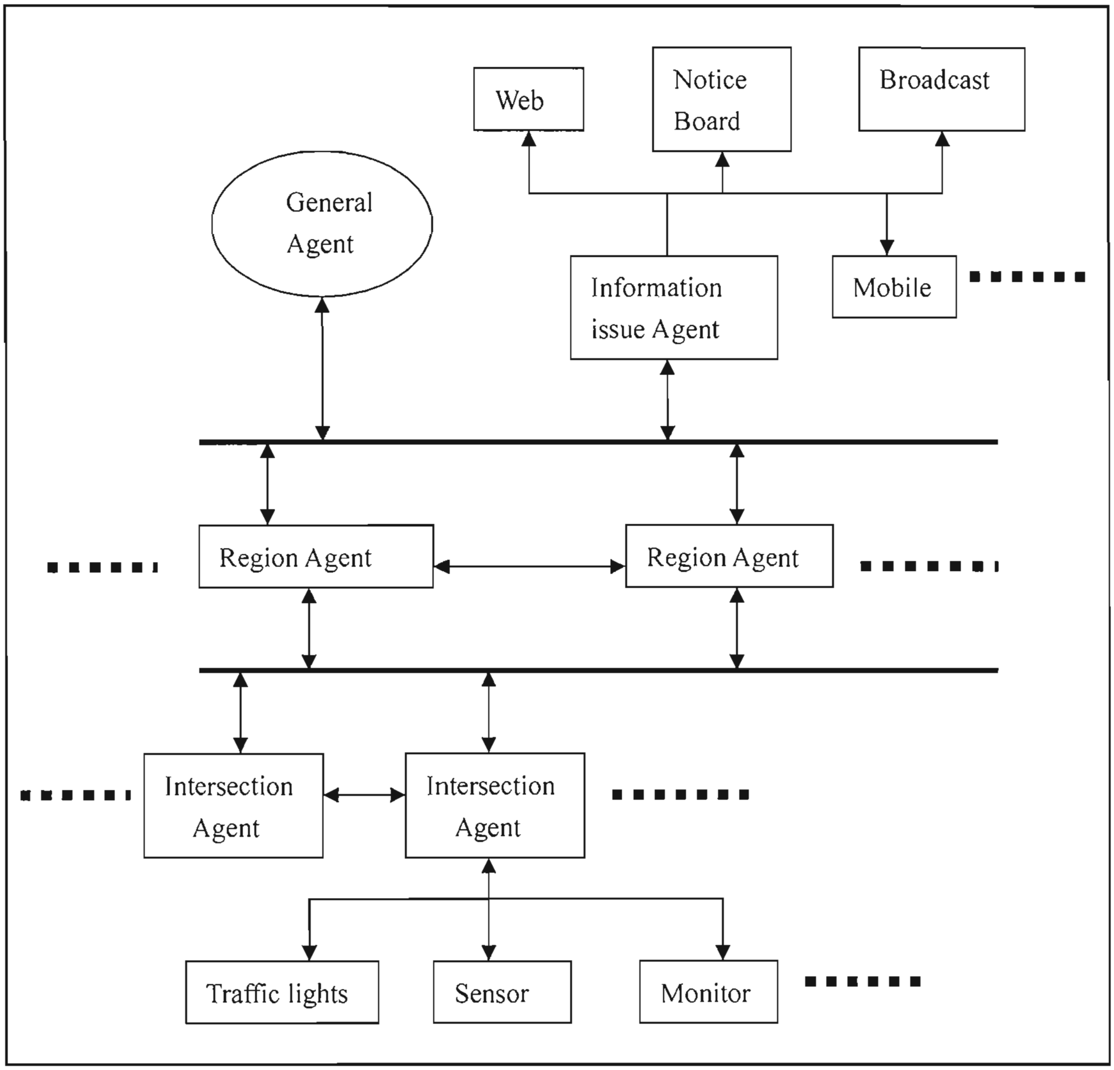

Figure 3.4 Agent-based intelligent traffic control architecture

Because of the application of agent, the system is characterized in:

- High reliability: Any failure of an individual control agent will not cause the whole system shut down, so it is well fault-tolerant.
- Good execution: Individual intersection is designed with the capability to adjust its traffic signal, which helps it make response based on local traffic situations. The real-time response capability of the system increases which helps to satisfy the complicated traffic requirements. Moreover, since each individual intersection is stored with local road geometry structure and other traffic information, it helps the intersection-agent with more specific signal decision-making.
- Flexibility, scalability, versatility and portability

Traffic control system with the above mentioned structure is more suitable while confronted with the complex real-time traffic system. It can better adjust to deal with the change of traffic flow and any emergency.

3.3Study on Intelligent Traffic Signal Control Strategy

Traffic signal control is a very serious problem in traffic research. A good signal control strategy can make up for the shortcoming of traffic system's hardware, can reduce the length of vehicle queue waiting at the intersection, and reduce unnecessary loss caused by stopping, which is an important factor in relieving traffic congestion. We have to point out that the intersection signal control has its limitation. Effective signal control is conditioned on the premise that the intersection transportation demand must be lower than its design capacity. Otherwise, if the intersection is at the saturation condition, then congestion is inevitable. To solve such problems, we can only depend on limiting the amount of traffic flow, reducing the transportation demand or improving intersection's geometry, and enhancing the most greatly traveling capability, etc.

3.3.1 Major Problem Existing in Current Traffic Signal Control Strategies

Current traffic-response signal control system such as SCATS and SCOOT has the following problems:

- Systems like SCATS and SCOOT, etc. were developed in the 1970s. Most of them adopted traditional optimization control technique. There was little intelligence in the control strategy and the whole model was out of date.
- Both SCATS and SCOOT adjust signal step by step, which takes longer time, usually about several minutes. Considering from theoretical angle, they can adjust signal optimization gradually. But their non real-time control strategies cause a time gap then the traffic flow is not at the right time. Therefore, they hardly meet present traffic requirements.
- While carries out the area-wide traffic signal control, both systems determine the signal optimization based on data from critical intersection with the maximum volume of traffic flow,

and their system control cycle is the signal cycle of critical intersection. This setup will lead to illogical timing plans in the whole system and time waste in green light at some intersections.

- Actually SCATS system does not belong to a real-time self-adjust control system. It is designed to pick up the most optimized one from the existing plans. Its control efficiency is limited due to limited choices of plan.
- As a model control system, SCOOT needs a complicated control model and a parameter model to support its operation. But because of the complexity and the changes in traffic, an ideal model does not operate well in practice. Furthermore, if the operation model could not adjust itself in accordance with the outside circumstance, it fails to satisfy the changeable developing traffic system. In practice, a system works well at the early stage but its performance becomes worst after a period of time.

From the 1980s, some of our cities imported this kind of system. But due to the existing problem of these systems and combined with complexity of traffic flow in China, mixture of all kinds of vehicles and interference of non-motor and motor vehicles, those systems have not fulfilled satisfying control effect.

Along with the rapid development of modern technique, computer technique, control theory and control measures, higher requirements on traffic control technique are put forward. Modern traffic control technique must be developed with the support of advanced computer technique and artificial intelligence.

3.3.2 Current Research Situation on Traffic Signal Control

The essential factor in traffic control is control strategy. Traffic system is complex, non-linear and timing changeable. Seen from macroscopic scope, some traffic phenomena such as arrival and departure of traffic flow meet certain mathematic rule and identify certain physical characteristics such as fluid and wave. But when it goes to microscopic world, especially the individual traffic area, individual traffic object and the activity of the object at different time, its running characteristic is various. Therefore, the intensions of describing the actual traffic rule by accurate mathematic model and performing control on traffic can hardly achieve an efficient control effect.

Along with the development of control theory and control strategy, intelligent control composed with fuzzy theory, artificial neutral network and genetic algorithm replaces traditional control measure step by step, which is a hot point in current study. Their non-model control raises the capability to solve complicated system and is proved by good control efficiency. With the development of control technique, intelligent control technique is applied in traffic control. Related simulation study proves that intelligent control strategies are more efficient than the traditional traffic control strategies with fixed time and traffic-response. It is inevitable to apply intelligent control technique in the development of traffic control.

The material obtained at present in the traffic signal control research is not sufficient. To do a better discussion if signal traffic control strategy, our thesis does a study based on artificial intelligence.

3.4Real-Time Dynamic Traffic Flow Forecasting Model Based on NN-GA

The real-time dynamic traffic distribution is a theoretical basis of ITS. While the premise of dynamic traffic distribution is real-time forecasting of the traffic volume on-line, this will influence the result of traffic distribution. Therefore, we first study how to real-time forecast the traffic volume.

3.4.1 Selection of Forecasting Methods

We use NN technology to establish forecast model for adaptive forecast of traffic volume. Artificial neural network is made up of a lot of simple neuron. It is put forth on the basis of studying the parallel architecture of animal brain with human brain as the representative. Theory has verified that three-neural network can realize any complicated mapping of no-linear problems. So we use three-neural network that has single hidden layer to carry out adaptive forecasting and modeling. According to the characteristics of intersection's traffic volume, there are six neural $(T, Q_{k-1}, Q_{k-2}, q_1, q_2, q_3)$ in the input layer, all of them take "Linear transformation function". The number of nodes in hidden layer is unknown. They take "alterable non-linear transformation function", and we select "alterable Sigmoid function".

$$S = \sum_{i=1}^{n} x_i \bullet w_i \qquad (1)$$

$$y = F(S) = \frac{1}{1+e^{-s/a}} \qquad (2)$$

In the formula, "x_i" refers to "input vector"; "w_i" refers to the weight; "S" refers to the input value of the neuron; "a" refers to the alterable parameter; "y"refers to the output value of the neuron; "$F(S)$" refers to the function of "alterable Sigmoid function"; output node which will forecast traffic volume is "Q_k", which is also "alterable non-linear transformation function" . Selected "complementary error function" is:

$$E = \frac{1}{2}\sum(1-\frac{y_k}{t_k})^2 \qquad (3)$$

In the formula, "y_k" refers to actual output of sample point of "k th"; "t_k" refers to the ideal output of the sample point "k". Then we define the number of nodes in the hidden layer, which is very important, because if the number of nodes in hidden layer is few, the learning process may not convergence; but if the number of nodes in hidden layer if many, low efficiency network performance and redundant node may occur. In traditional BP algorithm, the number of nodes can only be defined in accordance with experience and trial calculation. We use GA to optimize them. Although we can obtain optimal network structure and the connected weight by using GA, it costs such a long time. Therefore it does not suit for real-time forecasting of traffic volume. Therefore, GA is only used to learn network structure, while for the weight of NN and adaptive adjustment of alterable parameter, we use intelligent neuron model of ANN, which can speed up the convergence rate, satisfy the real-time forecast precision of traffic volume and reduce the running time greatly.

3.4.2 Use High-Order Generalized NN to Forecast Traffic Volume

The difference of high-order generalized NN and normal NN lies in that the former has two kinds of structures: one is network-level macroscopic level structure; the other is neuron-level microscopic level structure. A neuron of normal NN does not have the inner function's handing ability, but a neuron of high-order generalized NN has intelligent characteristic, that is, its transference function can be dynamic change and dynamic selection according to system function requests. Its network training is not only able to adjust the weight immediately but also the parameter of the neuron's inner transference function. The high-order generalized NN has two kinds of handling ability: the neuron interior and exterior that suits for the highly non-linear and time-varying urban traffic flow. The following explains specifically.

Network training process:

- Forward computation process: That is gradually computing the input/output condition of the neuron in every layer from input to output, thus the actual network output can be obtained. We use GA to obtain the optimal number of nodes in hidden layer and the value of " a " of alterable parameter. The formulas are as follows:

$$u_j^{(h)} = \sum_{i=1}^{n} w_{ij}^{(h)} x_i \qquad (4)$$

$$O_j = f_j^{(h)}(u_j^{(h)}) \qquad (5)$$

$$u_k^{(o)} = \sum_{j=1}^{h} w_{jk}^{(o)} O_j \qquad (6)$$

$$y_k = f_k^{(o)}(u_k^{(o)}) \qquad (7)$$

In the formulas, "$u_j^{(h)}$"and "O_j" refer to the neuron of hidden layer of input and output respectively, "$u_k^{(o)}, y_k$" refer to the neuron of output layer of input and output respectively, "$f_j^{(h)}, f_k^{(o)}$" refer to the alterable Sigmoid function of the neuron in hidden layer and output layer respectively, "$w_{ij}^{(h)}, w_{jk}^{(o)}$" refer to the connected weight of from input layer to hidden layer and from hidden layer to output layer respectively.

- Learning process: The learning process of the network weight is to be adjusted according to the following formulas:

$$\varepsilon_k^{(o)} = t_k - y_k \qquad (8)$$

$$\delta_k^{(o)} = \varepsilon_k^{(o)} f_k'^{(o)}(u_k^{(o)}) \qquad (9)$$

$$\varepsilon_j^{(h)} = \sum_{k=1}^{m} \delta_k^{(o)} w_{jk}^{(o)} \qquad (10)$$

$$\delta_j^{(h)} = \varepsilon_j^{(h)} \bullet f_j'^{(h)}(u_j^{(h)}) \qquad (11)$$

$$\Delta w_{ij}^{(h)} = \eta \sum_{p=1}^{P} (\delta_{pj}^{(h)} \bullet x_{pi}) \qquad (12)$$

$$\Delta w_{jk}^{(o)} = \eta \sum_{p=1}^{P} (\delta_{pk}^{(o)} \bullet O_{pi}) \qquad (13)$$

In the formulas, "$\varepsilon_k^{(o)}, \delta_k^{(o)}$" refer to the error of node's condition and the error of node's reverse transmission of the neuron in output layer respectively, "$\varepsilon_j^{(h)}, \delta_j^{(h)}$" refer to the error of node's condition and the error of node's reverse transmission in the neuron of hidden layer, "$\Delta w_{ij}^{(h)}, \Delta w_{jk}^{(o)}$" refer to the adjustable value of the connected weight from input layer to hidden layer and from hidden layer to output layer respectively, "η" refer to the learning rate and "P" is sample size. The learning process of the alterable parameter of nodes adjusts according to the following formula:

$$\Delta\alpha = \beta\varepsilon x \tag{14}$$

In the formula, "ε" refers to the error of node's condition, "β" refers to the adjustable rate of parameter, and "$\Delta\alpha$" refers to the adjustable value of parameter. We use the data of traffic volume to training network. When training approach the extreme point, convergence rate will slow-down obviously, then the raising of "η" can reduce the training time. Therefore, in order to raise convergence rate, we design the learning rate that is variable criterion based on genetic times and gradient vector.

The above discussion is only about forecasting the traffic volume of single intersection's exit. The experiment indicated that this method could accurately forecast the traffic volume in seconds and could compute every vehicle with traveling time or congestion function in difference road on-line. It also guides the optimal route of vehicle traveling. These are able to increase the efficiency of traffic system greatly.

3.4.3 Control Design of Agent Based on NN

For a complicated multiphase intersection, intersection-agent should be real-time self-adjustment according to practical traffic conditions, at the same time achieving the optimal phase timings and phase orders. A signal control strategy of intersection-agent is composed of two self-learning neural networks and a performance-evaluation unit. Two neural networks are always alternative in the state of learning or working during the process of self-learning according to the decision of the performance-evaluation unit on the traffic conditions of intersection.

Here we indicate the performance-evaluation unit, and we have introduced the training method and network structure of traffic NN in the preceding part. It evaluates control effect of a signal timing strategy within an evaluation period, moreover, according to the performance-evaluation; it modifies signal cycle and the traffic light's green signal ratio. For example, a four-phase intersection that has the shape of the sign "+", suppose: "P_i" is the total queuing length at the end of "i th" cycle, "Q_i" is the total length of vehicles within "i th" cycle, "R_i" is the arrived length of vehicle within "i th" cycle, "$X_i^{(j)}$" is the sum of queuing length from all directions, which is the phase of "j th" at the end of "i th" cycle. It is easy to see that

$$P_i = P_{i-1} - Q_i + R_i \tag{1}$$

$$P_i = \sum_{j=1}^{i} X_i^{(j)} \tag{2}$$

Definition is offered as: $$\overline{P} = \frac{\sum_{i=1}^{n} P_i}{n} \tag{3}$$

We grade "$\overline{P}$" into the big one, the biggish one, the moderate one, the small one and the smaller one, corresponding to the cyclic increment "Δc" is 10s、7s、5s、0s and negative, then

$$C_{i+1} = C_i + \Delta C \tag{4}$$

In the formula, "C_{i+1}" refers to the new signal cycle to be used in the next evaluated cycle. For convenience, we still note "C" for short. Then calculate

$$\overline{X}_j = \frac{\sum_{i=1}^{n} X_i^{(j)}}{n} \qquad j = 1,2,3,4 \tag{5}$$

$$B_j = \frac{\overline{X}_j}{\overline{P}} \qquad j = 1,2,3,4 \tag{6}$$

The "$B_j\,(j = 1,2,3,4)$", which is the new traffic light's green signal ratio every phase. Therefore:

$$\sum_{j=1}^{4} B_j = \frac{\sum_{j=1}^{4} \overline{X}_j}{\overline{P}} = \frac{\sum_{j=1}^{4}\sum_{i=1}^{n} X_i^{(j)}}{\sum_{i=1}^{n}\sum_{j=1}^{4} X_i^{(j)}} = \frac{\sum_{j=1}^{4}\sum_{i=1}^{n} X_i^{(j)}}{\sum_{j=1}^{4}\sum_{i=1}^{n} X_i^{(j)}} = 1 \tag{7}$$

In intersection-agent, our control strategy sets up two rotational NN, according to the method introduced previously every evaluated cycle set up N signal cycle to form an evaluation cycle according to practice. Intersection-agent makes one NN work while the other idle one trained. Once training is completed, they rotate their states automatically in the next evaluated cycle, that is, the original working NN changes into an idle state which is trained according to the related parameters while the other turns to control signal. Two NN wok and learn alternatively so that the agent's controller effect reaches the optimization gradually. But we find that with time going on, do repeatedly, the training samples will be more and more and it will be more and more difficult to train NN. In order to avoid "samples explosion" we use "samples interception", that is, stipulate in advance the training scale of samples according to practical request, and then eliminate the old samples one by one with the new ones in a way of " the order shifting ". Finally, through learning and training, two NN will be satisfactory and one of them may be backing up which raises the fault-tolerance of the intersection-agent.

In order to testify the controlling effect of the self-learning control scheme (we call it Scheme 1) in neural network, we carried out a simple simulation in which we compared the effect of it with the learning-from the traffic police's experience scheme (we call it Scheme 2), and the results are shown in Table 3.1. We can see that the difference between these two schemes is not great when the traffic is not crowded. However, when the traffic becomes more and more crowded, the difference becomes greater. It proves that as the NN controlling strategy mentioned in this thesis is capable of self-learning and step-by-step optimizing, its controlling effect is superior. In the test, we used the stochastic number that is obedient to binomial distribution to describe the arrival of the vehicles, and we supposed that the saturation point of the vehicles on the straight lane is 1500 per hour; the saturation point of the left-turning and right-turning vehicles is 1200 per hour. When all these vehicles get to the intersection, 30% of them turn left, 50% of them go straight ahead, and the left 20% turn right. The average number of the vehicles at each entrance is equivalent to each other, and the lost time of green light in each traffic lights period is 8 seconds. The simulation lasted for 50 thousand signal periods.

Volume of traffic in intersection	Average queue (Vehicle/T)		Volume of traffic in intersection	Average queue (Vehicle/T)	
	Scheme 1	Scheme 2		Scheme 1	Scheme 2
< 800	< 3.9	< 3.9	1440	30.04	38.34
880	4.73	5.12	1520	36.71	46.97
960	5.45	6.97	1600	43.57	55.41
1040	8.14	10.33	1680	50.86	64.10
1120	11.28	14.87	1760	57.94	73.19
1200	14.98	19.53	1840	66.83	89.36
1280	19.27	24.61	1920	77.45	112.53
1360	24.26	31.29	2000	89.26	139.75

Table 3.1 Comparison between the proposed NN control scheme1 and scheme 2

3.5Introduction of Traffic Signal Control Strategy Based on Fuzzy Control

3.5.1 Brief Introduction of Fuzzy Control Theory

Human beings use a fuzzy language to describe the outside information. For example, "big and small' "quick and slow" "hot and cold" etc. all of which could not be demarcated clearly by a precise mathematical language. The fuzziness of human language cause a certain human's intelligence not to describe precisely a model science based on mathematics. In 1965, Prof. L.A.Zedeh put forth the fuzzy theory for the first time. The fuzzy theory based on strict mathematics foundation describes the human fuzzy language information, the computer using it is able to process the fuzzy language question, and moreover, it has erected a bridge for artificial intelligence and modern science. English Mamdani and Assilian are forerunners that apply the fuzzy theory to the control domain.

- The characteristics of fuzzy control system
  - The fuzzy control system has better stability and robustness.
  - It is easy to design a fuzzy controller and the debugging is also convenient
  - We do not have to establish a precise mathematic model for control system. Thus it is suitable for a complicated traffic control system that is usually variable, non-linear, and multi-perturbation. Considering the actual situation, an experienced traffic policeman can effectively unblock the stream of vehicles under all kinds of traffic conditions; therefore we established the fuzzy control rule coming from experts (traffic police's experience) in intersection-agent to carry out the automatic control to the stream of vehicles.
- Mechanism of fuzzy controller

Fuzzy controller is composed of fuzzification, fuzzy-inference and defuzzification. Fuzzification transforms the precise value that is assigned or feedback into the fuzzy quantity.

Fuzzy-inference is made up of aggregation of condition, implication and accumulation. Defuzzification transforms the output fuzzy quantity from fuzzy-inference into the precise value according to a method. The knowledge base provides the control rule to the fuzzy controller. I/O membership function base defines the methods of fuzzification and defuzzification. Figure 3.5 illustrates the structure of traffic signal fuzzy controller in intersection-agent.

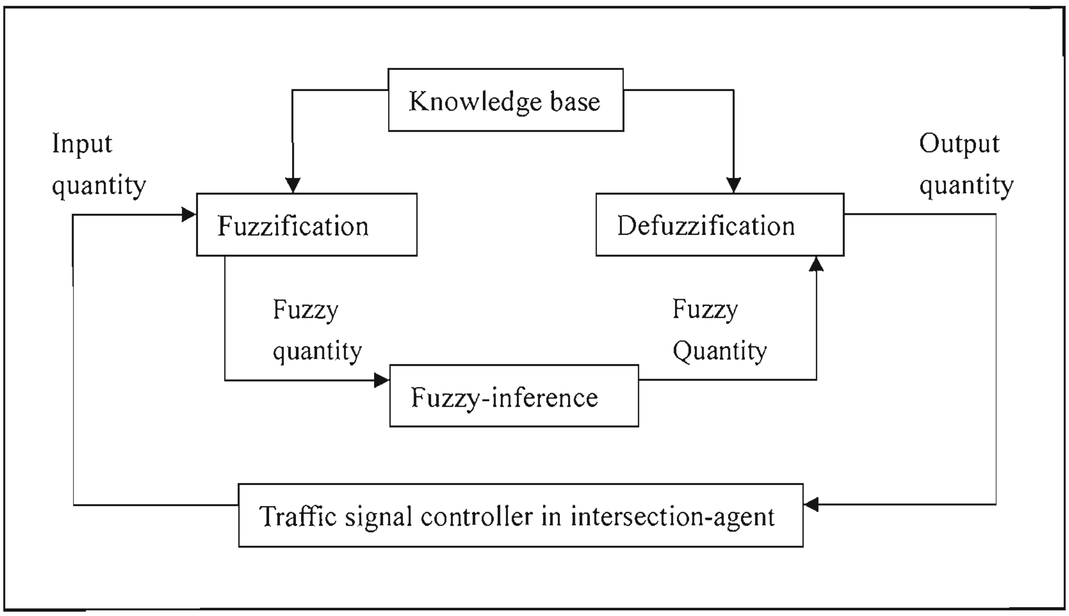

Figure 3.5 The structure of traffic signal fuzzy controller in intersection-agent

3.5.2 Introduction of Fuzzy Control Intersections

In 1976, Pappis proposed applying fuzzy control to traffic control. Simulation of the ideal plane crossing indicated that this fuzzy control algorithm reduced the average 7% of the vehicular delay compared with the traditional control algorithm reduction vehicles in intersection. [35] Hereafter, although many researchers applied the fuzzy technology in the traffic control, there still existed many deficiencies in the control strategy utilization and understanding, which include:

- Research is limited in one-direction flow in a simple intersection.
- Most of them only consider the two-direction straight-going traffic flow but ignore the impact of left-turning flow.
- While using fuzzy control, selection of fuzzy variable is too simple without integrating the different changes of traffic flow in different driving directions and individual lanes.
- The decision-making process cannot manifest completely the actual condition of traffic signal control as compared with a traffic police directs.
- Single selection of signal phase results with poor flexibility, though some systems are designed with multi-phase control strategy, they do not have flexible phase switch capability.

To solve the existing problems caused by the application of current fuzzy technique, considering the actual character of traffic signal control, we put forward an intelligent traffic signal control strategy, Multi-Agent self-organized strategy. It is designed to perform fuzzy traffic control at multi-intersection in urban traffic network first and then go on with the further study on signal control strategy at single intersection. It is put forward to provide helpful idea on the research of intelligent control technique to solve traffic control problems.

3.6Fuzzy Control of Multi-Intersection

At present the traffic fuzzy control research object is mostly limited in the isolated single road intersection. It is rare for researching the multi-intersection. But in fact, each neighboring intersection is mutually coupled with each other, especially in the urban economic and cultural centers. We discuss the fuzzy signal control strategy of multi-intersection based on the urban traffic network and with universality.

3.6.1 Selective Area of Traffic Network

Fuzzy control strategy discussed here is set up at intersection-agent that receives parameter, like signal cycle, etc., from other agents then controls local traffic lights in line with real-time traffic flow. Cross intersection and T intersection are the most popular ones.3-dimentional intersection is used mainly at multi-branch intersection. Right-turn vehicles of any direction is not controlled by signal lights at a cross intersection. For the sake of clear description of control strategy, we setup two phases: the East-West phase and the North-South phase. Concerning Y intersection, it can be classified as T intersection by exaggerating the angle to 180 degree.

3.6.2 Control Strategy

Each intersection-agent computes and outputs its g_i/C according to table 3.2. It shows the detective traffic flow in local intersection and the neighboring intersection. The "$G_{\min}$" represents the minimum time of green light of each phase guaranteeing all vehicles and passersby get across the intersection, that is $G_{\min} = 5+0.11w$, "w" refers to the width of the relative road. Figure 3.6 shows the discussed topology of the area of traffic network.

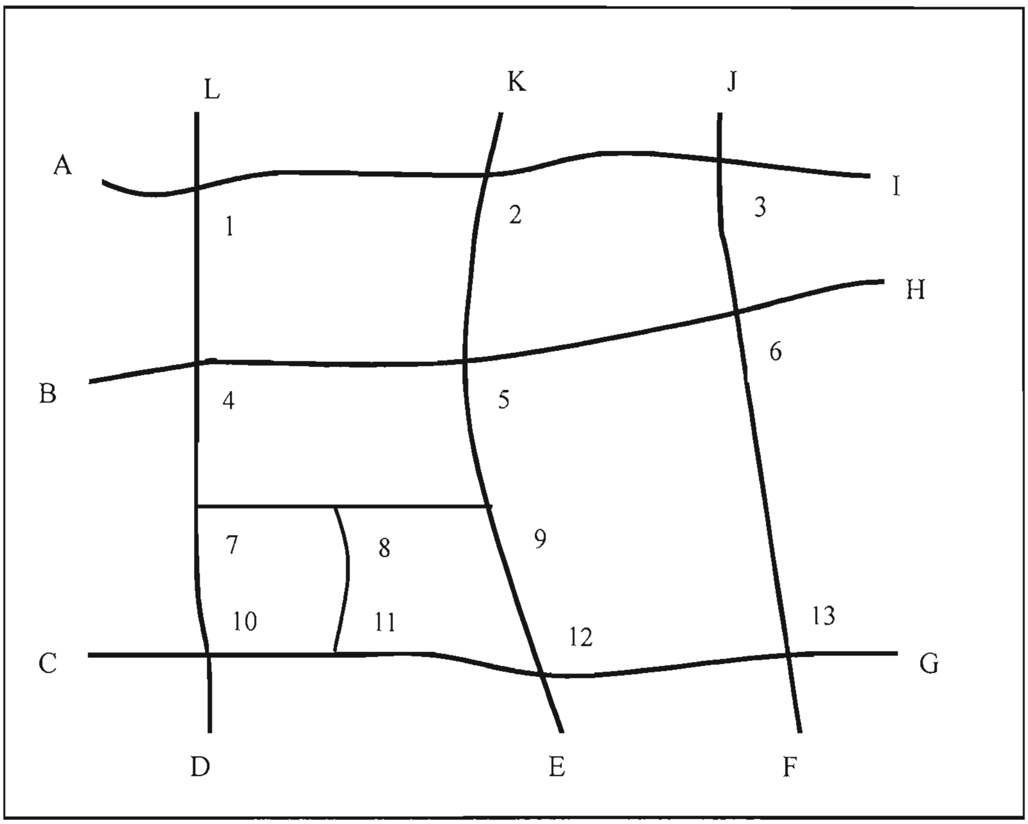

Figure 3.6 Topology of the traffic network area

Intersection (Serial number)		1	2	……	13
East	Neighboring	2	3	……	G
	Distance (m)	1200	1200	……	/
South	Neighboring	4	5	……	F
	Distance (m)	800	750	……	/
West	Neighboring	A	1	……	12
	Distance (m)	/	1200	……	1300
North	Neighboring	L	K	……	6
	Distance (m)	/	/	……	1600

Table 3.2 Intersection information in the traffic network area

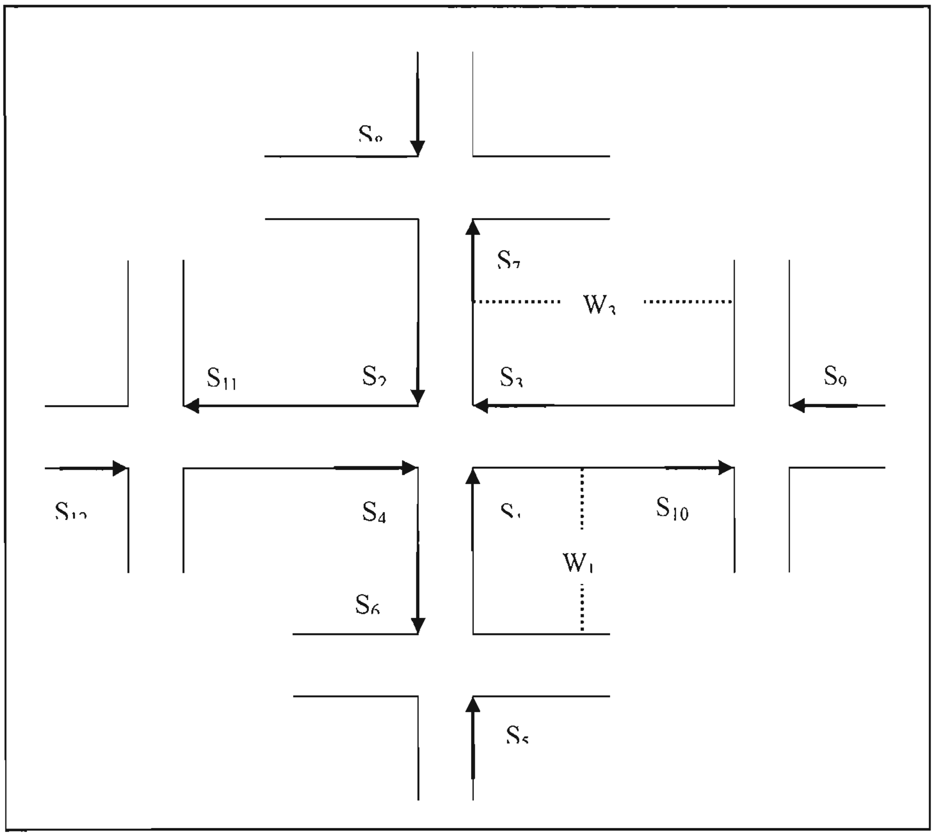

Figure 3.7 Illustration of the No.5 intersection in center

Since traffic condition is different at each intersection, we can find it in Fig.3.6, typical intersection No. 5 is selected for further study. Fig.3.7 is its local enlargement. "S_i" refers to the quantity of waiting vehicles from different directions at each intersection.

$$S_{NS} = S_1 + S_2 \;\;,\;\; S_{EW} = S_3 + S_4$$

It supposes that the North-South phase of traffic light of No.5 intersection transforms from the red light into the green light in Fig.3.7, the intersection-agent determines the g_i /C of this cycle and phase. As to S_1, its vehicle arrival probability obeys Poisson's distribution, that is

$$P(x) = \frac{\lambda_1^x \bullet e^{-\lambda_1}}{x!}$$

In the formula, $P(x)$: probability of arrival of x number of vehicles within a time unit, λ_1: the average of arriving quantity of vehicles in S_1 direction within the time unit. λ_1 has the function relationship with the quantity of northward driving vehicles in intersection No.9, but time lag appears when traffic flows moving from intersection No.9 to No.5,

$$t_{d1} = \frac{W_1}{v}$$

"W_1" refers to the distance from intersection No.9 to No.5. The average of vehicles speed is "v". Suppose the function $Near(t)$ refers to the closing time of red light, which is closest to the time of "t". Let $\bar{t} = Near(t - t_{d1})$, then

$$\lambda_1(t) = f[S_5(\bar{t})] = \frac{S_5(\bar{t})}{0.5T}$$

According to the same principle, extract "λ_2", let $\lambda_{NS}(t) = \lambda_1(t) + \lambda_2(t)$, $\bar{t} = Near(t - t_{d3})$, in the formula, "$t_{d3}$" refers to the time lag from No.5 to No.6. $\lambda_3(t) = f[S_9(\bar{t})]$, continue "$\lambda_4$", let $\lambda_{EW}(t) = \lambda_3(t) + \lambda_4(t)$. Let "$S_{NS}(t), S_{EW}(t), \lambda_{NS}(t), \lambda_{EW}(t)$" input fuzzy controller in N0.5 intersection-agent. This design considers not only the local real-time traffic situation but also the status at nearby ones. The "g_i /C" of north-south direction is output by fuzzy controller.

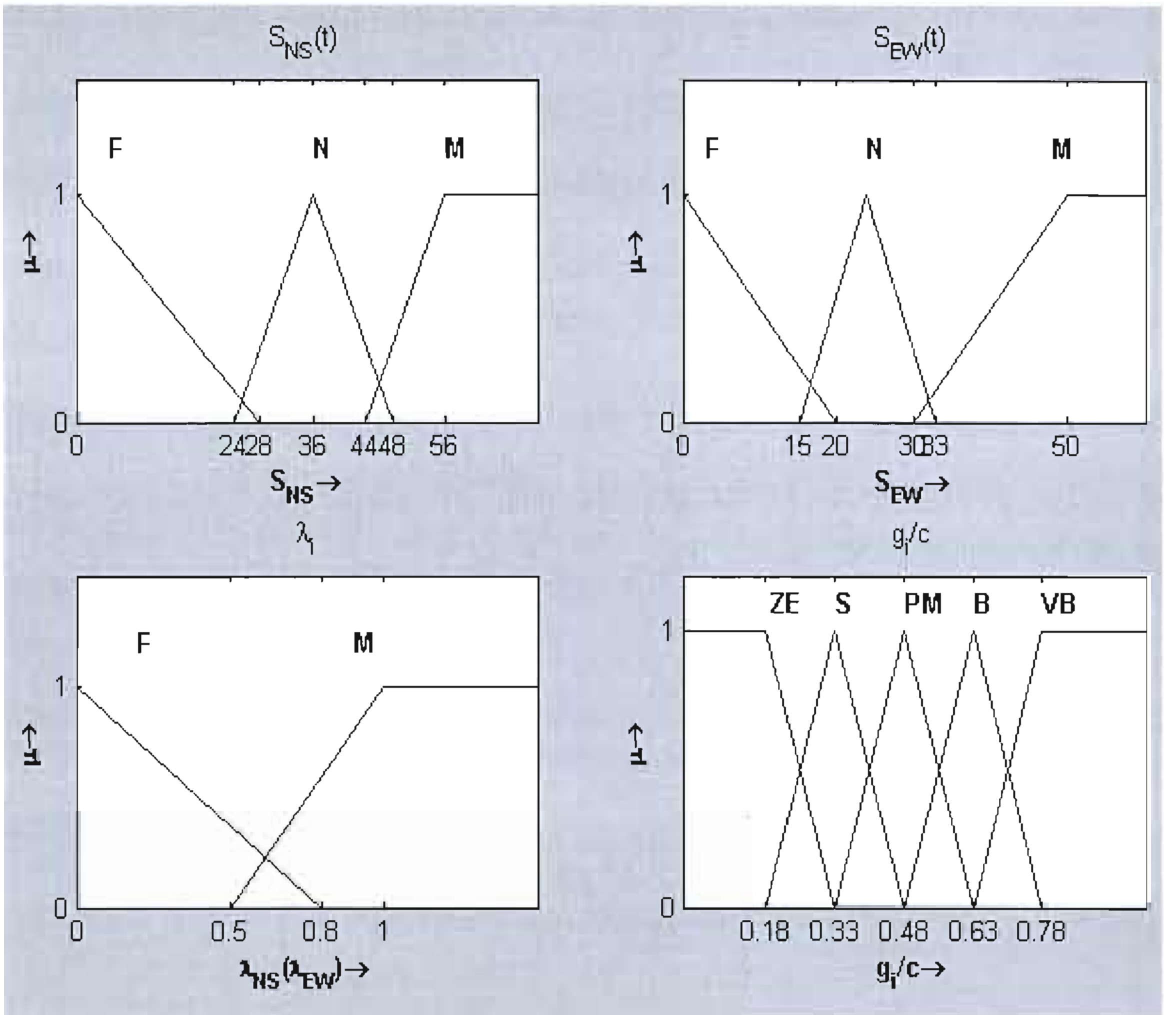

Figure 3.8 Rectangular coordinate plane illustrates membership function respectively

Figure 3.8 illustrates " $S_{NS}(t)$, $S_{EW}(t)$, $\lambda_{NS}(t)$, $\lambda_{EW}(t)$ and g_i /C" membership function respectively, we simplify the fuzzy variable and divide the quantity of vehicles into F (few), N (normal) and M (many); divide the " g_i /C" into ZE(zero extended)、S(small)、PM(positive medium)、B(big) and VB(very Big), discourse $\mu : U \to [0,1]$.

3.6.3 Simulation

We select the sample model to simulate just to testify the method's effect. Waiting vehicles pass through the intersection one by one when the red light of certain phase transforms into green. To simulate the traffic flow at intersection, a vehicle flowing model is setup as follows:

$$\lambda = \exp(\frac{-9.4(x_f(t) - x(t))}{v(t)^2})$$

$$a(t+\tau) = 0.2(\frac{2}{1+\lambda} - 1)(v_{\lim it} - v(t))$$

$$v(t) = v(t - \Delta t) + a(t)\Delta t$$

$$x(t) = x(t-\Delta t) + v(t-\Delta t)\Delta t + \frac{1}{2}a(t)\Delta t^2$$

In the formula, the " $a(t), v(t)$ and $x(t)$ " refer to acceleration, speed and displacement respectively. " $x_f(t)$ " refers to displacement of the previous vehicle and " $v_{\lim it}$ "refers to the maximum speed.

Table 3.3 is the comparison between the data calculated from vehicles flowing model and the data obtained from observation. In view of those data, this model can quite effectively display the actual vehicle condition. In the table, interval refers to the time difference of the two vehicles passing by the same point. Based on the description of this model, the quantity of vehicles released by green light can be computed, e.g. released vehicle quantity is 1veh if the time of green light is 3s; 4veh is released when green light time changes to 7s. So analogizes. In the process of stimulation, if the light is red, vehicles arrive at the intersection by Poisson's distribution. If the light is green, first arrived vehicle will get through the intersection and at the same time, more vehicles are continuously arriving. The quantity of arrived vehicles is determined by the quantity of vehicles at other intersections from the same direction. In Figure 3.6, there are 12 intersections, numbering from A to L. Arriving rate of vehicles in the entrance of each intersection is shown in Table 3.4.

Sequence	Observed value		Formula value	
	Interval(s)	Accumulation(s)	Interval(s)	Accumulation(s)
1	2.3	2.3	2.7	2.7
2	2.0	3.9	2.1	4.1
3	2.2	6.2	1.9	6.5
...	...	...	...	...

Table 3.3 Comparison between formula value and observed value

Plan	Arriving rate of vehicle in entrance (vehicle/s)										
	A	B	C	D	E	F	G	H	J	K	L
1		0.6			0.5			0.4			0.3
2		[0.3,0.5]			[0.3,0.7]			[0.3,0.6]			[0.3,0.8]
3		[0.4,0.7]			[0.5,0.7]			[0.3,0.5]			[0.3,0.6]
4		[0.5,0.7]			[0.2,0.4]			[0.5,0.8]			[0.3,0.4]

Table 3.4 Arriving rate of vehicle in the entrance

The actual input values of Figure 3 to 6 are the random values within the range of the two numbers in the bracket. Time unit is second.

It's supposed to have control parameters from predicted model of intersection-agent as follow: Signal cycle: 90s. Switch loss between red and green lights in one cycle: 2.5s each, 5s total. The minimum green light time: 15s. Average driving speed on road: 45km/h. A simulation period equals 60 signal cycles. Simulation tool is MATLAB. The simulation process is as follows.

Step 1: set up number of simulation cycle n=1;

Step 2: set up intersection m=1, that is to begin with the computation from the first intersection;

Step 3: Intersection "m" picks up the quantity of waiting vehicles of each phase; according to the data in Table 3.2 together with the average speed on road works out a time lag used by vehicles going from the intersection "m" to its neighboring intersections. Pick up the number of waiting vehicles before the latest red light ends. (If one neighbor intersection happens to be an entrance-simulated area, the number of waiting vehicles is replaced by multiplying the vehicle's arrival rate in entrance by half a signal cycle). According to the method discussed above, estimate the vehicle's arrival rate of each phase in intersection "m".

Step 4: According to the number of waiting vehicles and the arrival rate in two phases, fuzzy controller outputs "g_i/C" of a certain phase (here we use the North-south phase) of "nth" cycle at "m" intersection, thus obtain the time for green light and red light in two phases.

Step 5: According to the distribution of arriving vehicles, calculate the number of arriving vehicle (both red light and green light); then according to the green light time and Table 3.3 calculate the number of vehicles released; thus obtain the length of waiting vehicles of each phase at the intersection by the time of switch of red light and switch of green light.

Step 6: If m=13, it means that all the 13 intersections of this cycle have been computed, then turn to Step 7, and start the computation for next cycle; otherwise if m=m+1, turn to Step 3, and computer the next intersection.

Step 7: Stop once the simulation time is over; otherwise set up n=n+1 and continue with computation for next simulation cycle.

Suppose the phase is the same, a simulation comparison is done between the multi-intersection fuzzy control plan based on road network and the single-intersection plan. The average quantity of waiting vehicles in an intersection in a signal cycle is targeted for the comparison, and the simulation data is shown in Table 3.5.

Plan	Multi-intersection (vehicles/cycle)	Single-intersection (v/c)
1	67	94
2	79	107
3	91	131
4	84	116

Table 3.5 Result of a simple simulation

Analyzing the data, we draw such a conclusion that compared with the single-intersection fuzzy control, the application of multi-intersection fuzzy control reduces the quantity of waiting vehicles at each intersection and increases traffic transition though the traffic network and traffic flow density remain the same.

3.7 Autonomic Decision-Making of Multi-Agent

In modern Chinese cities, there are four lanes or even more at the intersection. Each of direction has its independent left-turning lane in a complicated intersection. As vehicles of right turning are not influenced by the transformation of signals, we don't consider them.

At a multiphase intersection, signal phases include the straight driving in North-South direction, the straight driving in East-West direction, left-turning in N-S direction, left-turning in E-W direction, left-turning and straight driving in the South direction, left-turning and straight driving in North direction, left-turning and straight driving in West direction, left-turning and straight driving in East direction, left-turning in South and straight driving in East direction, left-turning in North direction and straight driving in West direction, left-turning in West and straight driving in South, left-turning in East and straight driving in North, 12 phases in all. Figure 3.9 shows them. For a multi-phase signal control system, it not only prevents a certain phase taking too long a green light time but also avoids a premature transformation of signal. Each of intersection-agent realizes the optimal phase timing and phase order according to some relative information. It includes the shape of intersection itself, road agent detecting information and cooperation with the neighbor intersection-agent, etc.

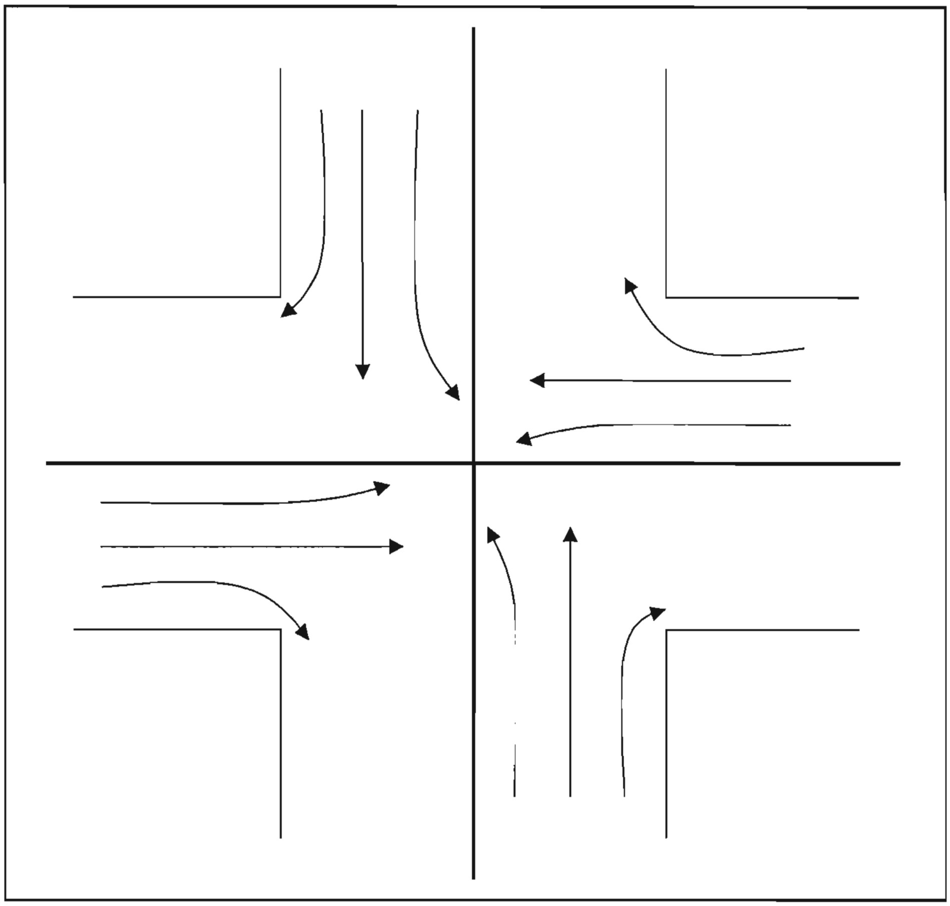

Figure 3.9 Multiphase traffic flows at a single intersection

What we have found in the research:

- Intersection-agent needs to receive all kinds of traffic information. Direct application of fuzzy control will cause too many variations. Fuzzy control rule is essential for fuzzy control; moreover, the number of fuzzy control rules is the exponential function of the number of control variables. Therefore, it is not easy to develop a conventional fuzzy controller based on rules. Even if we design such fuzzy controller, it cannot satisfy our real-time requirements because of the oversized computation scale. Confronted with such a dilemma, we apply decomposition-coordination method to fuzzy control. We introduce coordinate variable Λ_i to coordinate with the green light time and divide it into some corresponding subsets λ_i according to the actual traffic conditions. The optimal Λ_i and λ_i used by simulation help us define them. This method can not only reduce iterative operation but also raise the computed speed.

- We have studied some relative AI technologies. Fuzzy control can process the fuzzy information effectively, but control rules are usually produced too rashly, when using rule table to control, although computed speed is quick, it does not have self-learning ability. As what we have mentioned above, NN happens to supplement fuzzy control with each other. As to GA, its shortcoming is bad real-time, but it does not fall into a partial optimization in the searching process. Even if its fitness function is non-continual, non-ruler or noisy, it may probably find the overall optimal solution, which fits for studying macroscopic rule of traffic system. Moreover, using GA to optimize fuzzy control rules will avoid the subjective shortcoming by "IF...THEN " fuzzy control rule. It can design optimally according to the required control index.

- Multi-agent is a popular and effective technical process in the complicated intelligent control system. Each intersection is an agent. Set up a regional agent to control those closely related intersections based on the actual traffic conditions in cities. Individual intersection develops its signal strategy based on local situations and cooperation with related intersections. As different signals cause different impacts on the traffic flow at nearby intersections, sectional optimization may lead to overall jam if it lacks unified control. Region agent acts as the final arbitrator to control regional traffic. It dissolves traffic conflicts at the nearby area and reflects traffic flux in real-time control strategy, to achieve real intelligent control.

Intersections in traffic network have different geometric shapes and traffic requirements. Some of them only need a simple strategy to run well, however some for instance on an artery need the combination of multi strategies to make real-time adjustment. A major object of our simulation is to choose the optimal signal control strategy respectively according to self-conditions and other relative information until the overall traffic system runs optimally.

3.8Integrate Signal Control System with Other Transportation Systems

At present, urban traffic control can realize discrimination of all kinds of vehicles by vehicle positioning recognition system, which guarantees bus priority in future. In road network, public transport service is prior to all the others, which undertakes the main requirements of urban transportation and its controlled effect directly influences the entire urban transportation conditions. When a bus arrives at the area of detection, a detector embedded in road agent can recognize it and inform the traffic signal control system to give it the priority in green light time. In the actual operation, the range of signal control strategy caused by the priority must be limited. Obviously, we note that time variation of signal phase because of priority is to be at certain loss in the time of non-priority. We surely cannot accept signal switch frequently. We need to add new control rules to our strategy.

In China, rapid rail transit is the main force for public transportation. But it is impossible to replace the use of bus. How to coordinate signal control system with intelligent bus system will be one study emphasis.

3.9Summary

In this chapter, the author first made a brief analysis on the disadvantages of current traffic control system. The author claims that we should make a design on the real-time intelligent traffic control system by applying the multi-agent system to it.

Secondly, the author discusses the core of the agent's internal working mechanism ----the strategy for intelligent traffic-signal-control in details. The traditional strategy for traffic control can't meet the needs in real-time control, and so we are expected to find a solution to this problem by making use of something in the artificial intelligence field. Each of NN, GA, the Fuzzy Control and the Expert System may have its strong points. In practice, we are supposed to use the above four methods, and maybe their selective combination, so that we can actualize the optimal control effects that we expect. For example, it is proved in practice that an experienced traffic policeman can lead the traffic flow expertly, and so his experience can be shaped as an expert system. Furthermore, it can be regarded as the basis for NN and Fuzzy Control research. GA is superior to others in that it cannot easily run into partial optimization in the process of search. Even if the defined fitness function is not consecutive or regular, GA can get the overall optimal solution in a major probability easily. Moreover, owing to its connatural parallelism, GA is more suitable for harmonizing the signal control of various agents. At the same time, the author discusses something about the combined usage of the GA and NN in this chapter. The advantage of NN is that it is self-learning. However, the main problem with BP in NN is that it is slow for us to learn. Fortunately, we can make improvements in BP algorithm and introduce the fuzzy theory into it so that we can make an ANN-FC and two NN interactive learning to meet our needs for fast learning and good convergence. As we have known, it can be inferred that fuzzy control is still the mainstream in current traffic control research. Although it has a thirty-year-development history, it is still worth further studying. Of course, we have made great efforts to solve this problem. And we have made some simple simulations to test the rationality and actual effects of these technologies.

Finally, the author states that the most important thing is how to coordinate the intelligent traffic signal control system with the public traffic intelligent control system. In China, the huge population mainly depends on the public traffic in their daily life. It is one of the future prospects of our further research.

CHAPTER 4

INTELLIGENT TRAFFIC CONTROL SIMULATION RESEARCH BASED ON AGENT

4.1 Brief Introduction of Traffic Simulation

Traffic simulation technology is a kind of traffic analysis technology. It is the important application of computer analysis technology in traffic engineering. The traffic simulation system can show you the movement of all vehicles on the traffic network intuitively by way of the animation on the computer. You can see clearly from the animation on which road the traffic is congested, and where the traffic is smooth. As a matter of fact, human being's visual observation is a good commentary means for a traffic engineering design. We can roughly and visually know whether a traffic engineering design is good or not by watching animation on the computer. Owing to the adoption of time-scan technology, each vehicle's running course during each scanning period is perfectly registered, so, we can get some fixed quantity of estimating targets about the delay of parking, the time for queuing, and the frequency of collision on the road, etc. through some simple statistics. As a result, the traffic simulation system is a visual, convenient and flexible traffic-analysis tool to the traffic engineers for testing and optimizing all kinds of traffic and roadway designs.

4.1.1 Applying Agent Technology to Do Traffic Simulation

Agent technology can provide useful guidance for promoting the structure of a traffic system. The application of agent technology in traffic simulation can even embody the superiority of this technology. Intelligent traffic control system is a complex and large one. It will take us a lot of time to carry through traffic layout and administration reasoning and investigating so as to prove whether a design is reasonable or not. If we put it on trial, it would cost too much. So a computer simulation of how the traffic functions is a better solution to solve this problem. And it is not limited by time and place. The simulation can even be repeated and adjusted dynamically in the process of simulation. In this case, the actual capacity of the simulation system to simulate the genuine system is the very concern of common people. In traditional simulation, because of the limitation of hardware and software, to perform such a highly dynamic and stochastic simulation in the traffic system usually can't achieve unsatisfactory results. Fortunately, with the development of computer science, object-oriented technology has become the main purpose of software development, and this does great contributions to the development of simulation, however, it has lots of disadvantages in describing some mobile and intellective entities. The application of agent technology provides us an ideal solution to this problem. Agent technology can be regarded as the development and promotion of the object-oriented technology. It is the higher level of the object-oriented technology. And it has provided us an optimal resolution to this problem. As a highly real-time discrete system, the traffic system is the result of conjunctive effect of all the traffic participators and traffic facilities. It is also the macroscopic exhibition of the microcosmic individuals. Any simulation using mathematical methods can hardly achieve this outcome. However, as a non-model simulation, the agent technology suits for solving this kind of problem. With the development of intelligent transportation system, in order to understand the effect of all kinds of control systems on real transportation system such as UTFGS (Urban Traffic Flow Guidance System) and the USS (Urgent Succor System) as well as the running rules of transportation better, we should not rely on the traditional methods badly because they can not meet our needs. At present, many researchers are interested in the application of agent technology in traffic simulation.

4.1.2 Realization of Agent Technology

As a new method of software development, agent technique has inherited and developed from the object-oriented technology. Agent technology not only has most of the characteristics of the object-oriented one, but also is the enrichment and improvement of the objected-oriented technology. Therefore, we can carry out the research and exploration of agent technology by using the software tools coming from the present object-oriented technology. Furthermore, the developing surroundings of the object-oriented software supply us with the capability of realizing the agent's identities. Judging from the characteristics of the agent, autonomy is the essential property of it. At the same time, autonomy is also the substantial difference that tells the agent from the ordinary objects. The messages and the delivery of the messages are still the basis of its sociality. And it is the further abstraction and promotion of the object-oriented message pattern. No matter how profound it is in theory, the spiritual condition, namely, the spiritual quality of the agent can even be regarded as one of the attributes of itself. So, the main difference between agent and general objects lies in whether they have the active autonomy or not. But the process and the thread technique in computer science are the technical basis for the actualization of autonomy. We use both the Java Language, which is the neural and distributed architecture and multi-threads mechanism, and the MATLAB Product Integration Setting, which is often applied in concept designing, arithmetic exploring, modeling and simulating, as well as real-time achieving, to simulate the alternation of several different systems in practical environment. COMET (Concurrent Object Modeling and architectural design Method) is adopted in the simulation system. One of the goals of COMET is to construct several independent self-ruling subsystems based on the distributed application. And each of these subsystems is a collocating component that can use the local database when needed. The server subsystem can provide the database with a distributed access. In order to make a given application be collocated with all of its subsystems being configuring to the independent physical nodes, or be collocated with all or part of its subsystems being configuring to the same physical node, it is required that we determine the mapping from the subsystem to the physical node in the subsequent system collocating course, but not in the designing process. As a result, the communication among the different tasks that are related to the different subsystems should be demanded to use message communication. Only in this way can we establish a traffic environment in accordance with the reality, and thus we can get a simulation environment, which is highly collocating, concurrent and based on message communication.

4.1.3 The Characteristics of Traffic Agent in Cooperation

In the traffic simulation surroundings for the agent, all the transportation elements such as vehicle (including the driver), section of a road, intersection, and traffic lights together with the traffic-controlling center are the intelligent agents. And all of them are interacting and cooperating with each other so as to achieve the simulation in the real traffic system jointly.

The simulation system can be looked upon as a Client/Server System, in which the client (vehicle-agent) asks for traffic service from the relative server (road-agent), according to real-time condition, while road-agent give vehicle-agent the feedback of optimum travel route and calculate the number of vehicles that have different direction-turnings in the downstream intersection, then, it (client) periodically send message to relative intersection-agents (server). This is helpful for intersection-agent to make fast and effective adjustment for control strategy in advance. After receiving the order from the client, the intersection-agent corresponds with its neighboring agent about the coming and going vehicles from all directions. The region-agent coordinates in this process, and the central-agent monitors the traffic statues of the whole urban area together with the system-related coordination processing emergency case. After the vehicle-agent models are put into the traffic network by concerned models the vehicles produce the model in simulation, they are autonomous. Once they get into certain section on the road, they can communicate with the correlative multi-agent systems. Its working mechanism is closely similar with applying GPS and sensors in the real traffic condition.

The final goal of this system is to establish the multi-agent simulation system and the agent's pertinent systematic functions such as General-Control Agent, Region Control Agent, Intersection Agent, UTFGS-Urban Traffic Flow Guidance System, Information Delivering as well as the Running Modes of the Vehicle (including Free Driving, Following Driving, and Overtaking Driving) and so on. At present, we place our emphasis on the simulation of the vehicles and the agent intelligent traffic signal control. And in this way we can lay a foundation for further simulation in the future.

4.2Simulation Research on the Vehicle Agent

In the real urban traffic environment, the goal of all the traffic controlling methods is to serve the vehicles better and more reasonably so as to meet the needs of people's going-out and the economic and cultural development in the society. Hence, the simulation research of vehicles in the traffic simulation environment is very important. Most former simulation models of vehicles are based on mathematic model, not having taken into account of the fact that people control vehicles. People's subjectivity has a strong effect on the running of individual vehicle, and thus influences the traffic as a whole. Our hope is that we can grant the vehicle with intelligence in simulation so as to make the simulation in the whole system closer to real traffic conditions. Thus, we can make better controlling strategy by referring to the simulation effectively. According to the agent theory, the vehicle in this system should have the capability of making decision and judgment and should have its own knowledge. Moreover, the vehicle should be capable of adjusting the driving behavior in accordance with the outside traffic conditions. In the following part, we will discuss the simulation in vehicle-agent.

4.2.1 The Structure Characteristic of the Vehicle Agent

The vehicle-agent in this thesis refers to an abstract intelligent entity. It is designed to re-embody the driver's behavior while driving. We use some computerized simulation methods to do this simulation so that it can meet the needs in real traffic system research. The vehicle-agent has the attributes of both the physical vehicle and the driver. It can not only get information from the outside world by itself, but also adjust its driving behavior at any real-time according to the actual conditions of the outside world. At present stage, we don't take the specific machinery and its dynamic characteristics into account. We just consider the vehicle's traffic characteristics such as its driving behavior in the traffic system, etc. The vehicle-agent in this system has complex capability of making decision and judgment. It also has its own knowledge. Moreover, the vehicle is capable of adjusting the driving behavior in accordance with the outside traffic conditions. Figure 4.1 illustrates its model frame:

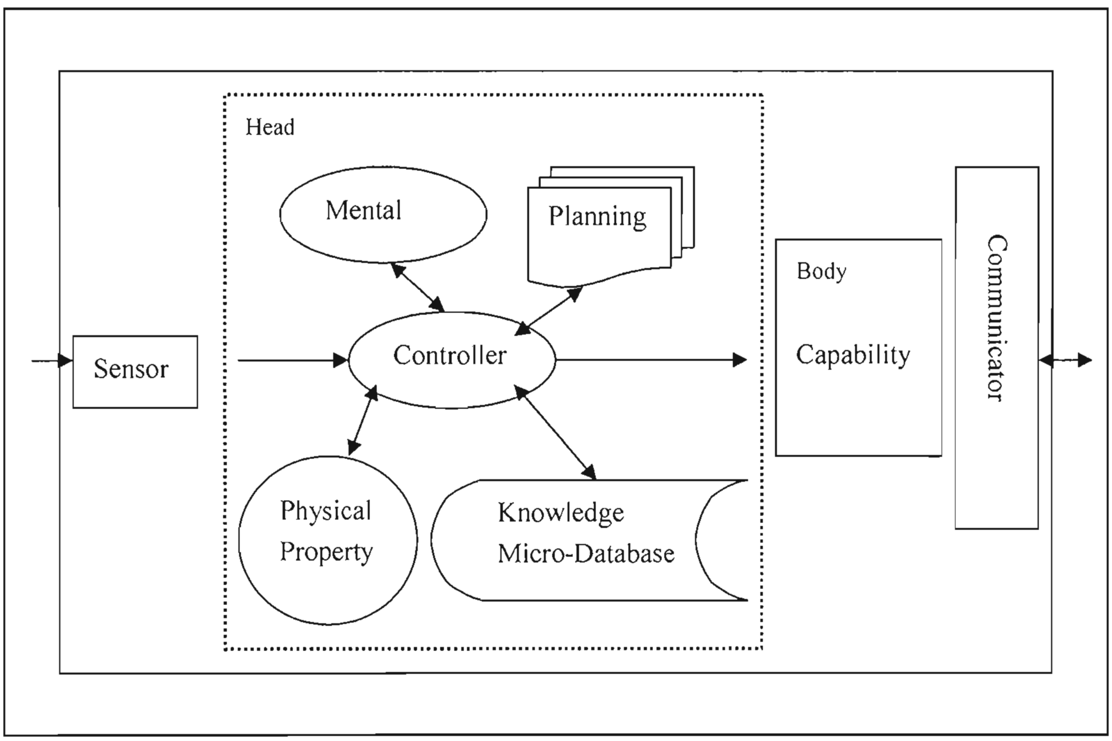

Figure 4.1 Model frame of vehicle-agent

In this model, the vehicle-agent exchanges information with the outside world through the sensor and communicator in it. The sensor senses changes of the outside world, while the communicator receives information from other agents or sends information to them. Planning stands for the driving plan. Physical characteristic refers to the geometrical characteristic and the performance index that are related to the vehicle. Mental factors refer to all the specialties concerning with the driver, which mainly include the driver's characteristics and intention at present. Knowledge Micro-Database is all the knowledge that the vehicle-agent has, which includes driving rules, controlling rules, and facts, etc. Controller is the running and controlling center of the agent, which is responsible for the circulation of all the agent's functions. Capability denotes the vehicle-agent's functions belonging to identity. Express it in details:

Physic attributes mainly include something about the vehicle's characteristics such as vehicle trademark, position, speed, acceleration, direction, height, weight, width, top speed, economical speed, destination and so forth.

Driver's attributes may include the type of the driver, sex of the driver, psychosis of the driver and the fatigue degree of the driver, etc. which are all connected with the driver.

Driving intention. It refers to the urgency degree of the driver's driving task.

Driving plan. It is the running plan of the vehicle, which mainly refers to the present route of the vehicle.

Capability: It refers to all the driving functions the vehicle has, such as speedup, slowdown, turn, overtaking, and parking, etc.

Controller: It is a strategy-controlling cell. The vehicle can make real-time driving strategy for the next step according to its own characteristics and the traffic information received from the surroundings by way of the controller.

Knowledge Micro-Database: It refers to all the knowledge, facts and controlling rules that the vehicle-agent has. It is the basis for agent's decision-making. Knowledge Micro-Database includes all kinds of data that belong to the vehicle itself as well as those the vehicle get from the outside world. Then the controller can make decisions and judgments according to all of the information.

Sensor: It is used to sense the stimulation and changes from the outside environment. It corresponds to various sensors in the real intelligent vehicles. But here it is only an invented sensor designed with some functions.

Communicator: It is used to receive and send messages. It can interact with other agents.

4.2.2 Functions of the Vehicle Agent

4.2.2.1 The Functionary Distance of the Vehicle Agent

A field of vision is the farthest distance that a man can observe in driving. In line with this trait, the vehicle-agent also has an observing field that is called the vision of the vehicle-agent. The objects beyond the vision are invisible to the vehicle-agent, and there are three types of distances with the vision:

The farthest perceptive distance: "d_L": The farthest distance that the vehicle can perceive is also called the vision of the vehicle-agent. The vehicle cannot perceive the objects that are out of this distance.

The controlled distance: "d_C": Within this distance, the vehicle can change its running state or perform the overtaking or following according to how far away the vehicle or barrier are from it within the vision as well as their running conditions.

The smallest distance: "d_S": Its aim is to prevent vehicles from crashing into another. It is the function of the vehicle's speed. If the distance between vehicles is smaller than this, an emergency brake is to be performed.

Generally speaking, the distance between vehicles (*d*) should be: $d_S < d < d_L$. When the distance is farther than the controlled distance, namely, $d > d_C$, the vehicle is believed to be in the free travel.

4.2.2.2 Travel Planning

At present, we assume that the destination of the vehicle is fixed. So the vehicle should be capable of adjusting its route momentarily in terms of the traveling environment. As a result, the vehicle-agent should have a planner with it so as to control the route of the vehicle dynamically. Thus the vehicle can regulate its traveling plan according to the variations of traffic conditions on different roads together with its driving tasks.

4.2.2.3 The Driver's Characteristics

We use the word "driver" to represent the Driver Part in the vehicle-agent. This part includes many factors such as characteristics of the driver, psychosis of the driver, sex, age and fatigue degree of the driver, etc. Different characteristics of different drivers may have an effect on the actual driving of the vehicle. For example, the young drivers are more intended to drive fast; however the drivers' sensitivities become worse when they are tired and so forth. But now we only consider what kind of effect the driver's characteristics have on his driving behavior. As to the other factors, we plan to perfect them in later researches.

In order to make it convenient for our research, we divide the driver's characteristics into three types: the rash one, the normal one and the cautious one. The rash driver tends to drive faster and make drastic actions in acceleration and deceleration, while the cautious driver tends to be careful drive slowly and make slight actions in acceleration and deceleration.

In order to reflect the changes in the drivers' types better, we define a variable "Φ_{driver}", which can be used as a token in describing the drivers' characteristics. The value range of this variable is [-1,1]. And the characteristic operator "λ_{driver}" is used to show the effects of the drivers' types on the vehicles. Table 4.1 shows their fuzzy relations. We define the value scope of the drivers' characteristic operator "λ_{driver}" as $[0.75, 1.25]$, and it is similar to the fuzzy division of the drivers' types. Figure 4.2 illustrates their membership function respectively.

Driver-type	Rash	Normal	Cautious
Acceleration/ Speed	Slightly quick	Ordinary	Slightly slow

Table 4.1 Relation between driver-type and Vehicles' driving behavior

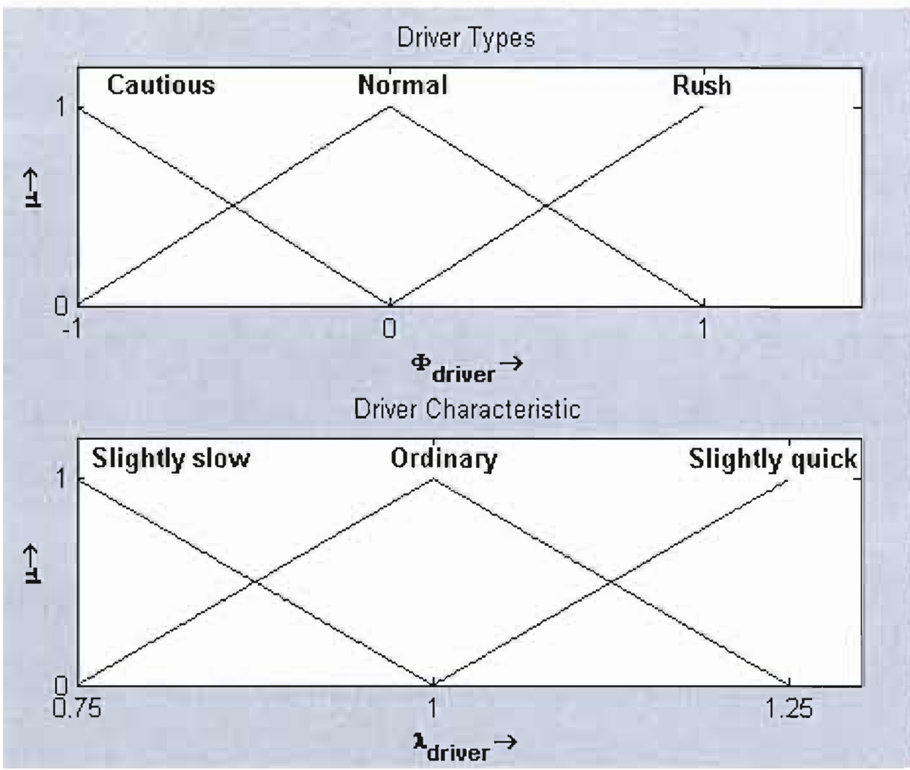

Figure 4.2 Membership functions of Φ_{driver} and λ_{driver}

4.2.2.4 Driver Intention

We introduce Driver Intention into the vehicle-agent's spiritual factors to show the difference in the driving purposes. We use the intentional operator "λ_{int}" to reflect the effects of the driver intention on the driving behaviors. Although people have different driver intentions according to various tasks, however at present, we only distinguish it into two different instances: the urgent intention and the non-urgent one. Figure 4.3 illustrates their membership function.

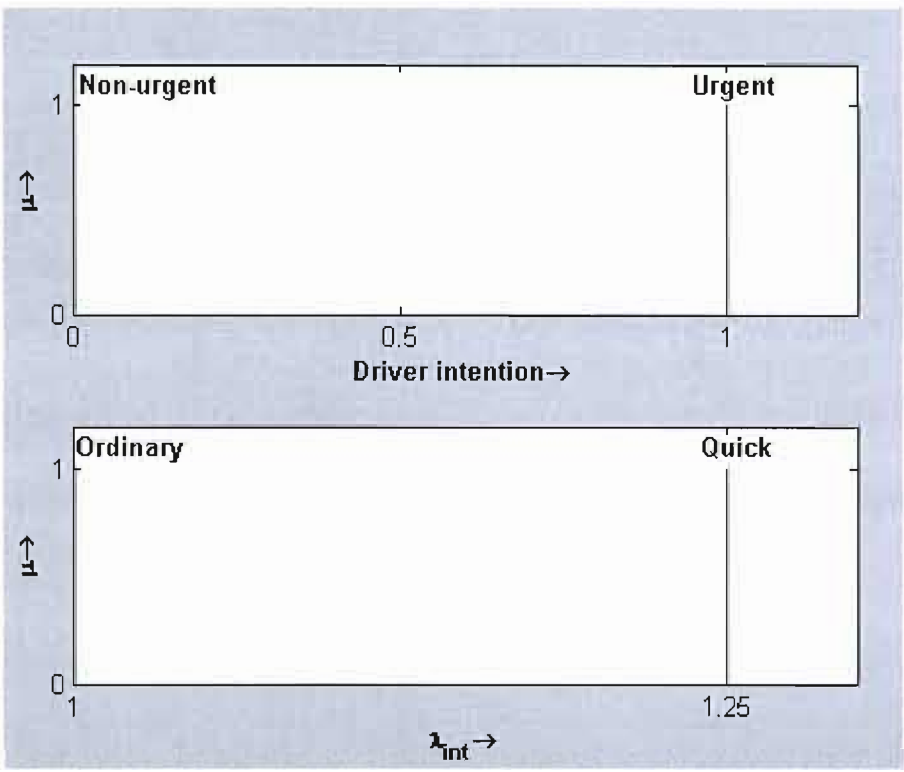

Figure 4.3 Membership functions of driver intention and its intentional operator

The influence of driver intention on the driving behavior is very complex, too. In the vehicle-agent, we hold the belief that driver intention influences the driving behavior. When driver intention is urgent, the vehicle's speed or acceleration should be a little bit higher. Table 4.2 shows the specific relation between interactions.

Driver Intension	Urgent	Non-urgent
Speed/Acceleration	Quick	Ordinary

Table 4.2 Driver intension influences driver behavior

4.2.2.5 Controller of the Vehicle-Agent

As the decision-making part of the vehicle-agent, the controller reacts sensitively to driving behavior on grounds of the information received from the outside together with the vehicle agent's capability and characteristics as well. There are a master controller and several function controllers in the present vehicle-agent controlling system. The master controller is responsible for the whole control on the vehicle-agent, while the function controllers are responsible for controlling on the specific driving function and behavior. When the vehicle is in the course of whole controlling, it should firstly carry out the collision detection to decide whether it is in the danger of crashing into other vehicles or barriers. If it were possible to crash, the vehicle would carry out the operation of avoiding crash at first. When the danger is over, the vehicle will go on to perform other controlling activities. Figure 4.4 illustrates it.

Among the vehicle's controllers, the master controller is superior to the others. When something unexpected happens, the master controller will stop the current controlling function and switch to other more advanced controlling functions. After finishing the advanced one, the master controller can switch back to perform the former controlling functions on condition that the needs are met. For example, if the vehicle wants to perform overtaking, but it suddenly finds that the vehicle in the front accelerates or goes into the overtaking lane, the vehicle can return to its primary lane and judge the proper condition for overtaking. When it is doable, the vehicle will carry out the overtaking operation.

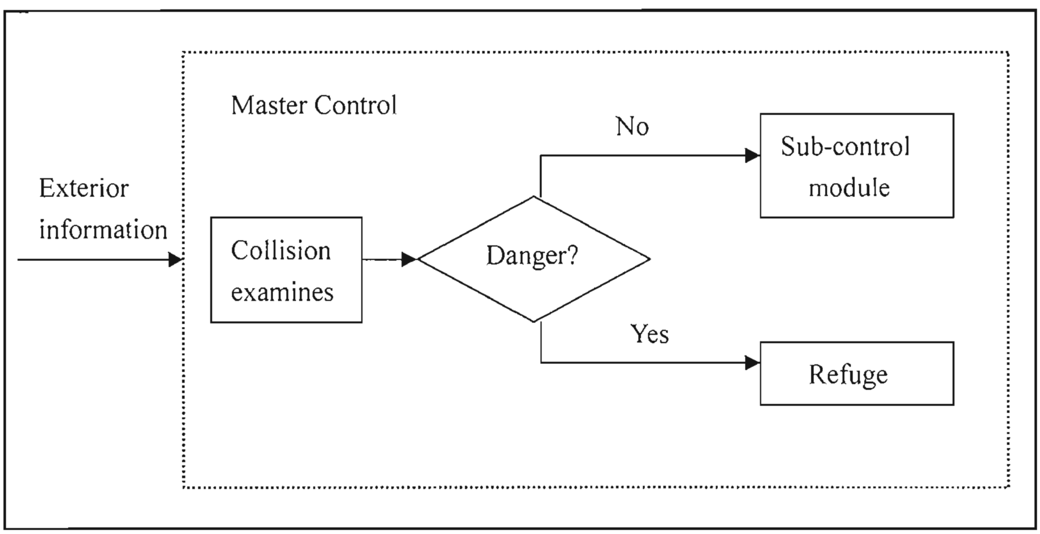

Figure 4.4 Vehicles master control implementation

The functions of each controller are as follows:

The master controller: It is responsible for the general control on the vehicle. It can make the next driving operation according to the external information and the vehicle's characteristics. Then maneuver the different driving behavior controlling modules through different driving operations.

Free driving controller: It is in charge of controlling the driving behaviors when the vehicle is in free traveling, or in other words, there is no vehicle in front of the controlled one or other vehicles are far away from the controlled one.

Vehicle following controller: It is responsible for adjusting the controlling process of its own driving behavior by referring to the preceding vehicles' behaviors. In such a case, the distance between the controlled vehicle and the preceding vehicles is within the retraining one, and it is unsuitable for performing overtaking.

Overtake driving controller: It is responsible for controlling the vehicle's overtaking behaviors, which includes changing lane and accelerating, regular driving on the overtaking lane, returning to the former driveway and so on.

Intersection-driving controller: It is a special controller that is responsible for controlling the vehicle's driving behavior at the intersection.

Turning controller: It is in charge of controlling the vehicle's turning behavior and this function is usually transferred to the intersection-driving controller.

4.2.3 Controlling Process of the Vehicle Agent

The control of the vehicle-agent is a very complex process. In the traveling course, the vehicle-agent must make continual judgments and then determine its driving behavior according to its position and other vehicles' status. In this process, the vehicle-agent should firstly judge its position correctly so as to make proper decisions on its driving behaviors (For example, the driving operation on the road and at the intersection should be different). The vehicle-agent should also determine its driving behaviors at the intersection on grounds of its traveling route. Then the vehicle-agent should make continual judgments on the preceding vehicle's driving behavior so as to make its specific driving operation. Figure 4.5 illustrates the main controlling flow:

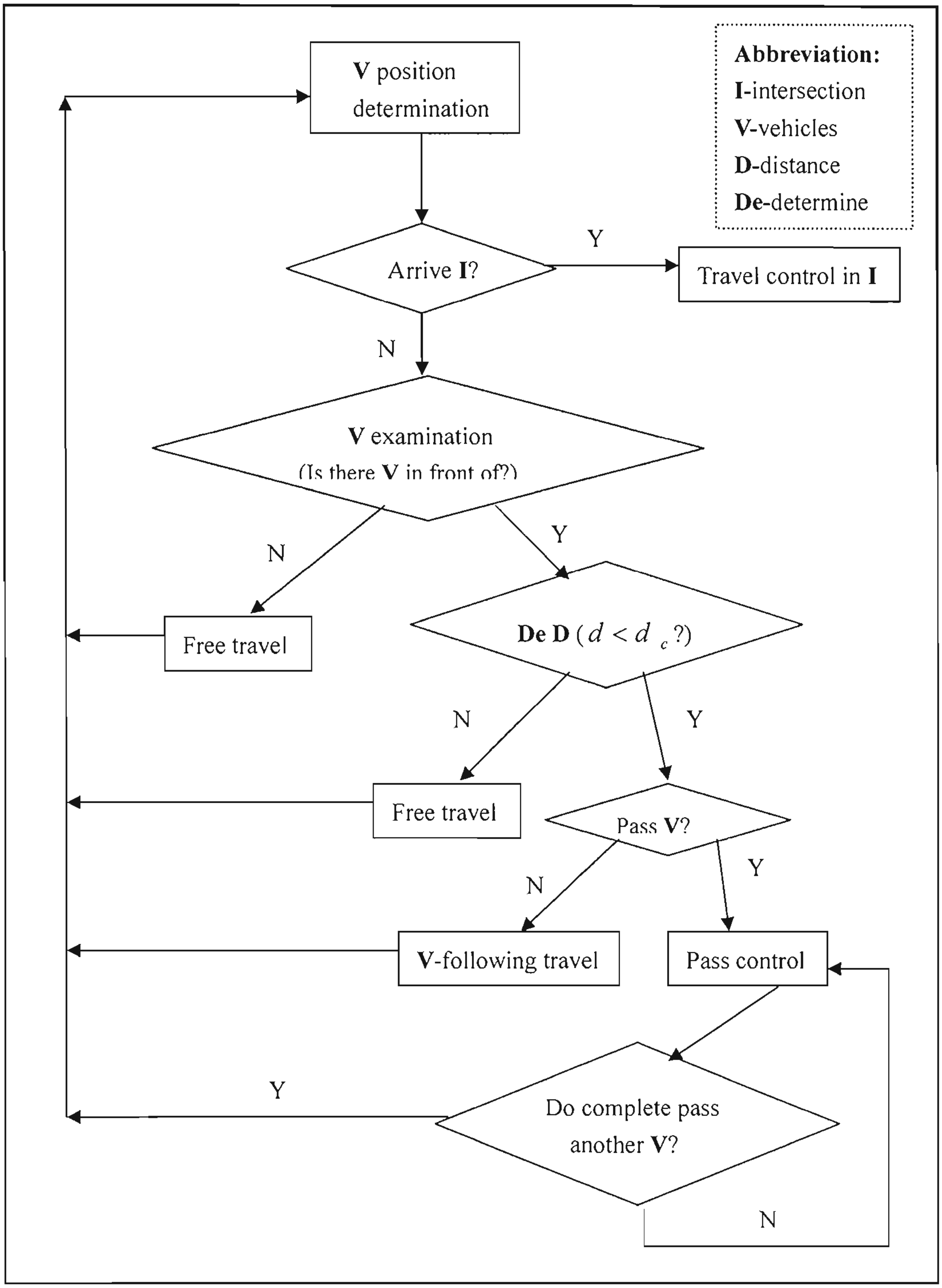

Figure 4.5 Controlling flow chart of the vehicle-agent

4.2.4 The Internal Decision-making Mechanism of the Vehicle Agent

In traffic simulation, we must make the vehicle-agent simulate human's real driving and decision-making process so as to make it reflect the real driving behavior. The development of the Intelligent Control Technology provides us with a more effective and useful solution to this problem. Fuzzy control can simulate human's decision-making process effectively, which provides us with an effective way to seek after the human's intelligent behavior course. Consequently, fuzzy control technology is used to probe into the vehicle-agent's decision-making strategy.

The vehicle's driving behavior includes free driving, vehicle following, overtaking, braking, etc. But we will mainly discuss the vehicle agent's free driving, vehicle following and overtaking in this thesis.

4.2.4.1 Vehicle-agent's Free Driving Control

The vehicle's free driving control is very simple. In this course, there are no other vehicles in front of our vehicle, or they are quite far away. So they have no influence on our driver's driving, and the driving behavior is mainly determined by its capability (the maximum speed) and the driver's characteristics together with the limitation of the roads. Among all these factors, the driver is the key factor. In free driving, it is believed that the vehicle-agent is running at the economical rate. But there are some differences because of the difference in driver's characteristics and intentions. For example, when something urgent happens, the cautious driver tends to drive at a speed that is slightly slower than the economical one, while the rash driver often drives at a speed that is faster than the economical one. However, the normal driver runs at the economical speed. Table 4.3 shows the relation of vehicle speed and driving behavior:

Driver-type / Driving-intension	Rash	Normal	Cautious
Urgent	Quick	Slightly quick	Economical speed
Non-urgent	Slightly quick	Economical speed	Slightly slow

Table 4.3 Free driving control's relation

If the vehicle gets a free driving speed over the road-limited speed owing to the influence coming from the driver's characteristics and driving intention, it will run at the road-limited speed.

4.2.4.2 The Strategy for the Vehicle Agent's Following Driving

1) The Vehicle's Following Driving Principle

The vehicle's following is a running state in which a vehicle has no way to perform overtaking operation but to follow the front one. In this case, the drivers are trying their best to keep their vehicles within the safe distance in order to avoid car crash. For this purpose, drivers have to adopt corresponding running scheme according to the front vehicles' running state. As a result, the back vehicle's running speed and the distance between the back vehicle and the front one is limited by the front one and the back vehicle is in a non-free running state. Furthermore, the drivers' inborn reactions are different, so the front vehicle's and the back one's actions are not synchronous. The back vehicle driver needs a course to react to the changes of the front vehicle's speeding-up and slowing-down, etc. If the front vehicle has some changes in action at the "t" moment, the back one can only react to it at the "(t +T)" moment thus causes the lag.

If it is supposed that the front vehicle " n " is in the position "$x_n(t)$" at the time of " t ", and the back vehicle " n+1 " is in the position "$x_{n+1}(t)$" at the time of " t ", the vehicle following driving model can be inferred from the above, namely:

$$\ddot{x}_{n+1}(t+T) = \frac{1}{T}[\dot{x}_n(t) - \dot{x}_{n+1}(t)] \tag{1}$$

And this is the vehicle's linearity tracking model. Unfortunately, this model hasn't shown the distance-relation between the two vehicles. This obviously collides with the truth. The modified vehicle following model should be:

$$\ddot{x}_{n+1}(t+T) = a\frac{[\dot{x}_{n+1}(t+T)]^m}{[x_n(t) - x_{n+1}(t)]^L}[\dot{x}_n(t) - \dot{x}_{n+1}(t)] \tag{2}$$

In this model, "$a = \frac{1}{T}$" is the measurement of sensitivity, "m, L" are constants. We can also say that the vehicle's acceleration and the two vehicles' margin in speed are in direct proportion, while the vehicle's acceleration and the two vehicles' spacing-margin are in inverse proportion. When $m = L = 1$, the second model can be changed into:

$$\ddot{x}_{n+1}(t+T) = a \frac{1}{\dfrac{[x_n(t) - x_{n+1}(t)]}{[\dot{x}_{n+1}(t+T)]}} [\dot{x}_n(t) - \dot{x}_{n+1}(t)] \qquad (3)$$

Here, "$\dfrac{x_n(t) - x_{n+1}(t)}{\dot{x}_{n+1}(t+T)}$" is the time-margin between the two vehicles' head parts. Hereby, in the vehicle following, the acceleration of the back vehicle is in inverse proportion with the time-margin between the two vehicles' head parts, while it is in direct proportion with the two vehicles' margin in speed.

2) Vehicle Agent's Controlling Decision-making Based on Fuzzy Control

Vehicle following is the most frequent driving controlling format in driving. It is the main driving form in urban areas because there are so many vehicles that they run slowly. In vehicle-agent, it is the vehicle following controller that is responsible for performing this function. Since we have taken the fuzzy control strategy in vehicle following, we could make the vehicle's intelligent driving come true. So, as a matter of fact, the vehicle following controller in vehicle-agent is also a fuzzy control system indeed.

① The Selection of Fuzzy Variables

As we are carrying out the microcosmic simulation in traffic system, we assume that the vehicle is an ideal vehicle; the road is also an ideal straight road, and the vehicle doesn't have any heeling-over and going-on-the-rampage in running. We also presume that the vehicle runs in a fixed direction in the following driving so as to predigest the vehicle's controlling behavior in movement.

According to the analysis of the vehicle's driving behavior in vehicle following, we know that it is the front vehicle's driving behavior that a mainly influence the back one's driving behavior. And the key factor that has an effect on the drivers is the speed-margin and spacing-margin between the head parts of the two vehicles. The driver can't get the exact speed-margin of the two vehicles. He can only judge the changes in the speed-margin on grounds of the changes in the spacing-margin. At the same time, the vehicle agent's driving behavior is also affected by some other factors such as the driver's characteristics and intentions, etc. Hence, in fuzzy control of the vehicle agent's vehicle following, we define input value as "d_t"(the time-margin between the head parts of the two vehicles) and changes in "Δd" (the spacing-margin between the two vehicles); while we define output value as "a" (the vehicle's acceleration, and it is minus when braking.). This decision-making process is affected synchronously by the driver's characteristics and intention. Figure 4.6 illustrates it:

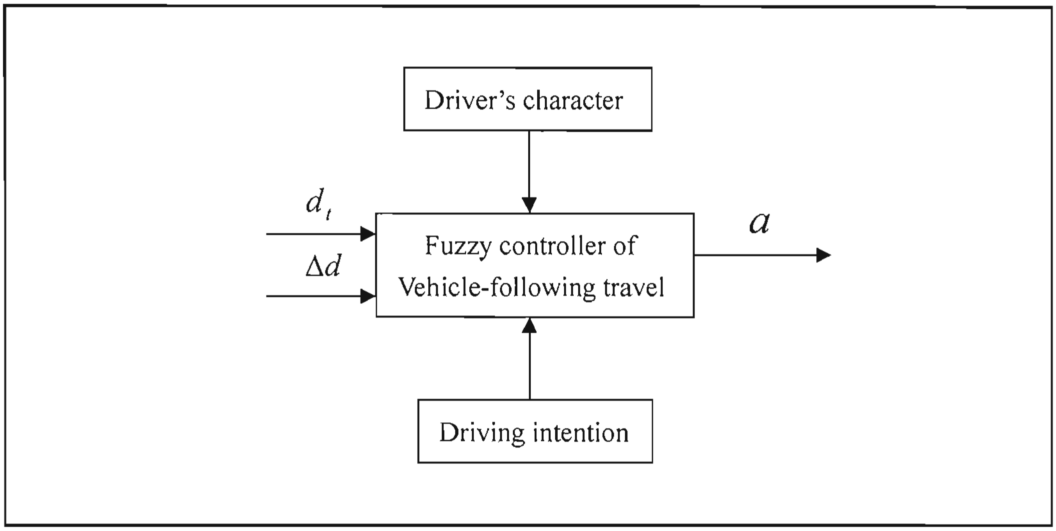

Figure 4.6 Fuzzy control of vehicle following

② The Determination of the Membership Functions of Fuzzy Variables

In this functioning system, it is the parameters' variable of the front vehicle that has decisive effect on the decision-making in driving. While the driver's characteristics and intention influences decision-making in driving. Researches have shown that the time-margin between the head parts of the two vehicles tends to be stable in vehicle following, and usually the minimal safety time-margin between the head parts of the two vehicles is about 2 seconds. The survey on 10 000 drivers about their vehicles' time-margin between the head parts has proved that about 49.4% of them obey this rule. But we still notice that the different characteristics of the drivers have definite effects on it, and that the proficiency of the drivers in driving has great effects on it, too. The non-proficient drivers tend to keep a bigger head-parts time-margin with other vehicles in order to make up for their insufficiency in operating. Meanwhile some outside conditions such as road's conditions and weather conditions also influence the vehicles' head-parts time-margin. For instance, the vehicles' head-parts time-margin tends to be a little bigger in a rainy or foggy day.

We define the fuzzy language variables of time-margin as five different instances in this thesis: the big one, the biggish one, the moderate one, the small one and the smaller one. We only take two factors---the driver's characteristics and intention into account, neglecting other outside factors provisionally. We are to find out in which way these two factors affect the driving behavior. We have talked about the effects of the drivers' characteristics and intention on the speed or acceleration in driving in the previous part. But in vehicle following, we believe that the drivers' different types influence the vehicle-agent mainly by influencing their choices on the vehicles' head-parts time-margin. We can easily know that the rash drivers tend to choose a lesser head-parts time-margin in driving, while the cautious drivers tend to keep a biggish one in driving. Therefore, based on the analysis of the three different types of drivers' characteristics, we can draw a conclusion that the head-part time-margin of different types of drivers in vehicle following differ from each other greatly. The normal drivers keep a normal head-part time-margin division in driving, whose value scope is (1, 1.5, 2, 2.5, 3); the rash drivers keep a lesser head-part time-margin, whose value scope is (0.5, 1, 1.5, 2, 2.5); while the cautious drivers keep a biggish one, whose value scope is (1.5, 2, 2.5, 3, 3.5). Figure 4.7

illustrates their fuzzy relationship respectively, and we define them as the big one, the moderate one and the small one.

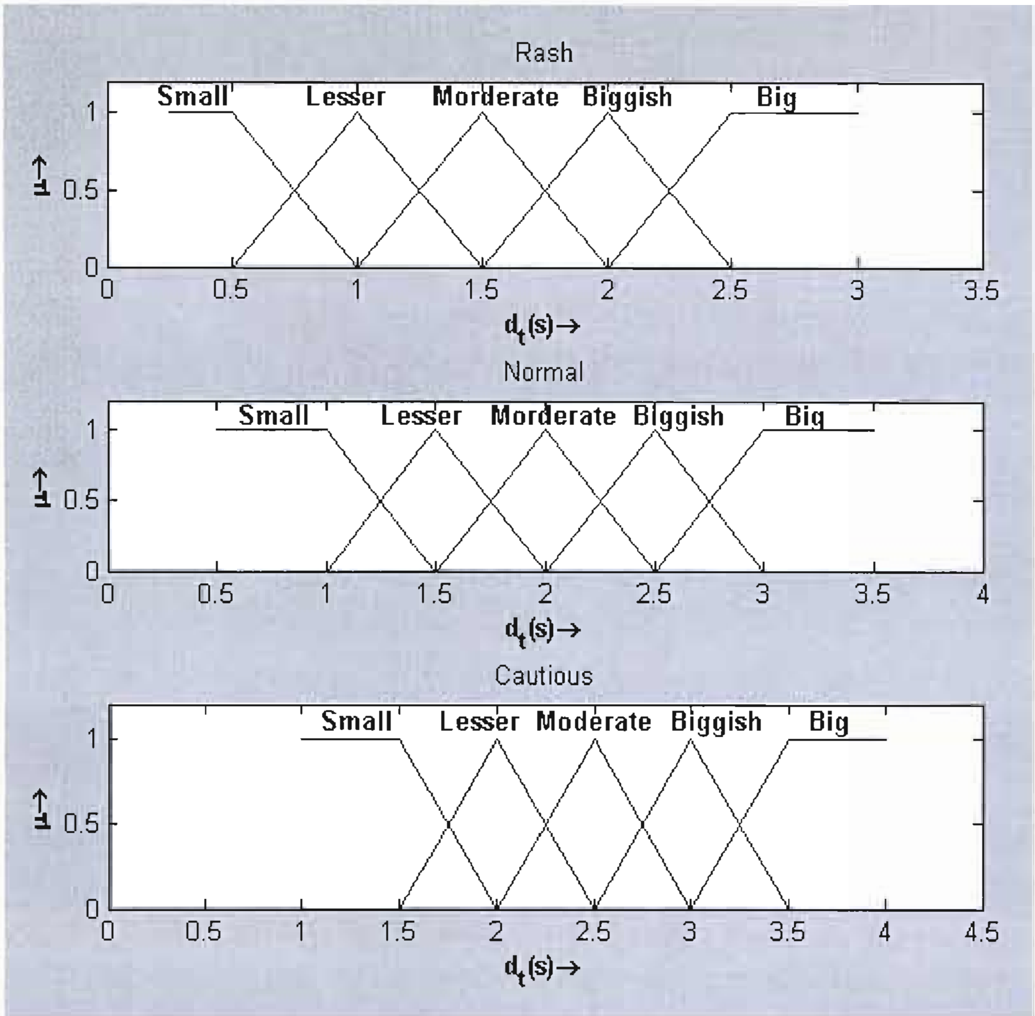

Figure 4.7 Fuzzy membership function d_t (unit: Sec) of different driver-types

Meanwhile different driving intentions of different drivers may also affect the choice of head-part time-margin. The driver with an urgent task may also keep a lesser head-parts time-margin. But because of the limitations coming from human's reacting ability, the vehicles' head-part time-margin mustn't be too short. As a result, in our present research, we believe that even if the rash drivers were in emergency, their vehicles' head-part time-margin would not become shorter ulteriorly. Table 4.4 illustrates its detailed interactive relation.

Driver-type / Driving-intension	Rash	Normal	Cautious
Urgent	Small	Small	Moderate
Non-urgent	Small	Moderate	Big

Table 4.4 The relationship of driving factors and head-part time-margin

Fuzzy language variables for spacing-margin changes and acceleration are {NB (negative big), NM (negative moderate), NS (negative small), ZE (zero extended), PS (positive small), PM (positive moderate) and PB (positive big)}. Their value scopes are (-3, -2, -1, 0, 1, 2, 3), and Figure 4.8 illustrates their membership functions.

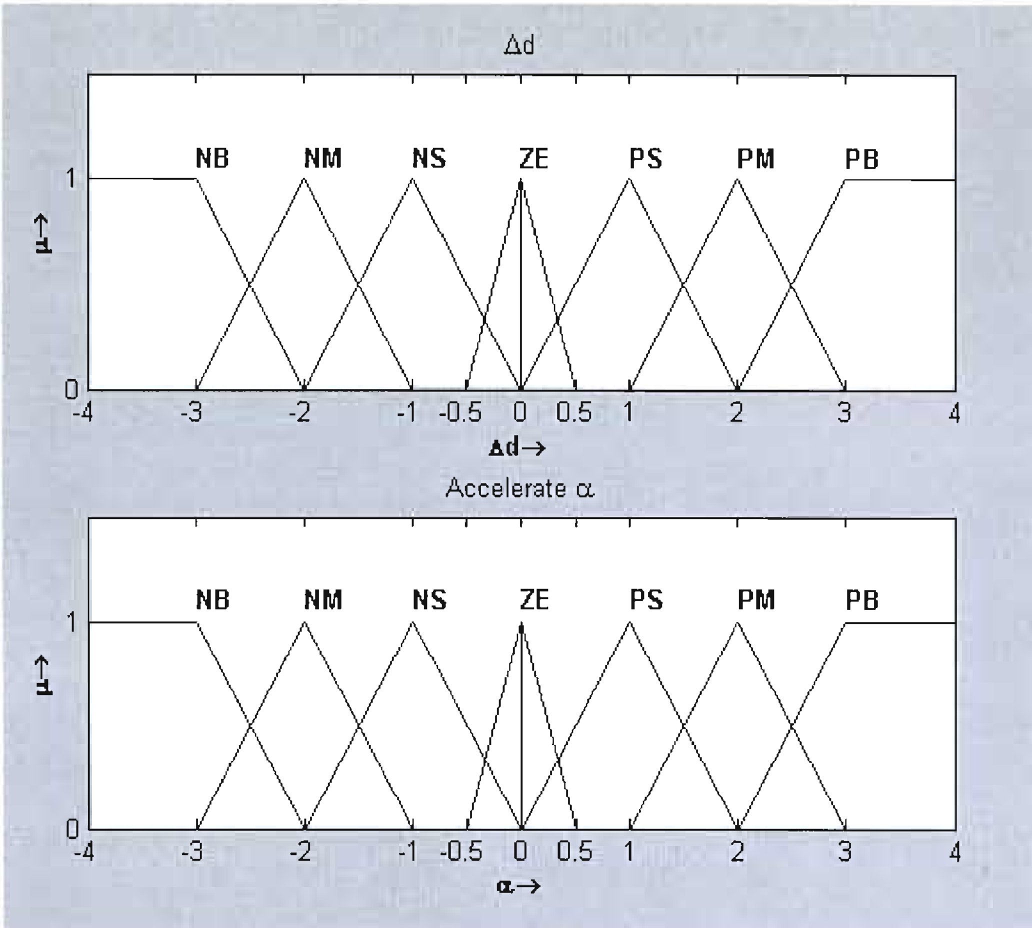

Figure 4.8 Fuzzy membership functions of spacing-margin changes and acceleration

③ Fuzzy Reasoning

The system adopts the procreant fuzzy rule which is in form of "IF...THEN", and it defines A_i as the fuzzy subsets for head-part time-margin, B_i as the fuzzy subsets for vehicles' spacing-margin, and C_i as the fuzzy subsets for acceleration. Their fuzzy relation is as follows:

$$R = \bigcup_{i}^{n} A_i \times B_i \times C_i$$

The fuzzy reasoning is:

$$C_i = (A_i \times B_i) \circ R$$

The system takes the MAX-MIN algorithm to achieve fuzzy rule evaluation. The output is:

$$z = \frac{\sum_{i=1}^{n} \mu_c(z_i) \bullet z_i}{\sum_{i=1}^{n} \mu_c(z_i)}$$

d_t \ Δd \ a	NB	NM	NS	ZE	PS	PM	PB
VB	NS	ZE	PS	PM	PB	PB	PB
B	NM	NS	ZE	PS	PM	PB	PB
PM	NB	NM	NS	ZE	PS	PM	PB
S	NB	NB	NM	NS	ZE	PS	PM
VS	NB	NB	NB	NM	NS	ZE	PS

Table 4.5 vehicle following control rules of vehicle-agent

Then we can get the above output table 4.5 based on the drivers' driving experience.

4.2.4.3 Controlling Strategy for Vehicle-Agent's Overtaking

1) The Principle for Overtaking

The vehicle cannot only perform vehicle following but also carry out overtaking operation when being permitted in running. Drivers often take overtaking operations. It is different from vehicle following driving. Overtaking is not only concerned with the driving behaviors of the overtaken vehicles, but also related to the driving behaviors of the vehicles on the opposite route (considering some relatively narrow roads in Chinese cities). Hereby, overtaking is a little bit complex.

When performing overtaking, the vehicle is to switch to the left lane or the opposite lane. So, there should be a safety distance that is called "S" for this performance. This distance is also named "full distance for overtaking", which refers to the safety overtaking distance that guarantee the willing overtaking vehicle is able to accelerate and overtake the front one. Overtaking is a complex process, which involves many stochastic factors. For example, the vehicle-type and the road's condition, etc. influence overtaking. And the distance suitable for overtaking is closely related to the speed of the overtaking vehicle, the overtaken vehicle and the opposite-route vehicle as well.

If the back vehicle wants to perform overtaking, it must speed-up at first to run faster than the front one and change its running lane. When the overtaking is over, having the safety distance that permits it going back to its normal running lane without influencing the overtaken vehicle, it will switch back to its original lane, then the overtaking is over. Owing to the existence of the complexity and uncertain factors in overtaking process, there is no strict definition on the specific steps in the whole overtaking course; however, we divide the whole overtaking process into three phases in this thesis:

① Accelerating and Changing Lane

We think that the acceleration speed of the overtaking vehicle keeps the same while the overtaking vehicle begins to accelerate and change into the overtaking lane or the opposite one. And in this period the overtaking vehicle has to run a distance, which is called "d_1". And we define "S_0" as the distance between the overtaking vehicle and the overtaken one before the overtaking is performed. We assume that "N1" is the overtaking vehicle, "v_1" is its initial velocity, its acceleration is "a", the time for accelerating is "t_1", and "v_2" is the speed at which the vehicle runs when the acceleration is over. We can get a formula from the above assumptions:

$$d_1 = v_1 t_1 + \frac{1}{2} a t_1^2$$

$$v_2 = v_1 + a t_1$$

② Uniform Speed Running on the Overtaking Lane or the Opposite One

When the acceleration is over, the vehicle will go into the overtaking lane or the opposite one and runs at the uniform speed. We assume that during this period the overtaking vehicle has run a distance, which is assumed to be "d_2". And we assume that "S_1" is the safety distance between the overtaking vehicle and the overtaken one in which the overtaking vehicle " N1 " has exceeded the overtaken one " N " but hasn't switched back to its former lane yet. It is assumed that the time needed for finishing this distance is "t_2", and then we can get the following formula:

$$d_2 = v_2 \bullet t_2$$

③ Returning to the Original Lane

The overtaking vehicle will return to its original lane when the overtaking is over. The running distance during this time is "d_3". We presume that the overtaking vehicle "N1" keeps the same speed "v_2", and the running time is "t_3". Then we can get:

$$d_3 = v_2 \bullet t_3$$

We assume that there is an opposite vehicle "N2" runs at the uniform speed on the opposite lane when the vehicle "N1" is performing the overtaking operation, and the opposite one is running at the speed of "v_3", we presume "d_4":

$$d_4 = v_3 \bullet (t_1 + t_2 + t_3)$$

And we make a presumption again that "d_5" is the distance between the overtaking vehicle and the opposite one when the overtaking is over. Thus we can get the safety distance for overtaking.

$$S = d_1 + d_2 + d_3 + d_4 + d_5$$

If the distance between vehicle " N1 " and the first opposite vehicle " N2 " is longer than " S ", we say that vehicle " N1 " can overtake vehicle " N" safely; otherwise, vehicle " N1 " can't perform overtaking operation. It has to do the following driving behind vehicle "N". During this period, vehicle "N1" will make real-time judgments on the distance between itself and the front vehicle as well as the vehicles on the opposite lane, then decide whether to overtake or not by considering all the information with its driving intention.

2) The vehicle agent's overtaking control

According to the above analysis on the overtaking process, we can conclude that the overtaking process includes the following steps:

① Making judgments on the possibility of overtaking. The vehicle will make judgments to perform overtaking or not according to the concerned data of the vehicle. If it is allowed to perform overtaking, it will carry out this function without any delay. But if it is impossible, the vehicle will maintain the vehicle following.

② Accelerating and changing lane.

③ Running on the overtaking lane.

④ Making estimation to see whether it is able to return to its normal lane or not. If the distance between itself and the object vehicle is longer than the safety distance, it will prepare to switch back to its normal lane.

⑤ Returning to the normal lane.

We simply analyzed the vehicle's overtaking process in the previous part, which is determined by the outside factors. But in the vehicle-agent, we also take the drivers' characteristics and intentions into account, and these two factors will also affect the vehicle-agent's overtaking behavior. In this case, whether to overtake or not is decided by the driver, who makes judgments according to the outside and internal factors.

We classify the conditions for the vehicle's overtaking as the following four types according to the vehicle's overtaking distance: Good, Generic, Bad and Unsuitable. Good condition means the overtaking distance is big, and the vehicle can easily finish the overtaking operation with lesser acceleration. Generic condition means the overtaking distance is mezzo and it needs a moderate acceleration to accomplish overtaking. Bad condition means the overtaking distance is short and it needs a biggish acceleration to finish overtaking constrainedly. Unsuitable condition means overtaking is forbidden. We can get the controlling relation between them based on the analysis of the conditions for overtaking and the vehicle-agent's characteristics. See Table 4.6.

Driving-intention	Urgent			No-urgent		
Driver-type / P-Condition	Rash	Normal	Cautious	Rash	Normal	Cautious
Good	P	P	P	P	P	P
Generic	P	P	P	P	P	I
Bad	P	I	NP	I	NP	NP

P: Pass the other vehicle; NP: No passing permitted; I: Indefinite

Table 4.6 Overtaking decision-making control of vehicle-agent

As to the uncertain conditions, it will be up to the computer to determine randomly in simulation.

4.3 Road Agent Study

To realize ITS, an intelligent road network is necessary. To lighten the burden of intersection signal control, it is necessary to make vehicles driving on roads communicate with intelligent monitor facilities equipped on urban roads at real-time. Obviously, each road is an agent, which makes up a multi-agent system. We'll do a research on road agent from the following aspects:

- Intelligent traffic guidance: when vehicle-agent drives onto a road, corresponding road agent should communicate with vehicle-agent at real-time according to traffic conditions at that time, meanwhile advise it to follow the optimal driving route, furthermore, guide classifiably according to the vehicle's characteristics.
- Real-time traffic control: an important factor to achieve real-time control is to reduce the system's complexity. All vehicles communicating with intersection-agent will greatly reduce the practicality and economy of the system; meanwhile inter-communication among vehicle agents will make vehicles fuzzy in so much information. So road agent is the bridge between intersection-agent and vehicle-agent. Not all the vehicles driving onto certain road should leave. Some of them may stop. Road agent should watch and collect necessary vehicle information (i.e. total number of vehicles to reach certain intersection and the number of vehicles to be divided into different directions, etc.), then feedback intersection-agent in time to control vehicles in advance using signal strategy; vice verse, road agent "suggests" vehicles on speed,

driving route, etc. according to relative intersection-agent control information and its physical characteristics.

- Accident inspection: when traffic accidents happen on certain road, inform relative intersection signal control agent not to let vehicles enter temporarily and meanwhile, guide better driving routes by multi-agent system.

We think that intelligent road network is the basis of real-time traffic control. At present we focus on intersection-signal control as the vehicle-agent indicated above. Simulation research on road network agent plays an important role in the whole real-time control system. It gets ready for further realization.

4.4Summary

This chapter mainly inducts what traffic simulation is and something about the tendency of using agent technology to do traffic simulation. In order to reflect the developing tendency of the intelligent urban traffic in the future, we are expected to make all the concerned models in the simulation system turn into agents. We believe that the vehicle-agent is the keyword to the whole traffic simulation system. Therefore, we discussed the operating strategies of the vehicle-agent in running in detail based on the assumption that the agent composes the mechanism of the system. We apply fuzzy theory to the vehicle's strategy making process on the presumption that people often make fuzzy controls in making strategy and judgment so that we can make the vehicle-agent more effective in making different strategies and judgments. According to the different operating types in practice, the chapter gives us a detailed description of the vehicle agent's specific decision-making methods in free driving, following driving and overtaking. Then we discussed in detail the influence of the driver's characteristics and intentions on operation. We introduce road network multi-agent system in the end. It offers us a valuable reference in promoting the authenticity and variety of traffic simulation.

CHAPTER 5

TO ACHIEVE SIMULATION USING OBJECT-ORIENTED TECHNOLOGY

The agent technology provides us with a more advanced means to develop software and it is more beneficial to solve the complex systematic problems. However, the present research based on the agent software-developing environment is comparatively slow versus the development of agent theory. The simulation in this system uses the object-oriented technology to develop a distributed architecture based on agent so as to make the agent's methods come true.

5.1 The Structural Design of the MA-URTC Simulation System

The basic functioning theory and aims of the traffic simulation system are: under a given traffic circumstance, make the vehicle go into the traffic network one by one in its producing area according to certain random distribution. Then use time-scanning method to scan each of the vehicles' running condition in each scanning period till it arrives at its destination or disappears in terminal from the traffic network. In this process, we can seek out a classic or optimum solution to solve traffic problem by comparing various traffic controlling strategies to serve the real-time traffic control better in the urban.

The single-computer simulation environment of the system is going to be changed. In order to re-embody the real traffic controlling condition exactly, the system takes the network as simulation surroundings to realize distributed simulation. It has better scalability, versatility and reusability, etc. More importantly, it can fast dispose the actual traffic control system. We can set several computers as Intersection-agents and then carry out the controlled signal simulation according to the simulation on its relative traffic network and traffic flows. And this intersection-agent can communicate with the neighboring intersection-agent conforming to the actual parameters. The Region-Agent computer controls and cooperates with the communication. Then we can simulate the watching-on, which is the responsibility of the General-Agent computer, over the traffic network. For example, we can set many a computer as the same simulating environment except that they are different in signal controlling strategy so as to find out the most optimum resolution by comparing simulation in the same period. In former simulation, the vehicle always appears and disappears at the edge of the traffic network, and this is not the case in reality. One of the advantages of distributed simulation is that a single computer can make the vehicle appear or disappear within the area controlled by it. Meanwhile it can take in other vehicles that come from other areas. It can even let these vehicles “drive out”, “disappear” or “stop and wait for driving again”. The vehicle’s coming-up and fading-away on the roads are the main factors which influence the traffic flows in urban area. The whole design in structure conforms to the real traffic conditions exactly, either macroscopically or microcosmically.

The computer simulation platform adopts a structure that combines the advantages of the two kinds of structure: the hierarchy model and the plug-in model. Figure 5.1 illustrates its hierarchy model.

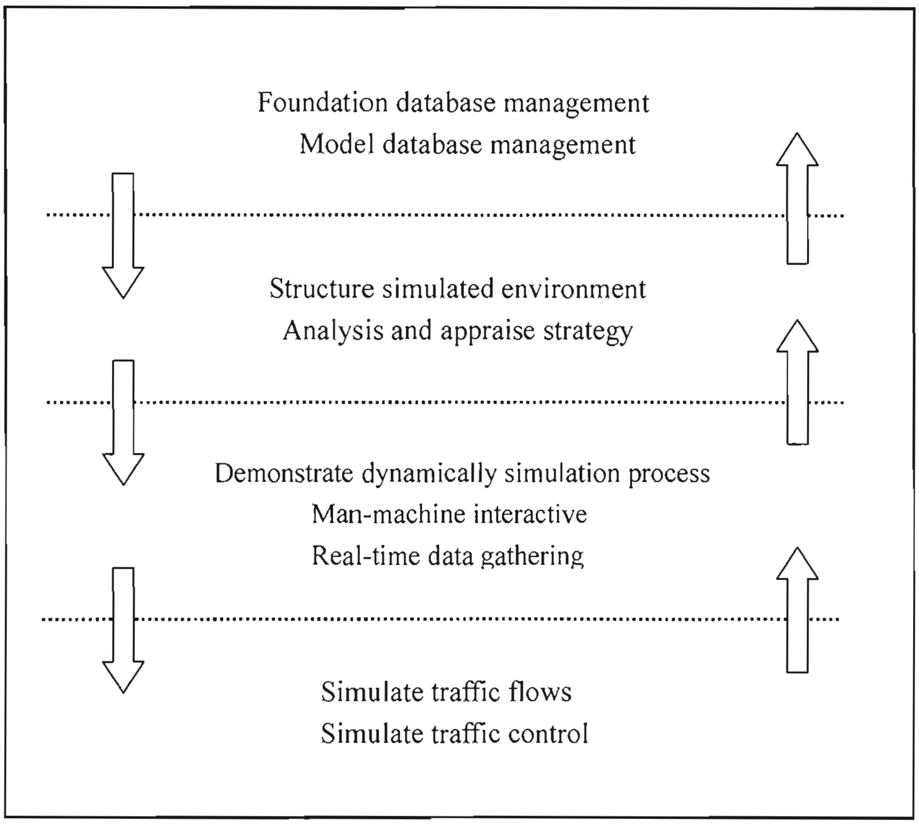

Figure 5.1 The hierarchy model

Plug-in structure means that the main components of the system are carved up into interdependent modules (plug-ins) according to their different functions. The modules exchange data through the database then actualize the function conjunction. To achieve the plug-in structure, we need some highly eligible interface modes. Figure 5.2 shows plug-in structure drawing.

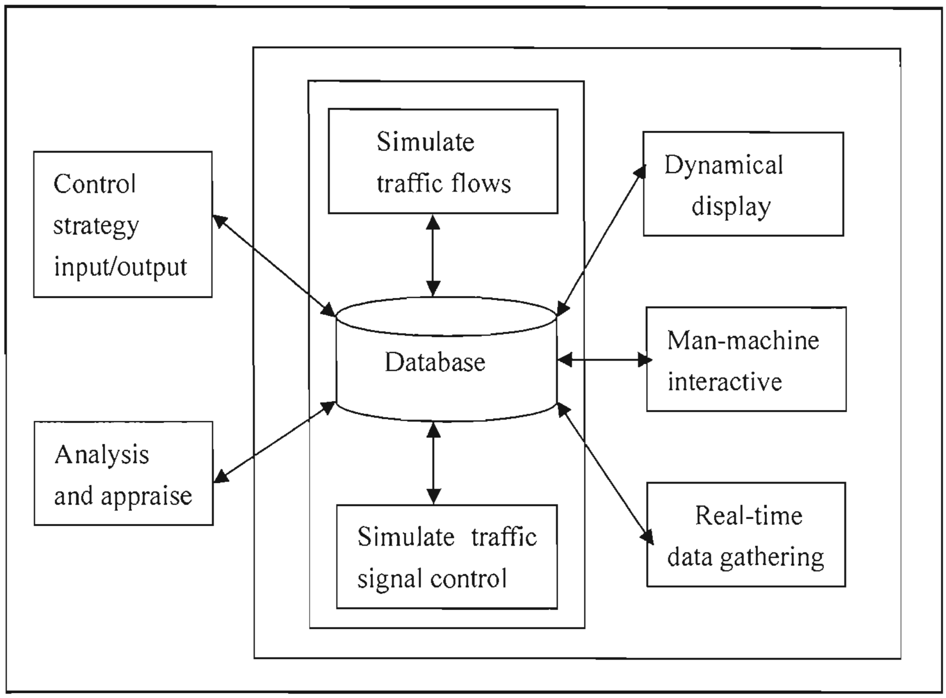

Figure 5.2 The plug-in model

MA-URTC aims to achieve all the systematic Multi-agent Simulation environments that are related to the traffic. But at present, we only perform the intelligent simulation designs on traffic signal controlling agent, the vehicle-agent and the road agent. Based on the analysis of the requests, our system only has four kinds of models: the Road-agent Model, the Traffic Signal Controlling Model, the Traffic Flow Simulating Model and the Contingency's Dally-over Disposal Model (conflicting point). Their main functional descriptions are as follows:

- Road-agent model: This model is used to describe the road's geometrical conditions and the traffic network's topology. Meanwhile it can help us make improvement scheme for the traffic network. It can also be used to simulate the traffic on the altered roads then comment on the alternation according to corresponding computerized targets. The former traffic simulation paid more attention to control the traffic flow in single-intersection area or the fixed traffic area. But current roads are expected to be intelligent and serve for the urban overall transportation plan and decision-making as well. This model differs from other road-description models in that it is an intelligent traffic network, which is composed of multi-road-agent to make real-time statistics on grounds of the specific transportation information, received and communicate with related agents. When a vehicle-agent gets into a road section or start in some place on this section, it is required to register in the corresponding road agent. On the contrary, when a vehicle-agent leaves off or stops on a road, it is demanded to logout. Furthermore, sometimes the road lateral sections are not consistent with each other. For example, the road may change from four-lanes into two-lanes. So if there were no watching-on, there might be a huddle, or foul-up or even traffic jam on the road. But because we have applied this model in the traffic system, we can learn about the position of the vehicle and the huddle in all the approaches at any time. In this case, the road is equal to a route on which advanced sensors have been installed in the intelligent traffic system.

- Traffic signal controlling model: It is responsible for describing various projects for traffic control and administration. These projects include the intelligent traffic signal controlling one and the route choosing one (It does some calculation in the vehicle's route choosing according to some strategy and arithmetic. It can also define the shared objects that can be supplied to other simulating members in the running route).
- Traffic flow simulation model mainly includes the following two types:
  - Vehicle producing model: This model can produce dynamically and stochastically the necessary vehicles in each entry of traffic network simulated model according to such parameters as the vehicle's O-D (origin-end) of the traffic flow, the vehicle's driving route, the probability distribution rules which the vehicle producing must obey and the ratio distribution rules of all kinds of vehicle-types. Generally speaking, the traffic flow on urban roads submits to the following four types of stochastic distribution: the Poisson's distribution, the negative index distribution, the binomial distribution and the negative binomial distribution. The Poisson's distribution is used to describe the traffic condition in which the enumerative time-interval is very short; the traffic flow consistency is not very big; the interactive influence between the vehicles is lesser without influences from the outside world. The negative index distribution is the most widely used method in describing the head-parts time-margin. It is suitable for the case in which the traffic flow consistency is not very big and the vehicles arrive stochastically. When the number of the

vehicles in an uninterrupted traffic flow is no less than 500 in a lane per hour, it is practical to use the negative index distribution. The binomial distribution is used to describe the traffic flow that is very crowded and with little freedom to drive randomly. The negative binomial distribution is used to describe the traffic flow that alternates with sparseness and huddle between the vehicles with high variance. Each of the vehicle producing modules of the above-mentioned four kinds of stochastic distributions in this simulation system has a corresponding program so that it can be used by different intersections in simulation when requested.

- Vehicle-agent's driving model: It is used to describe the vehicles' driving behaviors. We generally divide the vehicle-agent model into some sub models. The vehicle following model is used to describe the following driving behavior. The lane-changing model is used to describe the vehicles' lane changing course that includes free driving and overtaking. The event reacting model is used to describe the vehicle's reactions to some special matters such as the signal lights' changing, the bus' parking in the front and accidents, etc.

- Contingency's Dally-over Disposal Model [25]: As to this model, some accident spots can be added randomly in the selected section of road or at the intersection. Simulation occurs when there were any accidents in driving, how would the accident's influences transfer among the vehicles including those running in the accident area. Because of the accident on the road, the vehicles running on this section of road have to wait in queue. The theoretical basis for this phenomenon is the queuing theory. Queuing theory is a mathematic theory that studies the queuing phenomenon, which is caused by the demand-huddle in service system. Queuing theory includes one-pass serving system and multi-pass serving system. If it is assumed that the average arrival-ratio is "λ", the probability of having no vehicles in the system is "$P(0)$", the after-serving output-ratio of the one-pass is "μ", and we presume that "$P = \lambda / \mu$". Thus we find something special in the one-pass system:

① The vehicles mean value in queuing system is "$n^1 = \rho/(1-\rho)$".

② The average length of queuing is "$q^1 = \rho \bullet n$".

③ The average queuing time is "$d^1 = 1/(\mu - \lambda)$".

④ The average time spent in waiting is "$W^1 = d - 1/\mu$".

While in the multi-pass system (which has many a serving pass):

① $n^N = \rho + P(0)\rho^{N+1}[1/(1-\rho/N)^2]/N!N$

② $q^N = \rho^{N+1}P(0)[1/(1-\rho/N)^2]/N!N$

③ $d^N = n^N / \lambda$

④ $W^N = q^N / \lambda$

We hope that the MA-URTC simulation system can provide us with an interactive environment that is versatile, open and flexible. Versatility means it can supply analysis to most of the clients who are engaged in the research on the urban traffic environment. Openness means that the system can be linked to all the other relative systems perfectly and it can even perform simulation analysis by being compatible with other traffic projects. Flexibility refers to the system's capability of collocating and recombining with all the applied software and hardware according to all the simulation requests.

5.2The Description for the Simulating System

5.2.1 System Development Kit

This simulation system mainly includes the following toolboxes:

- Elementary toolbox: There are five parts in it:

  1. Network distributed computer platform.

  2. The open GL three-dimensional displaying platform.

  3. Database platform.

  4. The object-oriented software-developing platform.

  5. Computer simulation toolbox.

- Information inputting toolbox: There are three parts in it:

  1. Traffic network creating toolbox.

  2. Route modeling toolbox.

  3. The requested traffic information's input toolbox.

- Simulation toolbox: It includes five parts:

1. Traffic-flow distributed model storehouse.

2. Microcosmic simulation model storehouse.

3. Output analysis and management toolbox of microcosmic simulation.

4. Visualization toolbox for the two-dimensional simulation

5. Visualization toolbox for the three-dimensional simulation.

5.2.2 Realization of the System's Main Function

- Distributed coordinating and mutual exclusion: It can manage effectively the resource competition in the system.
- Network function: Its function supports TCP/IP agreements. It can also give enlarged support to other agreements then deal with the shared data communion successfully among computers.
- Dynamic dispatch: The system's plug-and-play structure can load, uninstall and re-collocate each of its module cells in the running process and it does not need to intermit other missions.
- To simulate the changes in traffic flow running and the signal controlling process: It is the basic function of the system and the basis of actualizing other functions. Since this system is a highly universal one, it should be suitable for realizing the simulation process in the urban traffic system macroscopically and microcosmically to meet the needs of different members. In the microcosmic simulation, the system focuses on simulating each of the composing

individual's characteristics in the traffic flow. While in the macroscopic simulation, the system can predigest the simulation on the individual's characteristics then emphasize particularly on describing the whole characteristics of the traffic flow. When the system models and evaluates an integrated traffic project, it often combines these two kinds of simulations with each other to achieve an optimal result.

- Conformation, storage and management of the traffic network: The traffic network is the most important and basic part in the traffic flow simulation. The system should be able to finish the conformation of the traffic network, which includes the alternating production and modification of the traffic network, the abiding storage of the routine network which means storing all the attribute information of the traffic network in the form of database or the outside data file, the management of the traffic network's memory files. The members can open, modify and restore the traffic network's data files momentarily.
- Constructing the simulation environment: We must finish constructing the simulation environment at first before we start simulating the traffic flow. The simulation environment contains such elements as the traffic network, the quantum of OD, the route-choosing model, the microcosmic vehicle driving model, the traffic-control timing assignment, the real-time collected data style and the simulated original point and terminus, etc.
- By simulating the individual vehicle or the traffic flow's driving behaviors on the section of a road or at the intersection dynamically on the computer, we can re-embody the real-time and

dynamic changes on the selected roads, and we can even simulate the inter-disturb driving of the vehicles at the intersection or on one section of a road.

- Following the terse and perspicuous menu on the screen, we can modify the control parameters (such as the controlling way of the traffic lights along with the traffic light's green signal ratio, the intersection's parameter, passing ratio, the entry and exit parameter on road, etc.) and determine the simulation relation among the factors of the signal timing, the queuing extent and delay. So we can adjust on-line the control strategy according to the real-time and dynamic changes, including the running principle of the traffic flow on the road and at the intersection. We can make real-time record and display on the statistic number of the traffic flow in the dynamic simulation process, then calculate and analyze these data using corresponding models to get the information useful for making strategy. The experimenters can input different kinds of simulation projects. Then the system chooses the suitable ones from the different simulation models and methods, data-collecting and evaluating forms to meet different needs of the members. Meanwhile this function can provide interface for the new traffic equipments' inputting. We can even reveal or print out all these in the form of related figures and forms.
- The maintenance of the model storehouse: The system should supply the members with some existing, common used and relatively mature traffic programming models, route-choosing models and the microcosmic driving models. Moreover, the system should be responsible for achieving and managing these models. Before simulating, the members can choose the most

suitable model that can meet their needs from the model storehouse in the system to actualize the traffic flow's simulation. For reliable service, the system is designed to be fault-tolerant at the I/O component level, processor level and the network level.

5.2.3 System's Communication Management Strategy

As the traffic simulation system is responsible for supplying the simulation members with communication services, therefore as to any exchanged data, the members must be the suppliers or the consumers. The suppliers only need to provide MA-URTC with data, while the consumers need to get the data from MA-URTC. And the transferring process is to be done by the simulating system. The requirements for the design of communication management in the simulation system should concentrate on its simplicity, reliability and highly practicability, etc.

The thorough process of communication management is: The simulation members exchange information declaration. → The MA-URTC do the matching calculation and produce information matching table. → Establish communication channels and create filter. → The simulation members transmit the exchanging data to the MA-URTC → The MA-URTC do matching, filtering and sending the data. → The simulation members receive the data, etc. All the above-mentioned steps are classified into two parts: the management of the data transmission (refer to the first two steps) and the dynamic data distribution (refer to the latter four steps). In order to make the data exchange more real-time, we often set these two kinds services apart from each other. Among them, we put the management of the data transmission on some server in network-MA-URTC_Server; while the dynamic data distribution-MA-URTC_Local, is distributed on various simulation nodes. And the MA-URTC_Local runs on the same computer as the simulation member does. When the MA-URTC_Server has finished the matching of exchanged data and has created the matching table, the MA-URTC_Local can get the matching message that is related to the local simulation members form the MA-URTC_Server; then produce sub matching table and filter. After that, it can establish communication links with the MA-URTC on the other simulation nodes to create communication channels. Thus the dynamic data exchange can be transmitted from one node to another directly without the server's interference. Figure 5.3 shows the dynamic process of data exchange from simulation member "A" to "B".

In data exchange, the form of the exchanged data is also an important factor that may influence the performance of data exchange. According to the systemic architecture of the simulation system, the members of the system are responsible for maintaining the activities of related simulation objects in order to represent their behaviors, which is mainly embodied as the changing course where the objects are staying. There are two primary ways to carry out data exchange in the system: shared objects' changing state and the communication of interactive event. The shared object is a simulation-modeling object that is maintained by a simulation member and whose state transition can be sensed by other related simulation members. This shared object only

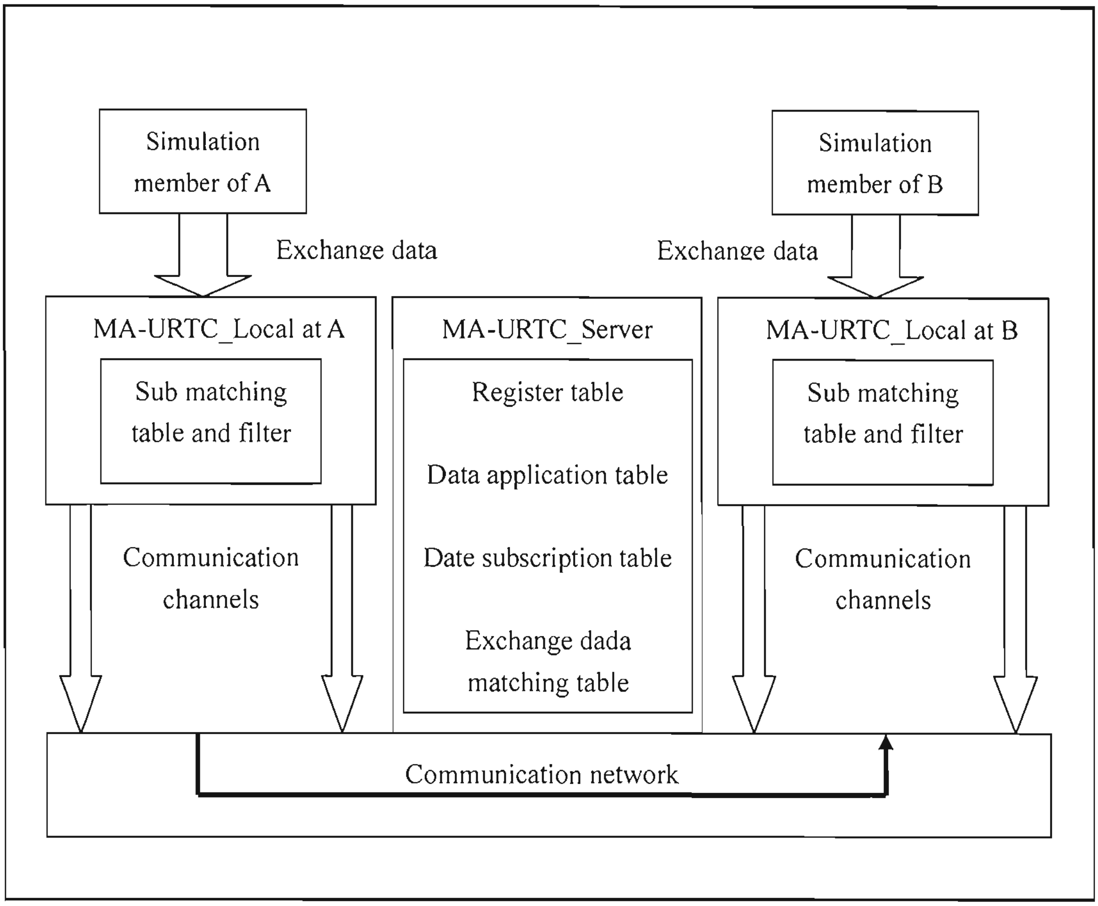

Figure 5.3 Data interaction diagram

involves the attributes that is related to other members and should be known by them. So, they are different from the simulating objects that are used by the system's internal part. Their use is special for data exchange. Some simulation member produces the interactive event which can be imposed on other members. The triggered members can repose on the event then accomplish some operation. The system divides these events into two groups: the simulated interactive events and the system controlled events. Most of the simulated interactive events are related to the actions of the simulating objects such as the vehicle's going through the detectors, the vehicle's going into or out of the detecting area and the vehicle's going into or out of the simulating area, etc. The system-controlled events mainly refer to all the instructions connected with the running of the system such as the initialization, to load the data, to start the running, to suspend or to resume the running and to keep clock synchronization, etc.

Each of the simulation members respectively defines a shared object that can be used by other subsystems or defines the interactive events that may be created. And then it can describe and explain all these objects and events information and make the system be responsible for managing them. Thus, the interactive among all the simulation members in the system can convert into the interaction between the shared objects and events. Furthermore, the interactive relation between them becomes simple and clear, which avoids the direct interference from one object to other objects in the application of the simulation. The independency of the simulation application system in developing and running guarantees the realization of the system's flexible further.

5.2.4 Output Results of Simulation System

There are two methods for the outcomes' outputting in MA-URTC system: animation output and data files output. The animation output is the direct-viewing expression of the outcomes, while the data files output is the quantitative analysis of the outcomes.

5.2.4.1 Animation Output of the Simulation Outcomes

The animation output of the simulation outcomes includes three kinds of entity.

- Static entity: Static entity refers to the entity whose spatial position and state will not change, for example, the brim of the road, the lane's divisional line, the parking line and the road sign line, etc. We just need to output these entities once during the whole picture-outputting process and don't need to repeat them at each of the simulation intervals. In fact, the static entities are the backdrop of the animation output interface.
- Semi-dynamic entity: Semi-dynamic entity mainly refers to the traffic lights. Although the position of the traffic lights will not change, and we don't need to repeat its outputting at every simulation interval, we are expected to change our outputting content--the color of the traffic lights at a given moment. The semi-dynamic entity is also the backdrop of the animation outputting interface.
- Dynamic entity: Dynamic entity refers to the vehicles running within the scope of the intersection area. In order to reflect the vehicles' movement, we are supposed to output the pictures of the vehicle in different positions at every simulation interval.

The animation output of the simulation outcomes is a typical multi-objects movement displaying in static backdrop. The simulation animation output is mainly connected with the following techniques:

- Realization of the animation output based on the raster operation: The primary method for actualizing the animation is to scrape the object off from its former position, and then redraws it in a new position. However superposition of the dynamic and static entity may come up. For instance, it is very easy for the vehicles, the line of the traffic sign, the lane line and the parking line to be in superposition. As a result, if we simply scrape the dynamic objects (vehicles) off from its overlay area, we are bound to synchronously scrape the static objects off which have been blotted out by the dynamic ones. But if we take the "exclusive or" raster operating skill, we can solve this problem in a better way. The "exclusive or" raster operating means to put the new output displaying operate "exclusive or logical" to the stored data in the revealing card's frame memory together. If we only perform this operation once, we will scrape the new picture off from the display equipment but will not influence the former backdrop picture.
- Vibration processing of the animation picture: If the former and latter output images of the dynamic entity differ greatly from each other in position, or the interval between the former and later input is a little bit long, there will be vibrating in the picture. Hereby, we should reduce the position and interval gap of dynamic entity as much as possible in order to reduce the vibration. It is up to the computer's performance, the clock's set frequency and the procedure's arithmetic to ascertain the interval between the two successive inputs for dynamic entity. From the point of procedure designing, we should optimize the arithmetic as much as

possible so that the time that is used to calculate the new position of the dynamic entity is less than that of the clock's frequency. For instance, we assume that the computer's clock frequency to send out an instruction per 100 milliseconds, then it is required that it take less than 100 milliseconds to work out the new position of a dynamic entity in per simulation gap time. Otherwise, it is impossible for the computer to accomplish the established output although the instruction has been sent out and calculation can't stop either. To reduce the dynamic entity's former and latter position lag, we can do some appropriate cutout on the output picture.

5.2.4.2 Data File Output of the Simulation Outcomes

The MA-URTC simulation system has recorded each vehicle's running state at each simulation interval during the whole simulation period, on grounds of which the system has done some statistics to reflect the traffic-changing course on the traffic network. The output data mainly include the vehicles' speed on each intersection's area in a given period of time, the queuing length, the number of queuing vehicle, the delay-time of parking and the parking frequency.

At present, the system can provide us with a data file output in the form of text file. And we can perform some kinds of analysis on these data, for example, to get some simple diagrammatical delivery by using other universal software. In the future, we will develop some data-output software that is convenient to make statistic strategies according to the system's application in the real traffic environment.

5.2.5 Simulation System Maintenance

It is up to the distributed simulation members to maintain the states of the simulation modeling objects in the simulation system. The members can actualize the collaboration and interaction among them by supplying the outside world with the state of the simulation objects or by exploding some relative events. The modeling and simulating on the traffic flow, traffic signal controlling and the traffic network are indispensable to an integrated traffic simulation system. We believe that the state of the traffic flow simulation model and the traffic signal controlling agent simulation model as well as the traffic network agent simulation model should be the bottommost for the system. In practice, the users can select different simulation members to configure them together at first then try to finish the different simulation purposes. Sometimes the users may focus on some given aspects and ignore some certain simulation models in the bottommost station as they have on special requirements for it. In this way, their simulations may be short of the basic description for the condition of the simulation objects, and so some part of this kind of simulation can hardly get the information about the outside simulation objects so that it influences the integrality of the system. However coinstantaneous, as a distributed interactive simulation system, it should also have the self- completeness at each of the simulation nodes. In the users' opinion, whether the single simulation node (which is not in tightly relationship with the user's purposes) exists or not should have no influence on the system's running. Therefore, it is very necessary to maintain the integrity of the system.

To actualize the maintenance of the system's integrity, at first we should have such an understanding as the following: if the users don't perform the selection among the basic modeling objects, as to the users' specific simulation needs, the behaviors of these models will not affect the simulation results greatly. Accordingly, we should develop some substitute simulation members that are simple routine conditions and behaviors that can provide the outside with such kind of simulation models at any time to sustain the running of the whole system.

Therefore, the maintenance of the integrality in MA-URTC can be divided into five components: 1. Managing the substitute simulation members. 2. Checking on the integrality of the system before running. 3. Substitute disposal of the absent members. 4. Monitoring the integrality in running. 5. Substitute disposal of the simulation members in running. The management of the substitute simulation members mainly includes finishing the registering and updating of the substitute simulation members as well as storing them in the member-database.

5.3Simulation Model

As our system is studying to perfection and its big scale, we only introduce a part prototype to explain our design method. We use COMET to design the concurrent, distributed and real-time traffic system.

5.3.1 Use Case Model

Use case defines the external requirements of the system. In latter modeling analysis, it can help us determine object participants in the system.

- Driving Control Use Case: Figure 5.4 shows the use case diagram of driving control.

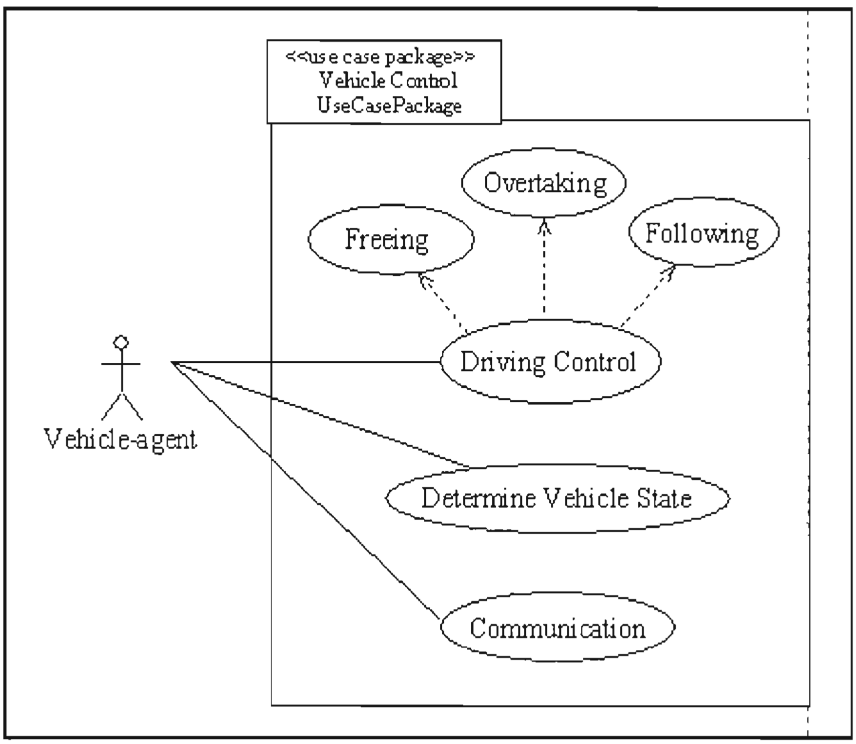

Figure 5.4 Use case model: Vehicle Control Use Case Package

- Use case's name: Driving Control

  Precondition: A vehicle is running.

  Brief description: It controls starting, stopping, acceleration, deceleration, turning and various running speed of a vehicle, which mainly includes free driving, overtaking and following.

  Substitution: If the vehicle receives an advice about a limited speed on a road, etc, it is to accept external order. For example, intersection-agent, which the vehicle will arrive at, informs it to accelerate or speed down, etc.

  Post condition: The vehicle-agent can adjust vehicle' running speed well according to real-time requirements and traffic conditions.

- Use case's name: Determine Vehicle State

  Precondition: The vehicle is in the traffic network.

  Brief description: (1) Internal timer of vehicle-agent computes periodically the distance traveled, the number of starting/stopping, the average speed on road and at every intersection, and the fuel consumption for a trip, etc. (2) Determine the distance from its neighboring vehicle. (3) When it starts running or enters the traffic network, it selects an optimal route according to the traffic conditions at that time and is able to make real-time adjustments.

  Post condition: The vehicle-agent is running well.

➢ Use case's name: Communication

Precondition: The vehicle is in the traffic network.

Brief description: The vehicle-agent needs to communicate with intersection-agent, road agent and other vehicle-agents, which guarantees the vehicle be on the best state.

Post condition: The vehicle-agent is running well.

- Road Monitoring Use Case: Figure 5.5 shows the use case diagram of road monitoring.

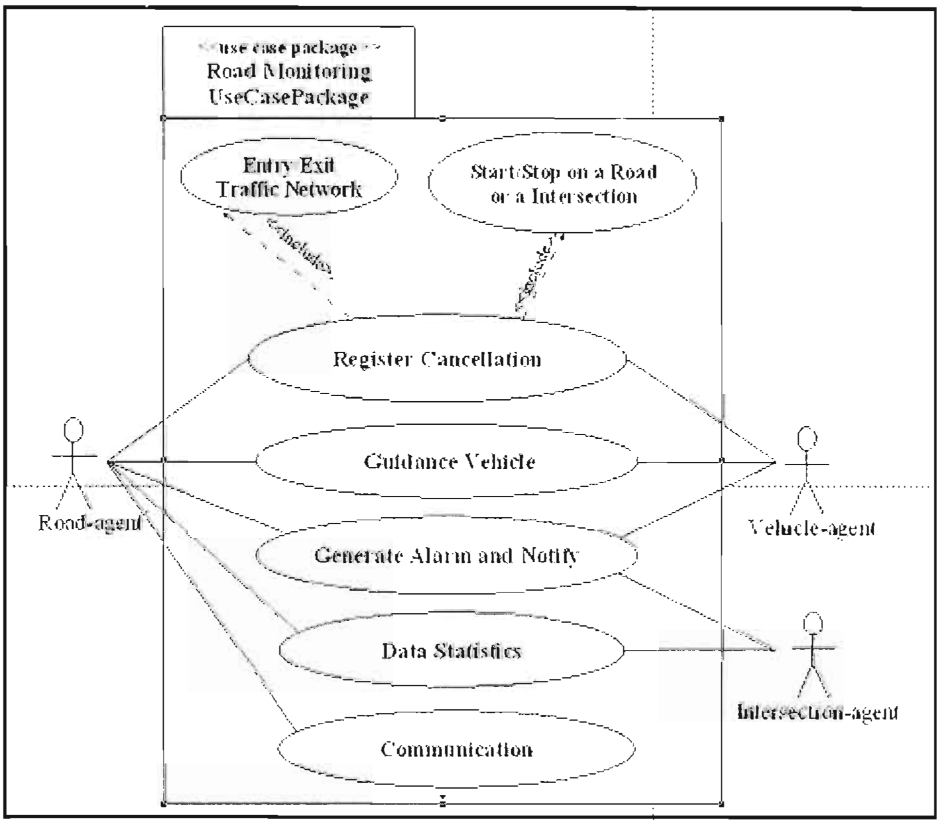

Figure 5.5 Use case model: Road Monitoring Use Case Package

- Use case's name: Register/Cancellation

  Precondition: The simulation system starts running.

  Brief description: In a dynamic traffic network, vehicles from different origins go to different destination. Each road has different traffic flows. A vehicle may not go through the entire traffic networks, as it may start/stop on different roads or at the intersections. When a vehicle-agent is running on a road, it is registered to its relative road agents, on the contrary, when it leaves or stops temporally, it is canceled.

  Post condition: Road agents can monitor every vehicle in the traffic network.

- Use case's name: Guidance Vehicle

  Precondition: A vehicle-agent is running on a road and informs his destination to the road agent.

  Brief description: Road agent produces several optimal routes to be selected by the vehicle-agent. Vehicle-agent makes its selection according to real-time traffic conditions acquired from other road agent and intersection-agent.

  Post condition: The vehicle selects an optimal route to reach its destination.

- Use case's name: Generate Alarm and Notify

  Precondition: A vehicle-agent is running on the traffic network.

  Brief description: (1) When a traffic accident happens on a road, the road agent notifies the relative intersection-agents that are to forbid other vehicles to enter the entry.

Meanwhile other road agents are not to be considered as a part of the route before the accident is solved. (2) Each road undertakes different traffic functions. Therefore, limitation of vehicle's speed, types, weight, height, and passing time, etc. is going to be considered when a vehicle-agent requests a route.

Post condition: The effective alarming and notification raises the efficiency of traffic simulation system.

- Use case's name: Data Statistics

  Precondition: The system is simulating.

  Brief description: (1) Road agent computes real-time traffic flow to inform periodically connected intersection-agent according to signal cycle in order to the relative intersection-agent can produce control strategy early. (2) Road-agent produces statistical data to researcher for studying. For example: the average magnitude of vehicles passing the road in different time, the probability of traffic accident in a simulated cycle, the average driving speed, the average length or number of queuing vehicles and the average speed of entry/exit the area of connected intersection, etc.

  Post condition: Road agent has the effective data statistics and updates according to the different requirements.

- Use case name: Communication

  Precondition: The road agent is running.

Sample description: In traffic network, each of road agent needs to interaction and communicate with other agents or external system. The use case is fundamental communication, moreover which subdivides and classifies the relative information in order to assure the validity and the rapidity of intelligent transmission. Along with it's the other function is modify the relative road parameter to test according to requirements of researchers.

Post condition: Road agent is good communication.

- Signal Control Use Case: Figure 5.6 shows the use case diagram of signal control.

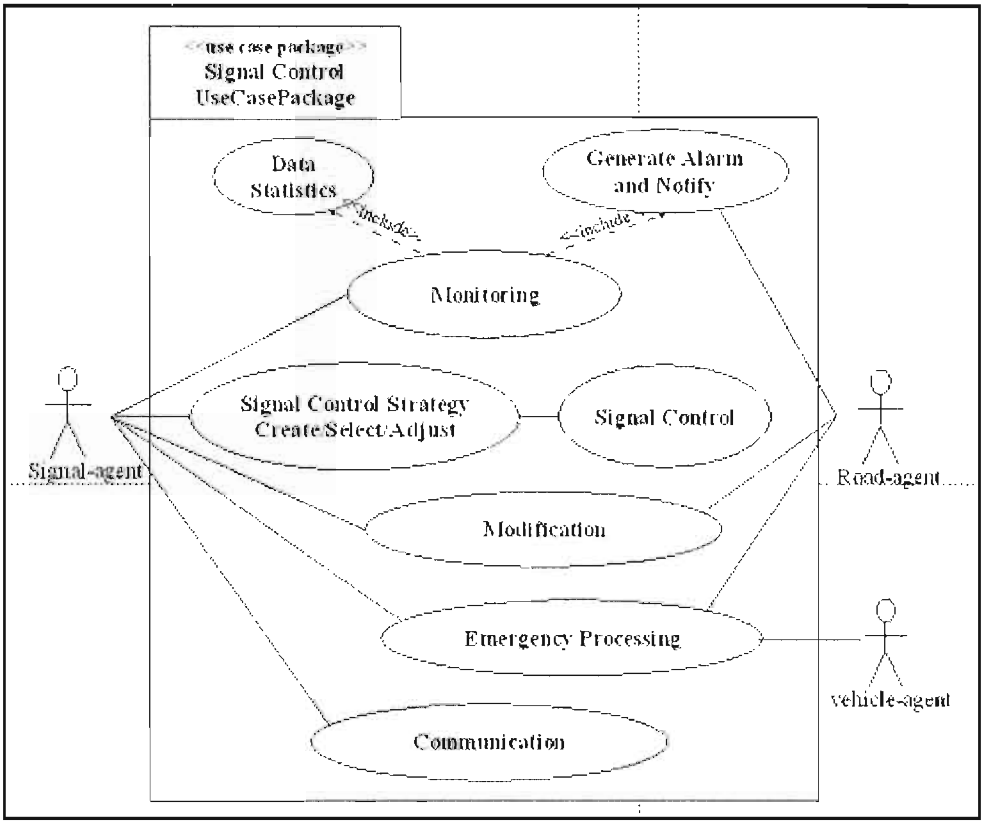

Figure 5.6 Use case model: Signal Control Use Case Package

Primary actor: Signal-agent includes intersection-agent and region-agent. Intersection-agent is the primary signal control and region-agent coordinates these correlative intersection-agents. Signal-agent start signal control Use Case Package.

Secondary actor: Road agent and vehicle-agent.

- Use case's name: Monitoring

  Precondition: The system starts simulation.

  Brief description: It monitors the intersections, which mainly includes the use case of "data statistics" and "alarming and notification of generation". Date statistics include traffic signal index computed at the different appraisal cycle, for example the average delay time and length of queuing, etc, which are helpful for perfecting the system. When there are exceed-permitted queuing vehicles from a direction or a mere traffic accident that is to cause traffic jam, it generates alarm and notifies the correlative road agent to reduce the current traffic pressure in advance. Moreover, it records the vehicle that violates traffic signal control or driving rules.

  Post condition: It meets our monitoring requirements.

- Use case's name: Signal Control Strategy (Create/Select/Adjust)

  Precondition: One or more vehicles arrive at the area of signal control from different directions.

  Brief description: It is the key of signal control system; every signal-agent creates real-time intelligent control strategy by itself according to traffic conditions. Time variation is not the only strategy in the urban traffic flow. A universal strategy that can deal with various real-time conditions is not real. We hope that signal-agent can go to autonomic selection and real-time adjustment. Once the strategy is determined, it will call the use case of signal control to carry out.

Substitution: If mistake of all intelligent strategies occurs unfortunately, signal-agent will use traffic-responsive control or fixed time control to rescue.

Post conditions: Urban traffic system is real-time and effective.

- Use case's name: Modification

  Precondition: Studying the urban traffic control.

  Brief description: Undoubted, urban intersection's geometry shape such as the number of lanes, the width of lane and the channelized layout influences the traffic streams obviously. Therefore, it helps researchers modify the area layout of an intersection. It is not only sure to synchronization between our control system and practical traffic environment but also able to advise a good plan in advance. Intersection's modification should cooperate with the correlative roads.

  Post condition: The modification can satisfy researcher's requirements.

- Use case's name: Emergency Processing

  Precondition: Emergency happens in the urban traffic network.

Brief description: An unexpected traffic accident or a vehicle with the urgent mission such as police's vehicle, fire engines and ambulances all request special signal control. Signal-agent must deal with them effectively and immediately. Emergency processing is superior in the urban traffic control.

Post condition: Emergency is solved and urban traffic flows restore to the normal order.

- Use case's name: Communication

  Precondition: Starts this control system.

  Brief description: This use case is the foundation of cooperation and coordination, which is essential for the multi-agent. Its function is mainly the bottom connection and communication.

  Post condition: Multi-agent are able to real-time interact well.

As some major use cases mentioned above indicate, we will go on with the perfection according to researchers' requirements.

5.3.2 Simulation Modeling

We only choose part of models: some static modeling and dynamic modeling. As they are not continuous, we do not indicate the use case of ID. Figure 5.7~5.13 show them.

Figure 5.7 illustrates a static modeling of the high-level traffic control system. This system is a multi-agent system, which communicates, coordinates and collaborates with each other in order to realize the real-time control.

In this figure, signal-agent should be the specialized region-agent and intersection-agent.

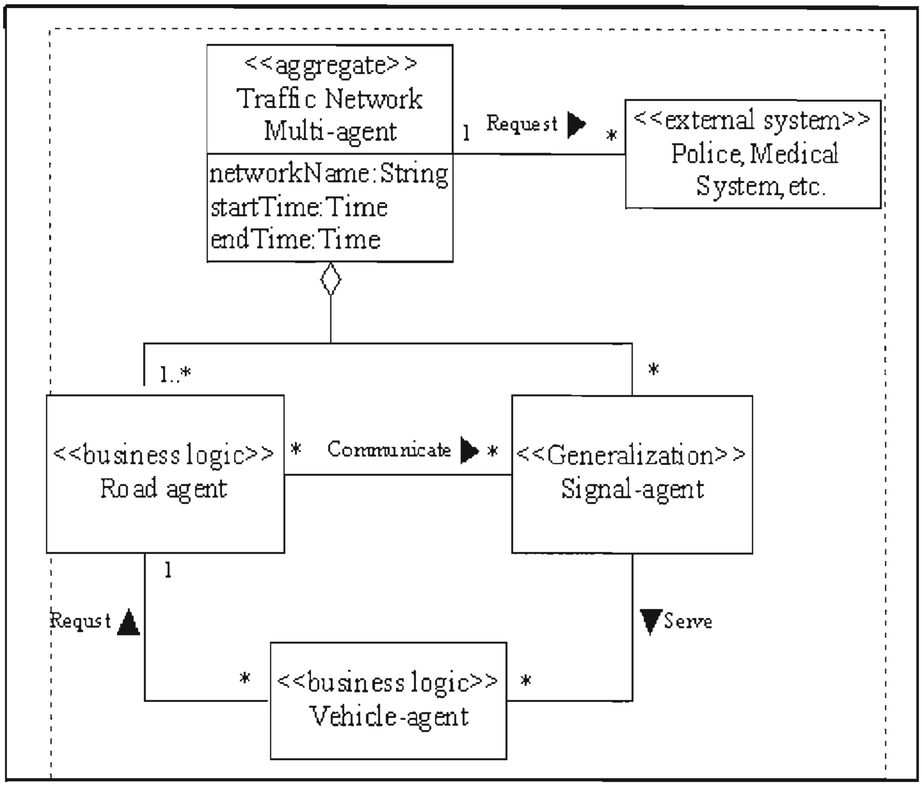

Figure 5.7 High-level class diagram of MA-URTC

Figure 5.8 illustrates classes corresponding to the above static model. We think that region agent can demand regional intersection-agent signal control when a special accident occurs. Therefore, abstract class of signal agent includes signal attribute.

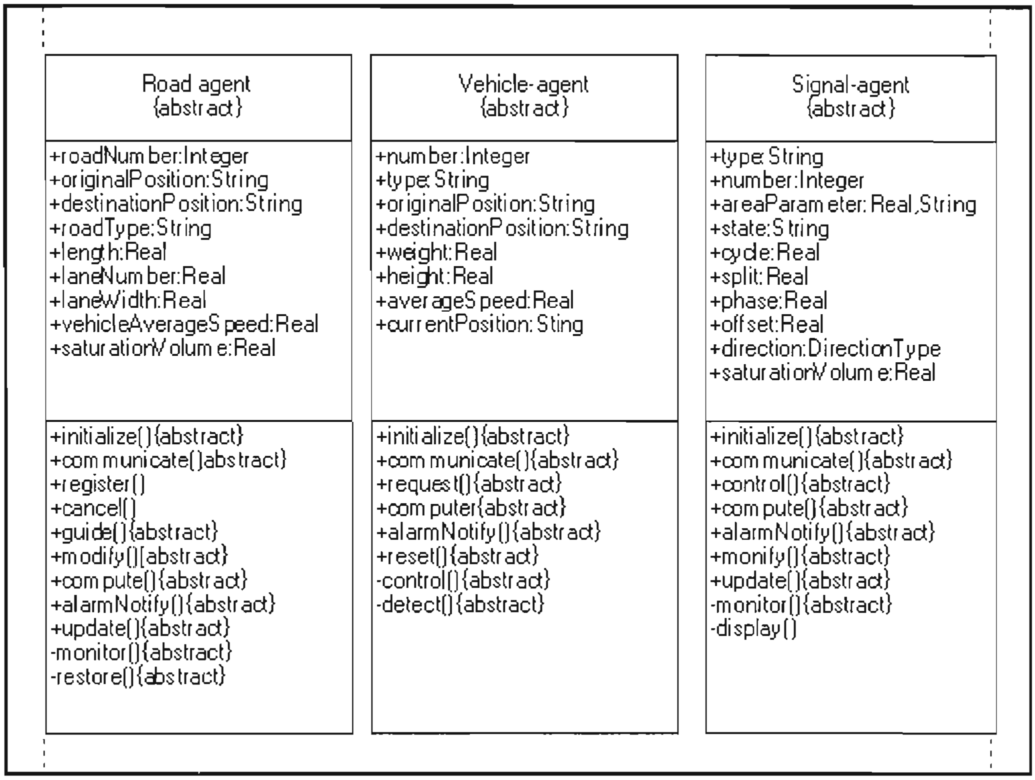

Figure 5.8 Attribute and method in abstract class of MA-URTC

Figure 5.9 illustrates a high-level state transition of vehicle-agent driving in simulation system. Vehicle-agent is produced according to requested producing model or is assigned by researchers.

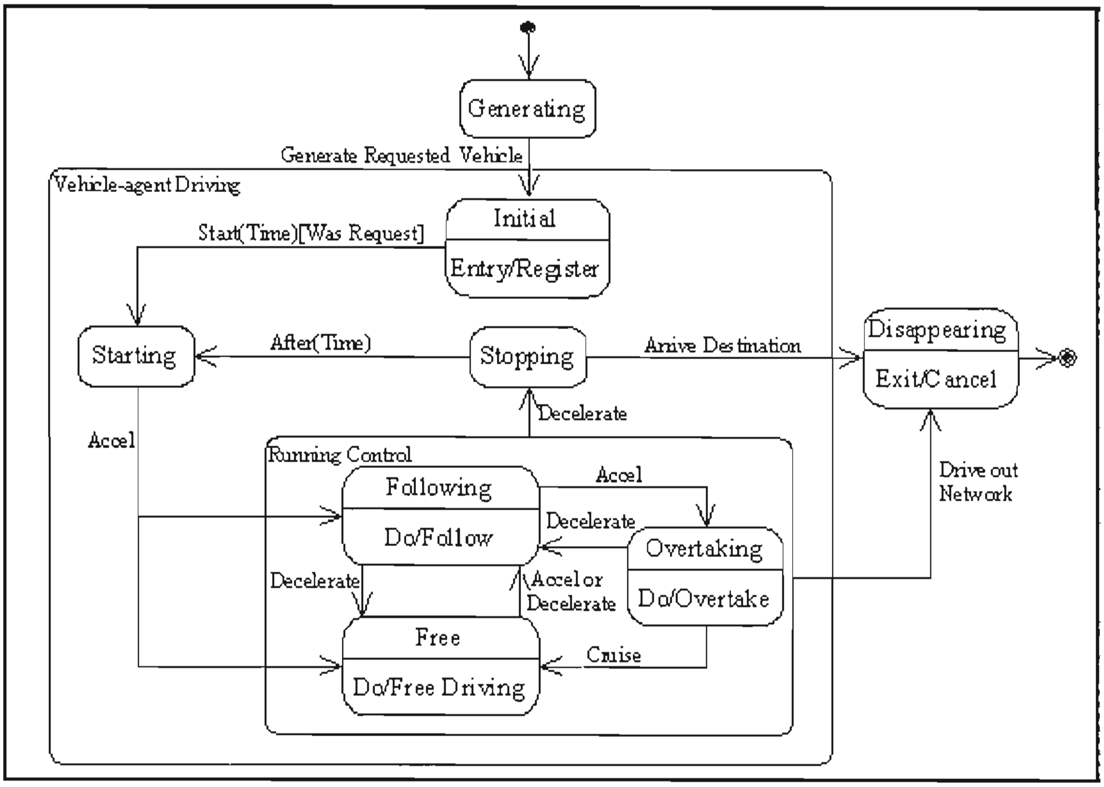

Figure 5.9 High-level UML state diagram of vehicle-agent control

Figure 5.10 is an orthogonal state diagram of vehicle-agent driving control. At any time, vehicle-agent driving super state is either as sub-state of road agent guidance or as sub-state of intersection-agent signal control. A vehicle-agent driving in traffic network is guided by road agent, but when it drives into intersections, it must be controlled by intersection-agent, certainly, when it drives out of intersections, it still interacts with other road agents on road. Intersection-agent signal control is described in the two possible states and emergent accident causes their state transition.

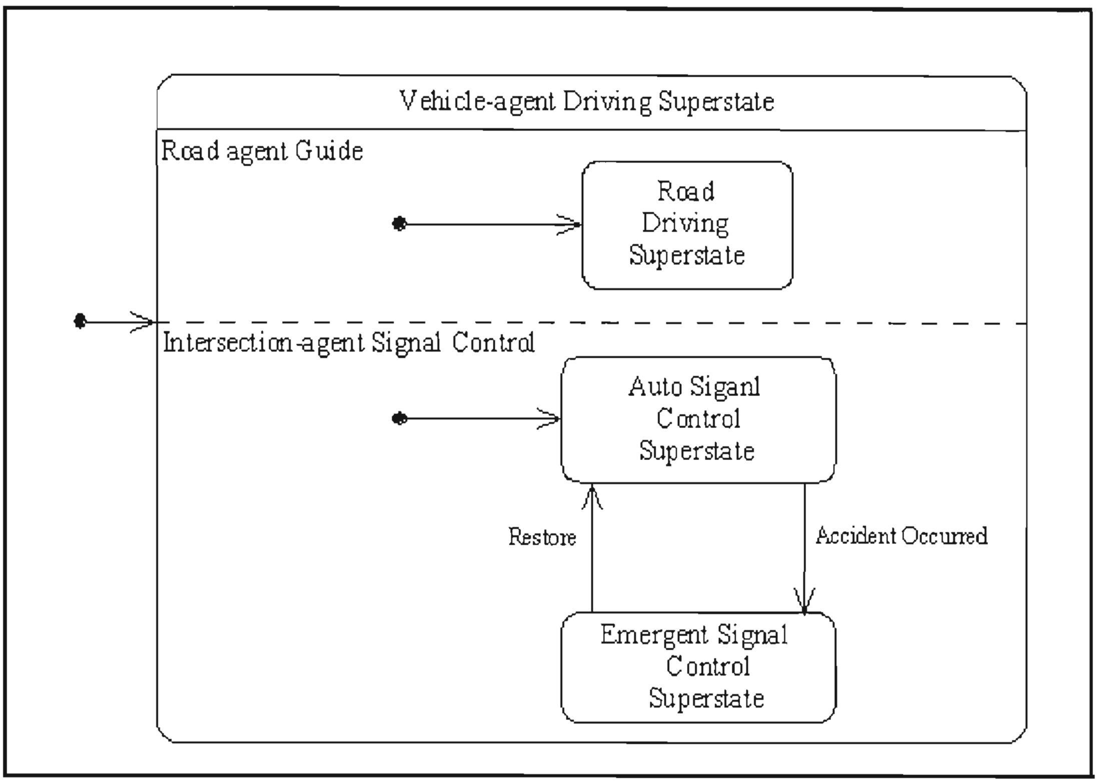

Figure 5.10 Orthogonal state diagram of vehicle-agent driving in simulation system

Figure 5.11 illustrates the UML state diagram of an intersection-agent signal control at the starting stage. Firstly, intersection-agent should monitor its controlling area and interact with other agents. Then, it creates or calls corresponding intelligent strategy to controlling signal according to practical traffic conditions. Meanwhile, if emergency occurs, it is able to call emergent strategy to controlling signal. But if emergent strategy fails, it will notify other agents and exit auto signal control system to request man-control. Intersection-agent monitors its area and collaborates with other agents continuously so that it can adjust controlling strategy according to the real-time traffic variations.

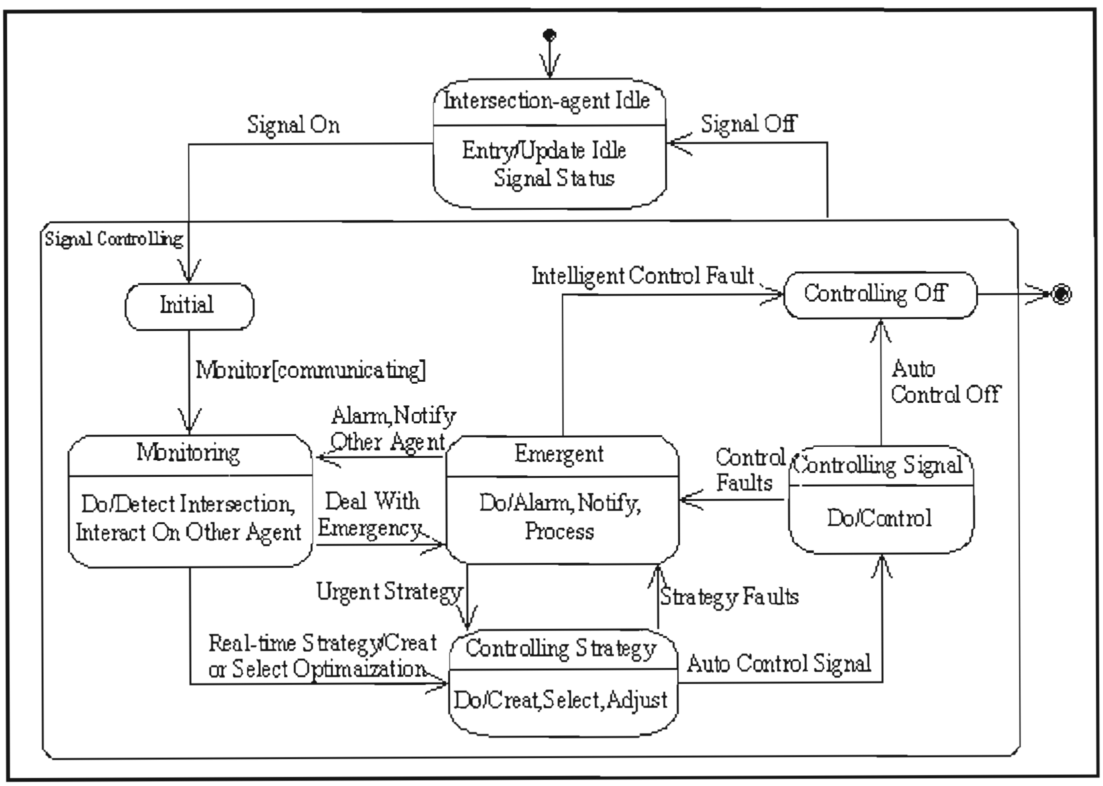

Figure 5.11 Signal control state diagram of intersection-agent: staring event

Figure 5.12 is the UML collaboration diagram of communication use case. It illustrates a vehicle-agent collaborating on driving with other agents in traffic network. In figure, "2" and "2a" indicate concurrent message.

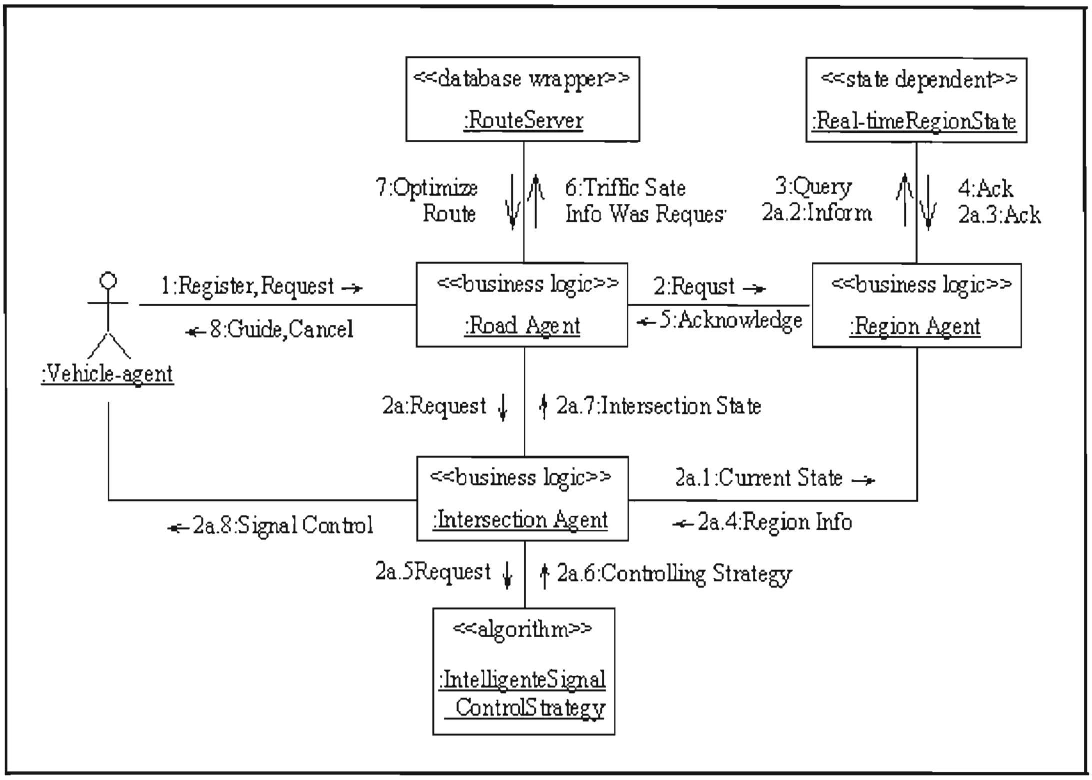

Figure 5.12 UML collaboration diagram of use case communication: interact driving

Figure 5.13 illustrates the UML collaboration diagram of a researcher formulating or modifying simulation map use case.

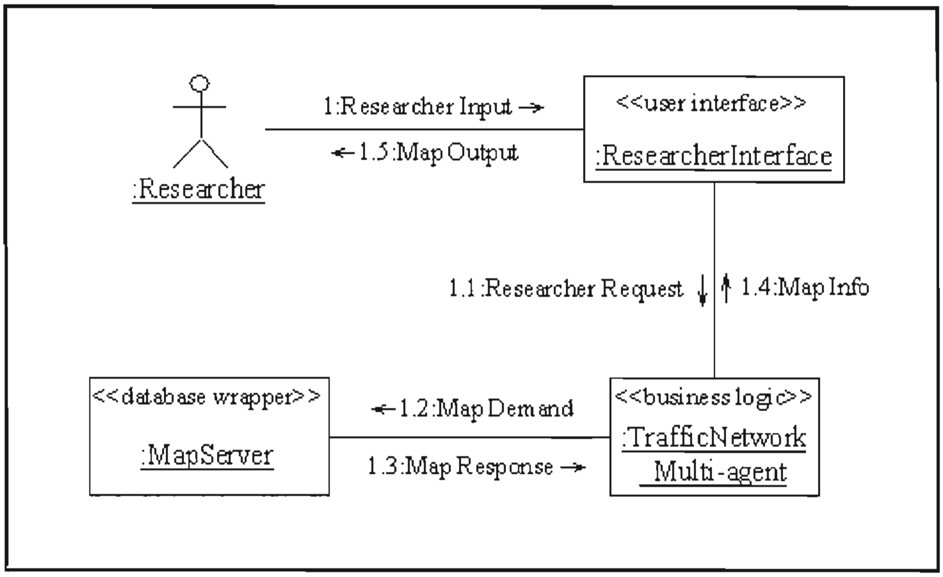

Figure5.13 UML collaboration diagram of user formulate/modify map

5.4Summary

We discuss about the structure design of the simulation system and its functions to be actualized as well as its developing implements in this chapter. It seems practicable to achieve the simulation system by applying OOP technology to it at present, but it is merely a transitional means. Our final goal is to achieve the simulation system by the application of AOP technology. As a result, the structure and mechanism design of the simulation system is very important, and flexibility is the most important in the design.

CHAPTER 6

CONCLUSION AND PROSPECTS

6.1 Thesis Conclusion

Urban real-time traffic control is a general and difficult topic. Research on intelligent urban traffic control system has numerous academic and practical values. This thesis mainly studies a key question of intersection signal control in this field based on comprehensively grasping the developing history and trend. Set up an agent-based traffic control system. Develop an open urban traffic simulation system, which can adjusts alternately to development of technology and needs.

Research products we achieved are mainly:

- We think that multi-agent theory fits for the complex and variable traffic control. It is obviously advantageous to former concentrated and distributed control system. Meanwhile we think it's a further advance to hierarchical control system whose sub-systems take on certain gradation according to superiority, subordination or time order of control. Upper sub-system of hierarchical control system can be used as a cooperative unit of its under one, determining coordinated countermeasure and coordinated parameter according to their inter-cooperative control, while under sub-system needs to transfer feedback about local system environment and control function to its corresponding upper one. Upper sub-system takes these as a decision basis. The whole system takes on hierarchical control structure. Each of Sub-system of the same gradation is paralleling distributed and independent. Under sub-system controlled by upper one is often concentrated and with small number. Hierarchical control system optimizes concentrated control and distributed one, so it should be the initial control mode for present complex system. Multi-agent system not only inherits hierarchical control system but also boosts agent's merits, making it more flexible and effective.

- Seen from materials we grasp, researches using fuzzy control theory on single intersection are more, so we attempt multi-intersections fuzzy control, which draw useful information from the actual traffic network information. Make effective use of expert system on based fuzzy strategy by cooperative communication among closely connected vehicles in intersection-group area, to coordinate traffic flow among multi-intersections. Real-time intelligent control needs be applied according to actual situation.
- We observe that although urban traffic has such characteristics as complexity, variability and high no linearity, etc. we may find out macroscopic law by comparing different hours. For example, peak-hour traffic occurs in time of relatively fixture while urban areas with great traffic pressure are fixed which enlighten us a new idea of real-time control. So this thesis studies how neural network, genetic algorithm, fuzzy control and expert system used in traffic control. Agent changes control strategy automatically according to changing traffic situation;

expert system provides effective control rules. With simple algorithm, quick decision, fit for real-time control, decomposition-coordination method to fuzzy control strategy of traffic meets control requests of normal intersection. As to be in busy and key position but comparatively isolated intersection, we think ANN-FC strategy has good effects. But if "intersection group" in some area is highly relative with great influence, region-agent plays important role, as can be seen:

- Avoid over communication produced by cooperative control among multi-intersection agents that results in delay. As to present intelligent research level, if we take the whole area as a neural network model, it cannot meet real-time demands because of so long a study time and so on. While communication among agents using fuzzy control theory can reduce the amount and complexity of communication that meets real-time demands.
- Region-agent acts as cooperation and arbitration, thus avoid over communication among multi-agents, meanwhile ensure flexibility of each intersection-agent. It takes a long time for GA to seek optimization but as we mention above, urban traffic embodies certain macroscopic. Based on GA optimizing on traffic network, using intelligent neuron model of neural network to train and study to get optimization in the whole area, then dynamic select to suitable control strategy for cooperating relative intersections. This can be looked as cooperative problem solving (CPS). Thus, after the initial period, the system control effect will be more and more good.

Each intelligent control strategy has oneself advantages. We should choose different control strategy combination according to actual traffic condition. But the key point is to find out the appropriate "transfer point" that guarantees the real-time traffic control system respond accurately and running the best of control strategy according to the extraneous information, which needs the help from the traffic simulation system. We design an open simulation system to meet different traffic simulation requests; use distributed multi-computer simulation system that differs from most mono-computer simulation system. We develop intelligent MA-URTC consists of multi-agent of road, multi-agent of vehicle and multi-agent of signal control to meet requests of actual traffic environment.

6.2Prospects

We need further research in the following aspects in the future:

6.2.1 Traffic Control Strategy

Artificial intelligent technology is a developing and comprehensive forward course each of whose products is worth our attention and applying in traffic control after proper reconstruction. Up to now, associated control strategy of neural network, fuzzy control, GA and expert system needs further perfect of simulation system. Simulation still using OOP but later will use AOP. It uses agent theory on only partial models but later we'll realize full multi-agent simulation system.

In the future, while considering urban public traffic, as to bus-control strategy, we'll research on the following: (1) Optimizes the location of bus stop and control coordinately relative vehicle driving, which is a mainly factor that influence steady movement of traffic flow;(2) In traffic signal control strategy, consider prior control on bus.

6.2.2 Further Research on Intelligent Agent

According to Schoham and Gerhard Weiss' works, intelligent agent refers to the flexible and autonomous agent that acts and meets its goal. Agent can be taken as a programming or entity. It is embedded in environment; feel the environment by sensors; function on the environment by effectors in order to meet demands.

Traditional intelligent general refers to focusing specific questions, programming arranges agent to reason and calculate, which cannot make agent keep greater problem-solving ability in an open and dynamic environment. Intelligent agent must own metal state to adjust to environmental changes and cooperative solving.

6.2.2.1 Study Traffic Agent's Structure

Gerhard Weiss divides agent into 4 types [17]: logic-based agent, reactive agent, BDI agent and layering agent. What we should do is to find agent's inward structure that fits for traffic field.

- Logic-based agent: agent decides by logical reasoning. But it has some main problems as a stiff structure; it takes a long time to transfer from reason and decision to operational programming, which makes it difficult to put it in an environment with strict time limit.
- Reactive agent: Agent's decision-making is realized by a direct mapping from scene to action. Its merits are simple, economical and easy to process computation, etc. Its demerits are as agent disposes of problems using short-term view, which make it difficult to learn from experiences and improve. We think that vehicles distributed in traffic network and inducement focusing certain vehicle is short-term, while reactive agent's merits just be fit for meeting multi-agent of traffic network needs.
- BDI agent: agent has data structure of B (belief), D (desire), I (intension) together with functions showing its deliberation and means-end. Operation on this data structure realizes agent decision-making. BDI agent is a practical reasoning structure whose reason is like daily used method by man. In our simulation system, we use BDI model to perfect gradually vehicle-agent development.
- Layering agent: In order to realize agent with reactive and pro-active behavior, one way is to

build respectively sub-system of these two behaviors. Organize theses sub-systems into layering structure. Interaction among different layers is allowed. Software's different layers realize agent's decision-making. Each layer realizes in the different abstract degree to the reasoning of environment. Generally speaking, there are two kinds of control flows in layering structure:

- Horizontal: each software layer is connected with sensor input and action output. Actually, each layer is like an agent that suggests the agent what to do. The greatest advantage of horizontal structure is its simple concept. If agent needs embodying n-different kinds of behavior, then realizes n-different layers. However, as different layers give action choice through competition, which may make the whole system causing interrupted. So in order to keep horizontal structure consistent, a mediator function is needed that is used determine which layer controls agent at any time. So we must consider all the possible interaction among layers. If there is n-layers each of which gives m-different actions, meant, m^n-interaction actions must be considered. From design angle, add central control part means adding bottleneck to agent decision-making. All the questions above can be partially solved in vertical layering structure.
- Vertical: input and output of sensor is in the charge of one layer respectively. The two main interactions among layers are bottom-up activation and up-down execution. Thus reduce complexity of interaction among layers. As there is ($n-1$) interaction in n-layers,

if each layer has m-different actions, then there are at most $m^2(n-1)$ interactions among layers, which is simpler than horizontal structure. However, it loses flexibility. In vertical structure, control must go through different layers to make a decision-making; meanwhile, vertical structure's fault-tolerance is less than horizontal structures.

In order to ensure real-time traffic control, we are experiment on the two kinds of layering agent model. Take intersection-agent as an example, it is a horizontal agent structure. Its model has two behavior modules that interact with the outside. To reduce interaction amount among layers, only 3 parallel control layers are designed, like figure 6.1 shows.

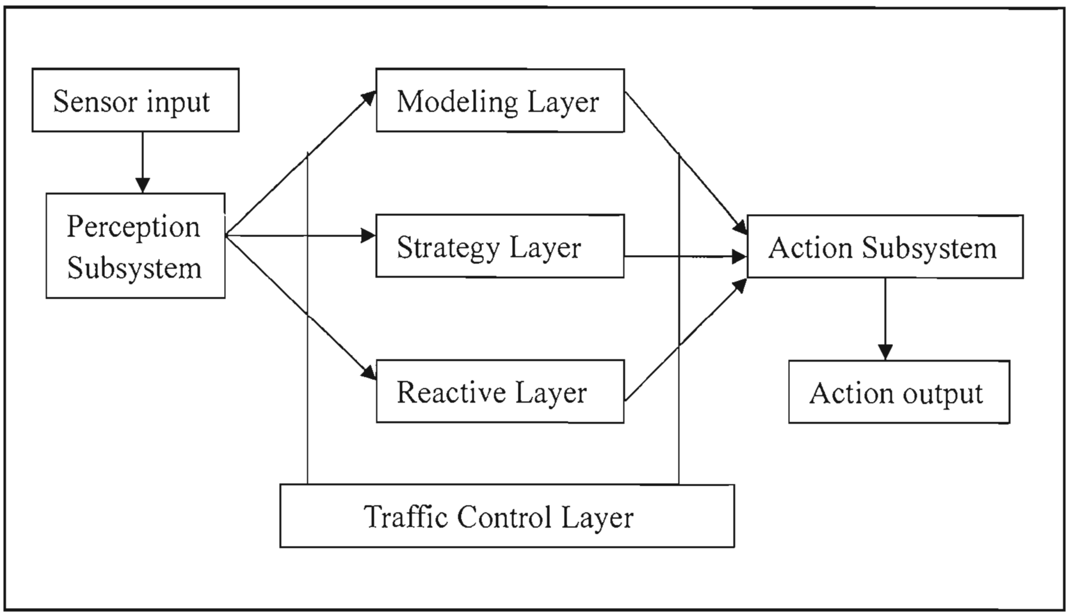

Figure 6.1 Horizontal layering structure of intersection-agent

Each layer contains different abstract models for the traffic environment to realize different assignments. Reactive layer is used to respond quickly to urgent incidents that other layers cannot respond; strategy layer constructs traffic signal control strategy to realize signal control; agent's modeling layer is a symbolic representation of other models in traffic control system. If we choose vertical agent model like figure 6.2, it is two-pass structured.

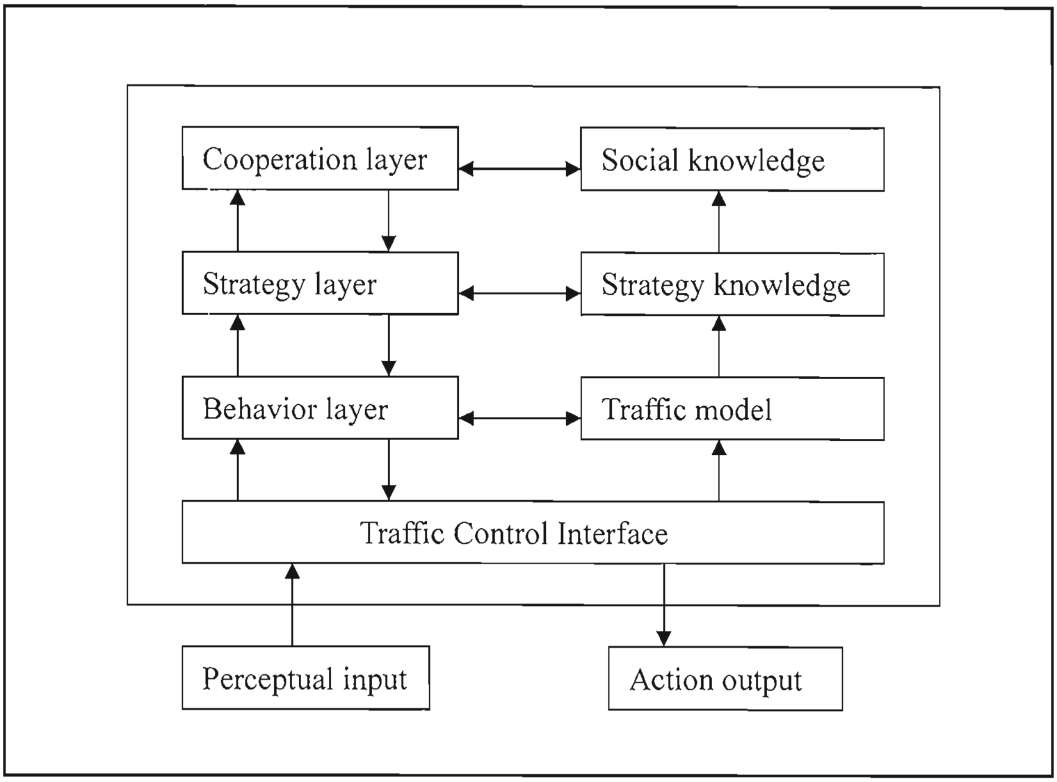

Figure 6.2 Vertical layering structure of intersection-agent

It is made up of control interface, controller and knowledge database. Controller is divided into three layers: cooperation layer, strategy layer and behavior layer. Knowledge depot of agent is made up of social knowledge, strategy knowledge and traffic model. Different layers correspond to different agent's function. Behavior layer allows agent to respond to certain outer circumstance; strategy layer allows agent to make deliberate reasoning to fulfill control object; cooperation layer deals with interactions with other intersection-agents.

Because intersection has different geometric forms and undertakes different assignments, actions designed in agent are different. So we need to design different agent layering structure model according to actual situation respectively to realize optimization of the whole control.

6.2.2.2 Study Agent Communication

We generally think that communication plays key role in DAI system. Multi-agent system relies on communication coordinate their actions and behaviors; makes behavior of it better keep continuous.

Meaning of message in agent communication cannot be understood solitarily. It has relations to agent's mental statement, environmental changes and historical evolution. Explanation of message directly relates to agent's former messages and actions. There are two basic message types in agent communication: assertions and queries. In traffic control system, each agent can send and receive these two messages, which we call "peer-to-peer agent". So we pay attention to the development of P2P (peer-to-peer). We think that using P2P in traffic control is more effective and economic than using C/S.

We adopt message communication, which needs improving. At present, semantics and agreement set for distributed computation environment can offer good service and support, but it cannot support agent effectively. Because these semantics and agreement is used to deal with relations among processes or threads rather than deal with programming made up agent or relations of a series of agents. So an effective agent communication language that can support high-layer communication among agent programming becomes important. Otherwise, agent has to fulfill transferring from high layer to low one by itself, which costs time and energy. There are differences among traffic network agent, vehicle-agent, traffic signal control agent and other agents to be developed in traffic system. In order to exchange message, they needs "public language". It is demanded be able to independent of agent's realization and agent's inner structure. At present, KQML (knowledge query manipulation language) and ACL (agent communication language) of FIPA are the two main communication languages in agent system. They are still in improvement till now. Their semantics are not totally definite. This is also why we use a comparatively mature technology while developing traffic control system. The worth noting is KQML and ACL are based on RPC and RMI (RMI is a technology that can be used only for Java platform. If we need to integrate Java Application procedure and non-Java Application procedure together, using RMI only cannot do.), which enables them to have the certain limitation in the traffic control system. They demand that all nodes participating calculation exist in the network simultaneously while interacting. The whole computation is to fail if some necessary resources cannot be visited temporally. Sine our traffic control is based on multi-agent system, we hope that to better solve communication problem using mobile agent. Mobile agent can be regarded as a combined product of software agent and distributed computation technology. It differs from traditional network computation pattern in essence. It differs from RPC because it can move from one node to another in network. Besides, it can choose movement according to own need. It differs from ordinary process migration because generally speaking ordinary process migration system doesn't allow process itself to decide when and where to migrate, while mobile agent can move at any time, in addition, can move anywhere. Mobile agent differs from applet in java language because applet can only make single-direction movement from server to client, while mobile agent can make bi-direction movement between server and client. It activates the design, realization and maintenance of distributed system. It has many advantages that traditional distributed computation model doesn't have:

- Mobile agent can reduce data volume in network greatly. Moving service request agent to goal main engine makes mobile agent visit resources of main engine directly; reduce interaction with the source main engine and avoid transference of large volume of data in network, thus reduce the dependence of the whole system on network band width; shorten communication delay; raise service quality.

- Mobile agent can work autonomously in asynchronous way. We can encapsulate assignments to be finished into mobile agent, dispatch them in network; and then disconnect source main engine and goal main engine. Then mobile agent independents of its process that produced it and operates autonomously in asynchronous way. Source main engine can reconnect with goal main engine at proper time and receive computation results, which is especially useful to later traffic control system and mobile equipment (i.e. vehicle) or mobile customers because at present, computation of mobile equipment all depends on the expensive and frail network connection. This needs continuous connection between mobile equipment and fixed network. This request isn't reasonable either from economic or technological angle.
- Mobile agent is highly reactive. It can feel its working environment and make proper response to environmental changes. It can decide dynamically moving goal according to load trends of server and network, which is good for keeping balanced load. Besides, mobile agent's intelligent route reduces the judgment that customers are browsing and searching, along with further strengthens real-time control.
- Mobile agent is good for parallel processing. Mobile agent can dynamically set up several agents in parallel working while fulfilling a task. Thus, raise efficiency and reduce response time. Multi-mobile agents have its special capability of dynamically and reasonably distribute themselves among network main engines. It can dispose optimally the special question according to certain rules.

- Mobile agent has natural isomerism. Distributed network computation platform is often isomeric, while mobile agent often independents of the special software and hardware environment, it depends on its running environment only. So It is suitable for the seamless system integration.
- Mobile agent is robustness and fault-tolerance. It is able to solve quickly unexpected state and incident, which makes it easy to set up a distributed system with robustness and fault-tolerance. When one main engine is closed, all mobile agents working on the main engine are alarmed, and there is enough time for them to move onto another main engine and continue working.

In a nutshell, traffic control should be real-time, effective and economical, merits of mobile agent meets the needs of our future intelligent traffic control. To develop mobile agent that fits for traffic control is one of our future research directions.

6.3Epilogue

Study on urban real-time traffic control relates to computer, math, auto-control and AI, etc. We must keep pace with their latest research products and transfer them work for traffic control. Meanwhile, our research should be divided into two ways: one is to develop real-time traffic control that can be put into use quickly and produce effects basing on Chinese conditions and technological reality; the other is to face future intelligent traffic control, develop intelligent traffic system in full sense supposing that whatever participates transportation is intelligent. These two ways are not isolated and don't contradict. The former is basis of the latter while the latter is developing direction of the former. We need not only to solve the traffic straits we face right now but also go in the forehead of time because fast development of Chinese economy needs developed traffic control system that belongs to ourselves.

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