Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 2349 - 2364, 2005

RESEARCH ON URBAN TRAFFIC INTELLIGENT CONTROL INTEGRATED SYSTEM

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Abstract: This paper introduces a distributed architecture of the intelligent control integrated system for area-wide incident response, information guidance based on signal control. The paper applies Multi-Agent technique to the system and introduces the relative cooperation and negotiation theories based on game theory, by which the system can realize real-time active intelligent control, especially to actively resolve the congestions happened or will happen at the intersection. Therefore, the coordination problem among several intersections can be handled, which is one of the most important problems of the area control system. In order to realize the integrated control system, the paper also presents the incident and congestion forecast algorithms. Finally, as one intersection signal Agent, it can realize the isolated intersection signal control strategy independently by means of fuzzy logic, which is also considering the bus-priority.

Key Words: intelligent transportation systems, intelligent control system, integrated system

1.INTRODUCTION

With the development of the information technique, network technique and communication technique, the Intelligent Transportation systems (ITS) have been studied and applied to many countries. Urban Traffic Control System (UTCS) which is one of the most important subsystems of the ITS, is hot problem to study. Recently, the study of the UTCS has developed quickly both in China and some developed countries. And with the deeply studying, the UTCS research areas get wider than before including not only signals, signal control equipment and some relative installation but also control cooperation, control pattern, control system and system control optimizing models. Although China is still a developing country, the intersection congestions often occur, especially in the major city, such as Beijing. Therefore, the research project which is presented in this paper, is so important that it is sponsored by the 10th five-year planning ITS research project by MOST (Project No.2002BA404A20B). The paper introduces a distributed architecture of the intelligent control integrated system for area-wide incident response, information guidance based on signal control and traffic control management. Moreover, from the point of the control system,

the paper applies the Multi-Agent technique to the system. In fact, the UTCS based on Multi-Agent is a kind of Multi-Agent System (MAS) performing through cooperation with each other. And each Agent may realize self-government and be independent. Although its objective and behaviors are out of other Agent limitation, it may resolve the conflict between different Agents by means of cooperation. So the paper introduces the relative cooperation and negotiation theories and algorithms based on game theory, by which the system can realize the real-time active intelligent control, especially to resolve actively the congestions happened or will happen at the intersection. Therefore, we can deal with the coordination problem among several intersections or several sub-areas, which is one of the most important problems of the area control system.

2.DESIGN FRAME OF UTCS

2.1 Design Frame Feasibilities

- Firstly, the system is based on perfect software and hardware. And the network communication technique and relative hardware developing and the velocity of the processor improving provide the technique basis for the distributed intelligent control system;
- Secondly, UTCS is achieved by the diverse area control systems coming into agreement or harmony, all of which construct the MAS;
- Thirdly, from the point of the intelligent control system, a single Agent sub-system might has not enough knowledge, resources and information to solve the complicated problem. So the large-scale complicated system need Multi-Agent to harmonize and cooperate with each other;
- Finally, from the point of the module designing and realizing, a complicated problem is broken into some relative independent modules. Therefore, we can solve and debug the problem more easily than before. Moreover, the system also has the stronger error admittance and reliability.

2.2 Design Frame Advantages

- Firstly, the MAS is based on the distributed method so that the system can overcome the area scattered and the limitation of the communication bandwidth;
- Secondly, the system can realize the resources sharing, and be prone to expanding;
- Thirdly, the system will be more simple and reliable than some others, as a result of the system being decomposed and the input area being reduced;
- Fourthly, the system can overcome the constructing the large knowledge base and avoid managing extending knowledge by means of cooperating and harmonizing with each other;
- Fifthly, from the point of the system obstacles, the system introduced in this paper is more robust and more reliable, because some Agent having something wrong will not affect the function of the whole system;
- Finally, Agent itself has some properties such as: initiative, reasoning, planning ability and cooperation etc. all of which are the necessities of the MAS. So constructing the UTCS based on Multi-Agent is the best choice for urban traffic signal control system.

2.3 UTCS Design Frame

Figure 1 describes the basic relations of the Multi-Agent System. In this relation model, we can learn that the MAS is made of several Agents, and the communications between the Agents are established through KQML (Knowledge Query and Manipulation Language) gauge. The management and cooperation function module is in charge of planning harmonizing, monitoring the state of every Agent and adding new Agent etc..

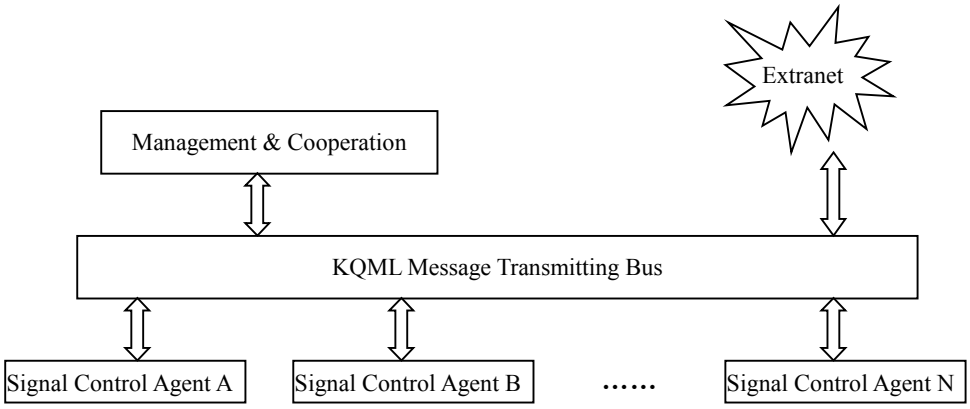

Figure 1. Basic Relations of the Multi-Agent System

Figure 2 describes the basic structure of the intersection signal control Agent. In this figure the function module of each intersection signal control Agent is shown in detail, so that we can learn the whole process of the system achieving the signal control function.

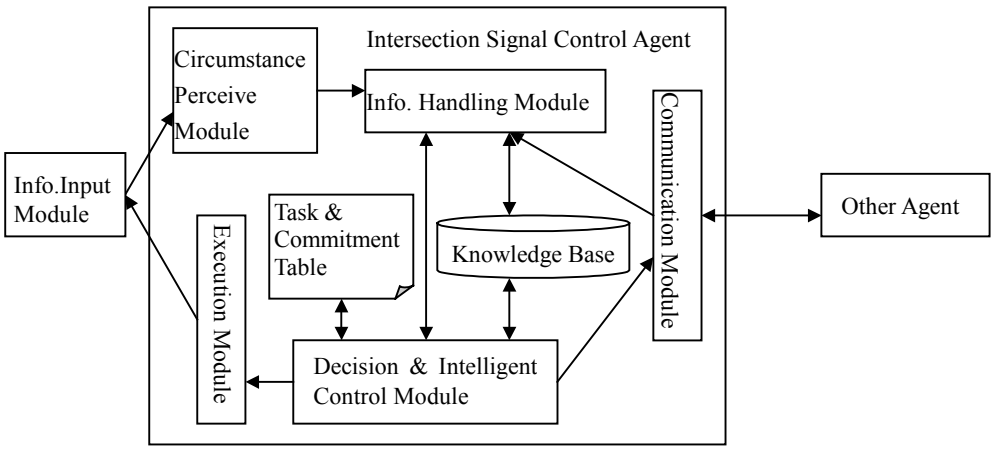

Figure 2. Basic Structure of Intersection Signal Control Agent

3.KEY TECHNIQUE OF DESIGN FRAME

3.1 Cooperation among the Multi-Agent Based Countermeasure Theory

As the self-government signal control Agent, it is necessary to cooperate with other Agents to solve the complicated problems in order to realize harmonizing area control. The study on the countermeasure theory is originated from Von Neumann's use theory. The theory is based on the use sets, i.e. for any target g, in order to maximize use function u (i,g) of the Agent i, but

can not maximize use function u(j,g) of the Agent j, in this case countermeasure theory is necessary. If inequation $u(X \cup Y) \le u(x)+u(y)$ exists, the cooperation is realized.

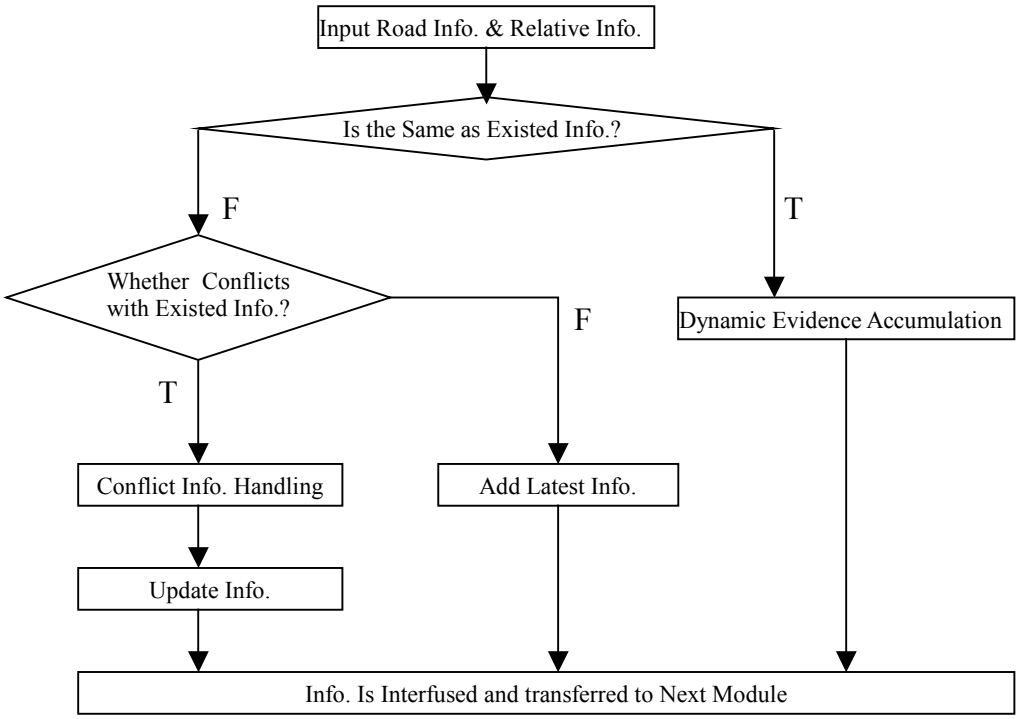

Figure 3. Relative Info. Interfusing Process of the Info. Input Module

A non-cooperation countermeasure theory based n men is established by three factors as following:

- Player set: I={1，2，…，n};
- Pure strategy finite set of every player: S={s(i)}={s_1(i)，s_2(i)，…，s_{mi}(i)}，i=1，2，…，n;
- Use function P of every player i, i=1，2，…，n.

After each player select a strategy s(i), state s=(s(1)，s(2)，…， s(n))，s(i)∈S of the countermeasure is formed. Each player gets profit: p_i=p_i(s). Therefore, non-cooperation countermeasure theory Γ based n men is denoted: Γ≡[I，{ Si }，{ pi }]. Where: S‖t(i)=(s(1)，…，s(i-1)，t(i)，s(i+1)，…，s(n))

- Definition 1 Balance State or Balance Point:Assume s* is a state of the non-cooperation countermeasure Γ based n men, then pi(s*‖s(i)≤p_i(s*)), any i∈I s(i)∈S，(s(i)=s_k(i)，k=1，2，…，m_i), so s* is called a balance state or a balance point of the non-cooperation countermeasure Γ.
- Definition 2 Mixed Strategy: Assume x_i is a mixed strategy of i, i∈I, i.e. to define a probability distribution based Si: x(i)=(x_1(i)，x_2(i)，…，x_n(i))， x_k(i)≥0，Σx_k(i)=1, so x=(x(1)，…，x(n)) is called a mixed state of the countermeasure Γ, and x‖z(i)=(x(1)，…，x(i-1)，z(i)，x(i+1)，…，x(n)). A mixed strategy Γ′ is denoted: Γ′ ≡[I，{ x_i }，{ p_i }].
- Definition 3: Mixed Strategy Balance Point: Assume E= E_i(x) is the expectance profit of i based state x, then E_i(x*‖x(i)≤E_i(x*)), if i∈I，x(i)∈X, so x* is called balance point

based mixed strategy.

In the area control system, two factors: real-time and quickness are most important. In case of the number of the player n>2, the relative computing quantity will increase greatly so that the function of the whole system will decrease greatly. As a result, we assume the type of the countermeasure is "two men and non-zero sum cooperation", i.e. n=2, the profit of one side does not equal to the loss of the other side, and meaning of this type of cooperation is to harmonize before making countermeasures.[1]

And the countermeasure Γ is denoted by double-matrix: Γ =(Agent A, Agent B; A, B).
Where: A denotes the profit matrix of Agent A; B denotes the profit matrix of Agent B.
Note that the profit function is important for the theory, but this is not the main content of this paper. So the relative of the profit function is negative in this paper. We suggest that delay time should be used as profit function. So we expect that the countermeasure will minimize the profit function, and the profit matrixes of the Agent A and Agent B, which are harmonizing with each other, are denoted as following:

$$\begin{array}{cc} & \text{Agent B} \\ & \begin{array}{cc} \text{Continue} & \text{Stop} \end{array} \\ \text{Agent A} \begin{array}{c} \textit{Continue} \\ \textit{Stop} \end{array} & \begin{bmatrix} (D_A(C,C) & D_B(C,C)) & (D_A(C,S) & D_B(C,S)) \\ (D_A(S,C) & D_B(S,C)) & (D_A(S,S) & D_B(S,S)) \end{bmatrix} \end{array} \quad (1)$$

Where:

- Continue denotes that the green signal of the phase continues;
- Stop denotes that the green signal of the phase stops and transfers the next phase;
- D_A(C，C) / D_B(C，C)denotes the profit value of Agent A / B when both Agent A and Agent B keep the green signal continuing;
- D_A(C，S) / D_B(C，S)denotes the profit value of Agent A / B when Agent A keeps the green signal continuing and Agent B stops the current phase to the next phase;
- D_A(S，C) / D_B(S，C)denotes the profit value of Agent A / B when Agent A keeps the green signal continuing and Agent B stops the current phase to the next phase;
- D_A(S，S) / D_B(S，S)denotes the profit value of Agent A / B when both Agent A and Agent B stop the current phase to the next phase;

In this paper, the delay time is the profit function, and the profit matrix of different Agents is described as formation (1). When Agent A and Agent B cooperates each other, the profit matrix (1) should be constructed and each element such as (D_A(C，C) D_B(C，C)) should be computed. After that, we compare the four elements of the matrix, and then choose the relative less element among all the elements, which means the delay time is relative little. For example, if we choose the element (D_A(C，C) D_B(C，C)), then both of Agent A and Agent B will continue the green signal. If we choose the element (D_A(C，S) D_B(C，S)), then Agent A will continue the green signal, and Agent B will stop the current phase to the next phase. If we choose the element (D_A(S，C) D_B(S，C)), then Agent A will stop the current phase to the next phase and Agent B will continue the green signal. If we choose the element (D_A(S，S) D_B(S，S)), then both Agent A and Agent B will stop the current phase to the next phase.

3.2 The Authority Limitation of the Intersection Signal Control Agent

Usually, there are three handling methods to resolve the authority limitation problem:

- Firstly, each intersection is equipped with several Agents, and every Agent takes charge of one phase. In this case, several Agents of each intersection need cooperating and different intersections also need cooperating, so that the complicate degree and the compute quantity will increase greatly. Therefore, the research and development of the whole system will get more difficult than before;
- Secondly, each intersection is equipped with only one Agent. In this kind of design scheme, each Agent has the ability of harmonizing the interests of the different phases at one intersection. And the different Agents based on countermeasure theory and relative social rules realize the cooperation between different intersections.
- Thirdly, every Agent takes charge of one sub-area. In this case, every Agent controls one or several intersections. The cooperation between different sub-areas will be realized by means of different Agents harmonizing with each other. In this kind of scheme, it is necessary to divide the controlled area at first, and in case of this step having finished the division result can not be modified.

In this paper, we consider that the second method is more practical than any other, so the design frame, which is presented in the context, is also based on that method. In order to realize the integrated control system, the paper also introduces the incident and congestion forecast algorithms and relative means. The forecast algorithms are based on three parameters such as average velocity, occupancy and traffic flow of the relative intersections.

4.FORECAST ALGORITHM OF THE INTEGRATED CONTROL SYSTEM

The forecast algorithm of the integrated control system is described as the figure 4. From the figure 4, there are three levels forecast: the first level is applied to the information service system to give the traveler the relative suggestion of the traffic conditions. And to the traffic police, the above information is used to regulate the relative signal timings. The second level forecast is used to awake the manager to prepare the emergency system to deal with the possible events besides the above measures. The third forecast is needed to take action to resolve the emergencies as quickly as possible. And the two different congestions of the intersection, the occurrent congestion and the frequent congestion can be recognized by means of the algorithm. Moreover, through the algorithm the exact station also can be ascertained. Therefore, we can determine the level of the forecast, the kind of the congestion and the exact congestion intersection all of which are the important factors to the system.

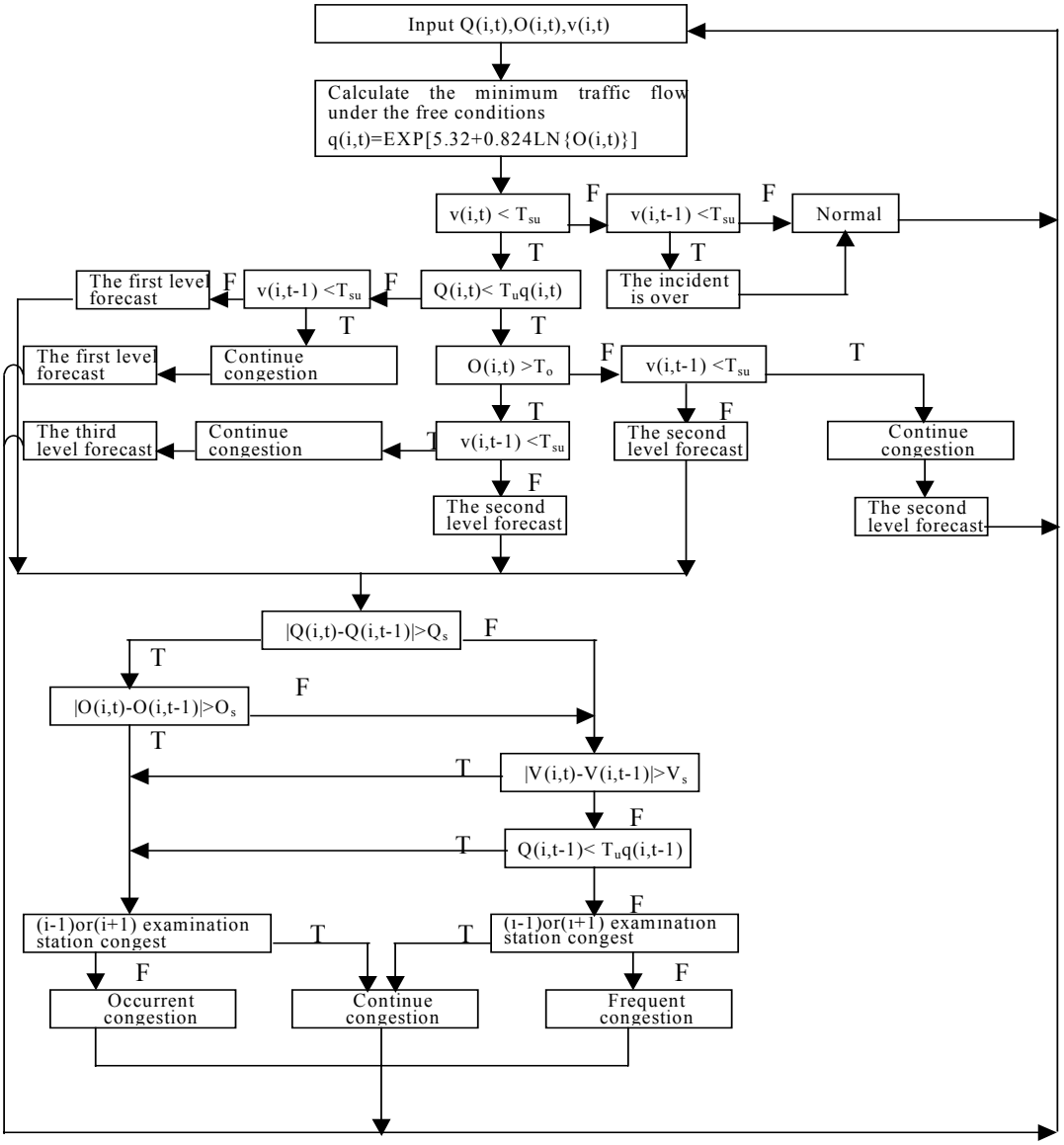

Figure 4. Auto-detection Algorithm

Where:

- T: time;
- i: the number of the examination station;
- Q(i, t): the traffic flow of the i examination station at t;
- Q(i, t-1): the traffic flow of the i examination station at t-1;
- O(i, t): the occupancy of the i examination station at t;
- O(i, t-1): the occupancy of the i examination station at t-1;
- v(i, t): the velocity of the i examination station at t;
- v(i, t-1): the velocity of the i examination station at t-1;
- q(i, t): the minimum traffic flow under the free conditions of the i examination station at t, the formula is the experiential formula of the McMaster algorithm and the formula can be modified according to the different conditions;
- q(i, t-1): the minimum traffic flow under the free conditions of the i examination station at t-1;
- T_{su}: the gate value of the velocity under the free conditions;

- T_0: the gate value of the occupancy under the free conditions;
- T_u: the percentage of the gate value of the traffic flow under the free conditions;
- Q_s: the difference of the traffic flow gate values at the adjacent time before and after the congestion;
- O_s: the difference of the occupancy gate values at the adjacent time before and after the congestion;
- V_s: the difference of the velocity gate values at the adjacent time before and after the congestion.

5.CALCULATION COURSE OF THE INTEGRATED CONTROL SYSTEM

Figure 5 presents the calculation course of the system based forecast, guidance and control.

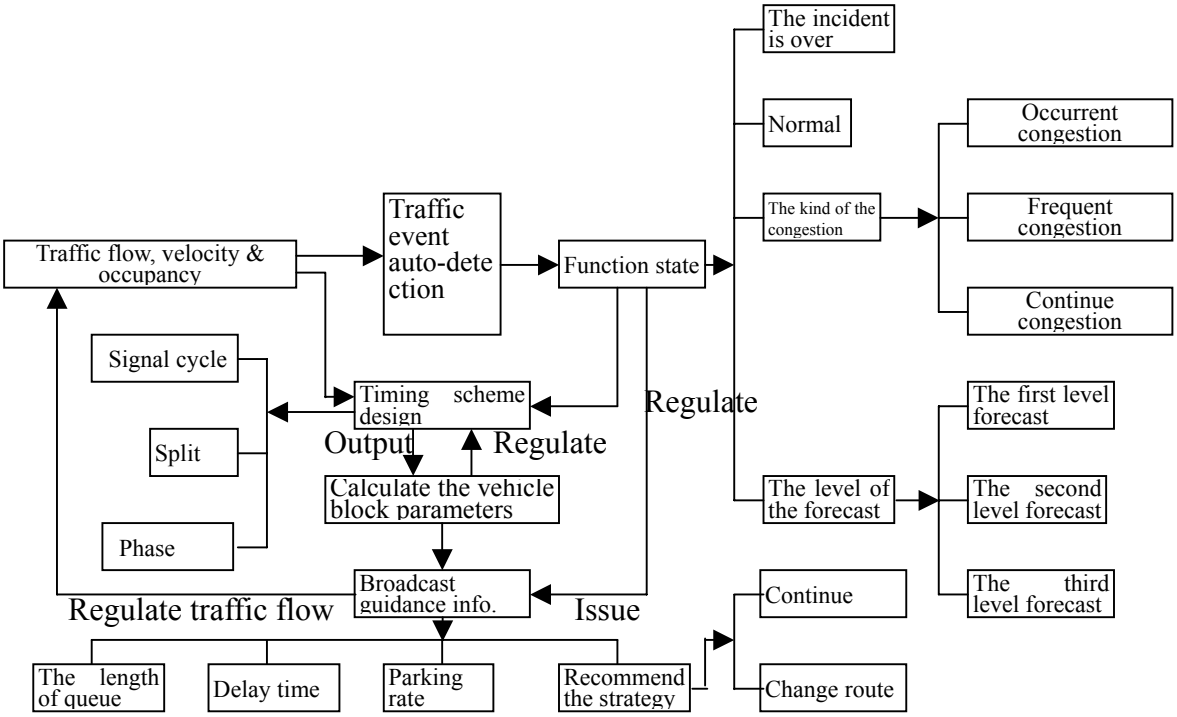

Figure 5. Calculation Course of the Integrated Control System

The relative guidance sub-system of the integrated system is one the most important factors to realize the active intelligent control. So the system can avoid the shortcomings of the traditional methods and be beneficial to realize effectively the area control system. The guidance algorithm is also based on the real time signal control scheme and the relative traffic-planning model. And this sub-system aims at the sub-area, in order to show the way as possible as quickly and effectively. Because the signal control strategy is real time and the delay time estimate is also combined with the current signal control modal.

6.ISOLATED SIGNAL CONTROL STRATEGY BASED BUS-PRIORITY

As everybody knows that the population of our country is much more than any other countries, so the bus-priority problem is one of the most traffic problems. In this part the isolated intersection signal control strategy based on bus-priority is described.

6.1 Precondition

The standard intersetion, rigid seperation between the vehicle lane and the bike lane, bus exclusive lane, the traffic flow of each lane can be measurable. The configuration of the case study intersection is described as following:

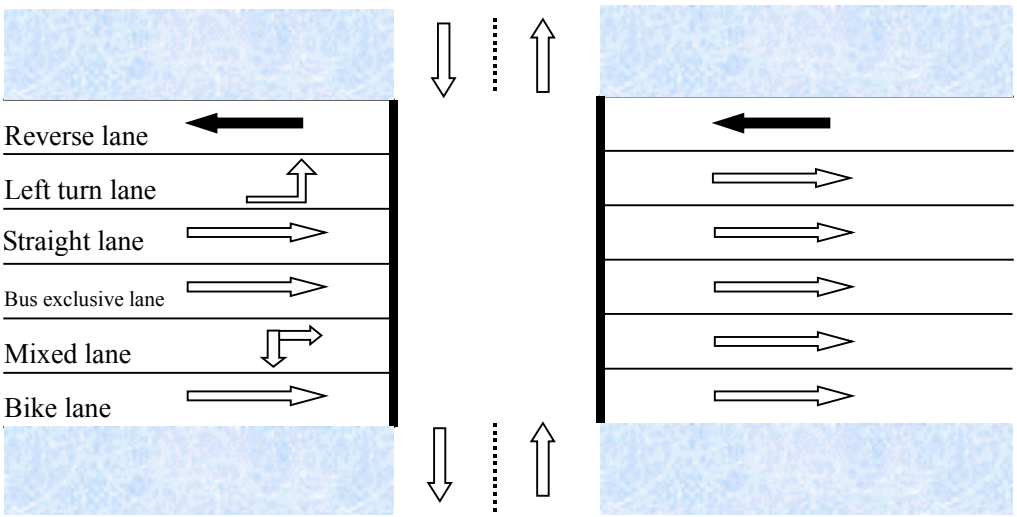

Figure 6. Configuration of the Case Study Intersection

From the figure 6, there are four lanes of each direction, and the other four lanes are omited because of the limited lenth of this paper. The left turn lane is designed for the left turn vehicles including all kinds of vehicles such as buses and cars. The Straight lane is also designed for all of the vehicles. But the bus exclusive lane is only designed for the straight buses the other vehicles and the buses which do not drive straightly have no access to this lane. The mixed lane is designed for the right turn vehicles and the straight buses also have the access to this lane. The bike lane is designed for all of the bikes drive directly. The planning of the intersection is directly related to the signal phase design. Usually, at the intersection the end of the bus exclusive lane is at the section before the access of the intersection, because to the approch of the intersection all of the lanes are divided by the driving direction. The buses also drive different direction like other vehivles, so we can not design the exclusive at the intersection. Therefore, the bus exclusive lane can not work at the intersetion. In order to resolve that problem, many experts present that the bus priority at the intersection can be realized by means of the special detector which can detect the arrival of the buses and then the signal offer the priority to the buses to some degree. In fact, this method can not work in China. Because there are a large number of buses especially at the rush hour. The special detector only detects the bus at the arrival line, the amount of the buses in the queue can not been detected. This paper introduces that the design of the bus route should drive along the right turn and straight to the destinition as many as possible. Therefore, the number of the left-turn buses at the intersection will decrease greatly. So we can design the bus exclusive lane lane for the stratight bus. By that means, we can detect the straight bus flow as easily as the other vehicles. And to detect the number of the straight buses is more reasonably than to detect the arrival of the bus at the arrival line. Consequently, the special bus straight signal phase is designed to realize bus priority strategy.

6.2 Mixed Traffic Flow

After resolving the exclusive bus lane problem, we will present the signal phase design to reaolve bike problem. As we know China has been called bicycle contry, just as its name implies that the bicycle can been seen all over the country, especially at the rush hour. So to resolve the mixed traffic flow problem is one of the key problem in China, by means of signal phase reasonably designing. So we design the special bicycle phase to resolve this problem. The special bicycle has special left turn bicycle phase and the special straight bicycle phase.

6.3 Signal Phase Expert System

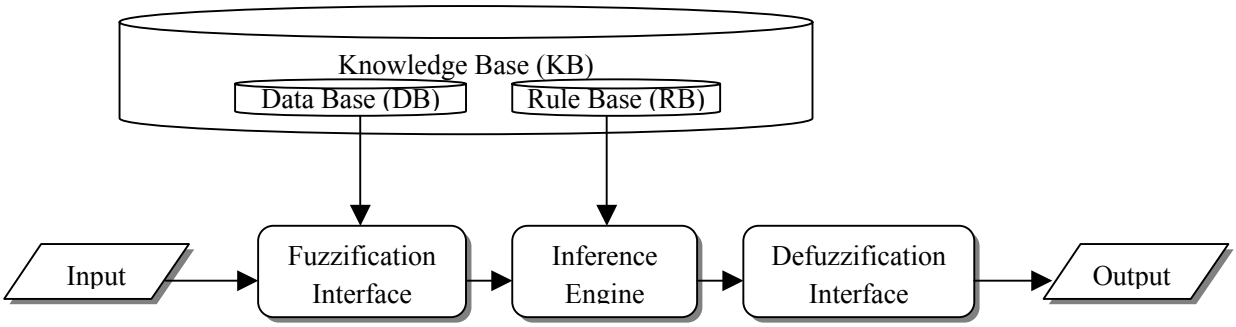

Figure 7. Frame Work of the Expert System

Because the design of the signal phase is related to many uncertainty factors and qualitative problems, the rule inference as the kernel of the expert system is based on the fuzzy logic.
To the standard intersection such as figure 6, we introduce the three factors which are related to the signal phase design scheme. They are described as following:

- Principle 1: The traffic flow of the different lane should be ballanced. Both of the usual signal phase design and the signal phase design introduced in this paper, should follow this principle, i.e. under the same signal phase conditions, the traffic flow of the defferent should be ballanced.[2] Such as figure 8:
- Principle 2: The conflict points at the intersection should be as small as possible. As we know that the the number of the signal phase should not exceed four becides some special conditons, because if the number gets more the delay time would increase. But if the number of the signal phase is small such as two phases the conflicts of the intersection will consequently get more seriously than before. Especially under the large traffic flow conditions, the aftereffects of the conflict points at the intersection will get more seriously than that of the usual conditions.
- Principle 3: The distance of the conflict traffic flow should be as long as possible. The distance of the two conflic traffic flow should be as long as possible. Each of the traffic flows comes from the two conjunctional signal phase. If the distance is long enough the conflict of the two traffic flow will be negligible. Fron this point, the red signal time of the intersection also can be negligible. Therefore the whole delay time of the intersection will decrease greatly.

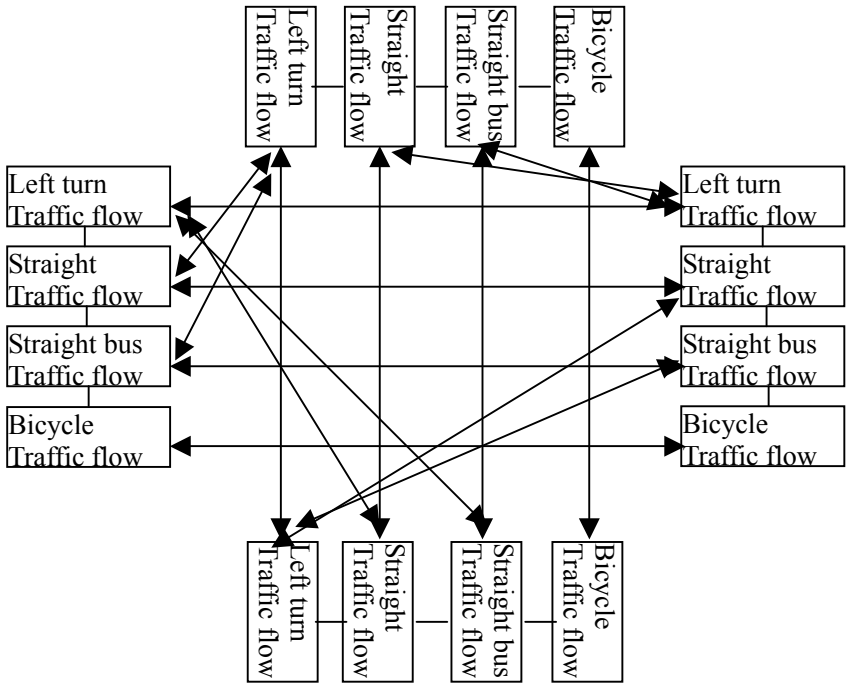

Figure 8. Judge Logic of the Balanced Traffic Flow

From the above analysis, we introduce the expert system based on the fuzzy logic to infer the signal phase design cheme.

6.4 Calculate Steps

From the figure 7, we can see the expert system has four basic components as follows:

- Rule base (RB), composed of finite if-then rules, from which an inference mechanism is formed. A standard form of RB with m logic rules are represented as:
  - Rule 1 IF x1 = A11 AND x2 = A12 AND … AND xn = A1n THEN y = B1
  - Rule 2 IF x1 = A21 AND x2 = A22 AND … AND xn = A2n THEN y = B2
  - ……
  - Rule i IF x1 = Ai1 AND x2 = Ai2 AND … AND xn = Ain THEN y = Bi
  - ……
  - Rule m IF x1 = Am1 AND x2 = Am2 AND … AND xn = Amn THEN y = Bm

where x_i,…, x_n are state variables, y is control variable. A_{i1} ,…, A_{in} and B_i ($i=1,...,m$) are respectively the linguistic variables of x_i,…, x_n,and y in the universal of discourse of $U_1,...,U_n$ and V.

- Database (DB), formed by the specific membership functions of linguistic variables:Ai1 ,…, Ain and Bi, in order to transform crisp inputs into fuzzy ones.
- Inference engine, formed by the operators within the logic rules. Generally, logic rules use AND or OR as connecting operators between state variables, taking minimum and maximum values, respectively.
- Defuzzification, the synthesis of inference results of all activated logic rules into crisp outputs for making a decision.

There are two kinds of basic signal phase of the intersection, described as figure 9 and 10:

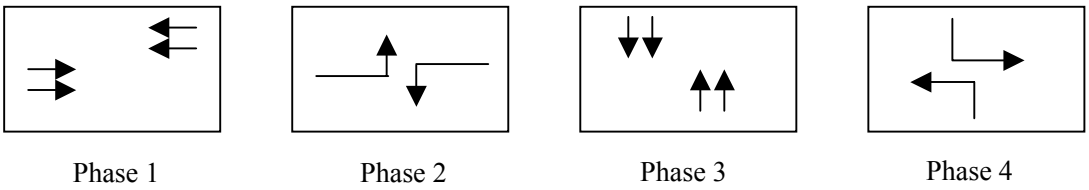

Figure 9. Model of Four Signal Phase

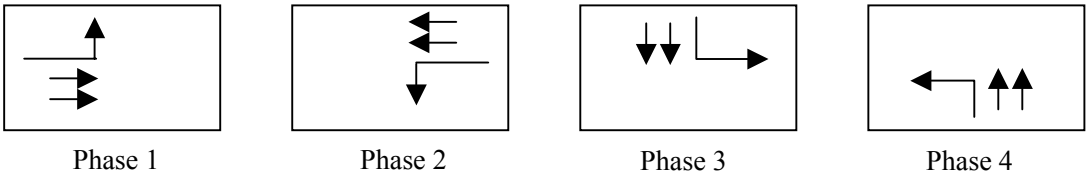

Figure 10. Model 2 of Four Signal Phase

From figure 9 and figure 10 we can see the basic phase scheme is not exclusive, so the phase will be adjusted to adapt to the the traffic conditions. Moreover, there are some special signal which means that the two traffic flow from the different direction having the pass right, but before the end of this phase one of the direction has no traffic flow. At this time, we should apply the special phase to make up this direction. From the expert system we could realize all of the above functions.Calculate steps as follows:

- Step 1: to design the original phase scheme
- Step 2: to adjust the phase scheme by means of expert system based on the fuzzy logic.[3] According to the collection data, whether to insert the special signal phase should be judged.
  - Calculate the queue Q of the forbidden lane (including the bus exclusive lane and the other vehicle lane), and the traffic flow of the passed lane
  - The four levels of the Q and O: (Z, zero), (S, small), (M, middle), (B, big), and assume the reliability is μ (0≤μ≤1). The fuzzy sets of the traffic flow O and the queue Q are described as figure 9 and figure 10 (The a, b, c, d, e in the figure 9 and figure 10 are variables which are stated according to the concrete conditions.)

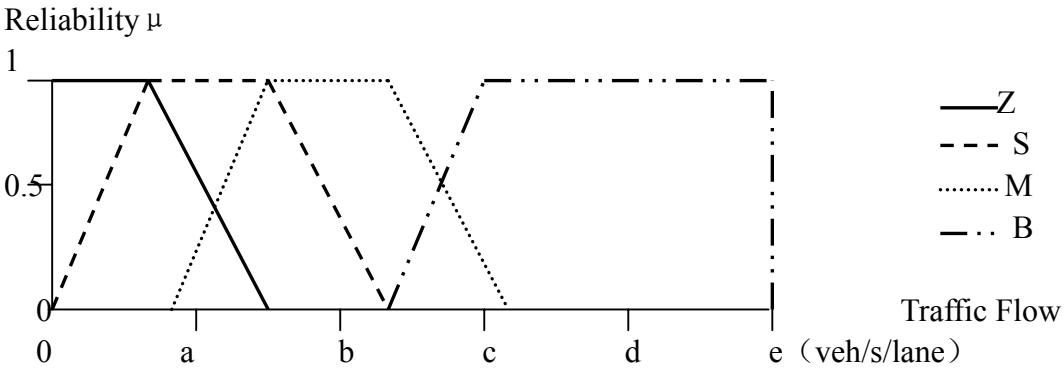

Figure 11. Fuzzy Sets of the Traffic Flow

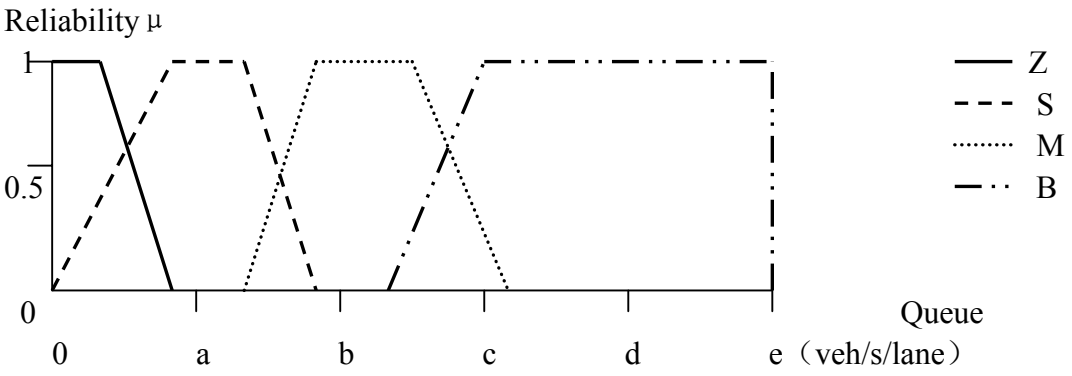

Figure 12. Fuzzy Sets of the Queue

Table 1. Fuzzy Rules of the D_{bus}、D_{car}、D_{bike}

Q / O	Z	S	M	B
Z	Z	S	M	B
S	S	M	B	B
M	M	B	B	B
B	B	B	B	B

Table 2. Confirm Whether the Special Phase be Inserted

$D_{bus}D_{bike}$ / D_{car}	Z	S	M	B
Z	No	Yes	Yes	Yes
S	Yes	No	Yes	Yes
M	Yes	Yes	No	Yes
B	Yes	Yes	Yes	Yes

- According to the fuzzy sets, the fuzzy rules of the traffic density of the transit Dbus, other vehicles Dcar and the bicycles Dbike are described as table 1. And the reliability of the traffic density is the minimum value of the reliability of O and Q.
- Confirm whether to insert the special phase described as table 2.If the above analysis result is to insert the special signal phase, the special signal phase scheme is stored in the knowledge base, and the system will apply the special signal phase based the three principles which are presented in this paper.

- Step 3: Evaluate the signal phase. For any UTCS the strategy must be evaluated so that the scheme will get more and more better. The simulation and the delay time analysis could be used to evaluate the scheme.

8 CASE ANALYSIS

An application case is studied to verify the theory proposed in this paper is effective. The evaluation carried out with the help of microscopic simulation shows that the benefits (in terms of the reduced delay time) of the new control strategy to other control methods, i.e. fixed time control, vehicle actuated control and adaptive control. We simulate the situations

on the basis of the data collected from the relative traffic management department. And the sub-area including five intersections (described as figure 13 and table 3), which are controlled by the active intelligent control system is developed in this paper. Moreover, in order to verify the effectiveness and practicality of the active control system, we apply the system strategy to an actual sub-area in our city. We analyze the results of the simulation by means of the intersection delay time through the analysis graphs. The results reveal that the active control system can curtail the total delay time at the intersection, especially at the congested intersection.

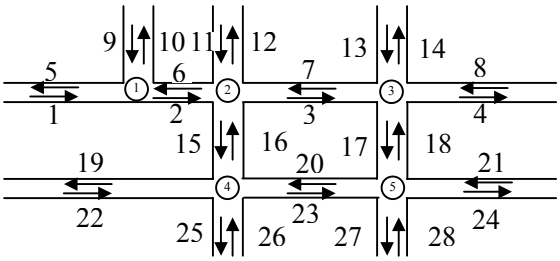

Figure 13. Simplified Route Network Structure

Table 3. Route Network Topology Structure

Lower intersection	Upper intersection	Pass distance(m)
1	2	450
2	3	1100
2	4	750
3	5	750
4	5	1100

From figure 13, the sections connect the intersection 1, 2 and 3 are the arterial road, the saturation traffic flow of which is 1600veh/h/l. And the sections connect the intersection 4 and 5 are the secondary road, the saturation traffic flow of which is 1400veh/h/l. The sections connect the intersection 1, 4 and 5 are the branch way, the saturation traffic flow of which is 1200veh/h/l. The traffic flow of each hour of the section connecting the intersection 2 and 3 presented as figure 14.

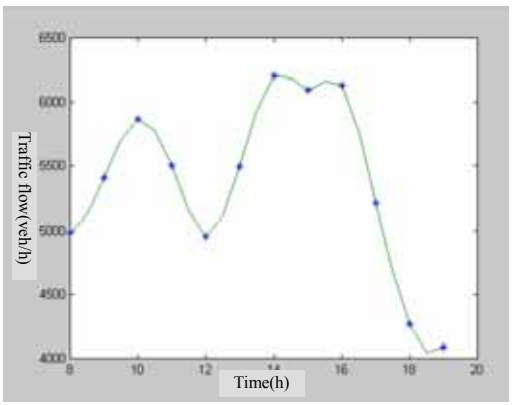

Figure 14. Average Traffic Flow of the Section Connecting the Intersection 2 and 3

From figure 14 the average traffic flow of the section connecting the intersection 2 and 3 is presented And the traffic flows of the other sections are omited because of the limited paper lenth. And there is obviously heavy traffic at the section 2 and 3 during the rush hour.

Figure 15 presents the difference of the delay time controlled by the existed system and the integrated system which is introduced in this paper when the occurrent congestion happened at the intersection 3.

From figure 15, the x-coordinate denotes the number of the intersection, such as intersection 1, intersection 2, intersection3……, and the y-axis denotes the average delay time of each intersection at the same period, such as the average delay time of intersection 1 at that period is about 13s. And from the Figure 15, we can conclude that at that peiod the traffic is the

heaviest at the section between intersection 2 and 3 than that of any other sections. If that section is not dealt with immediately the conditions will spread the whole area and then the traffic conditions of the area will get jammed up with motorcars. So through the system introduced in this paper, the heavy thaffic will be solved by cooperaing with relative intersections. So from figure 15, we can see at that period the delay time of the intersection 3 is less at the conditions of the integrated control system than that at the conditions of the existed system. Because the integrated control system can deal with the heavy traffic of the intersection 3 by means of cooperating with other relative intersections. Therefore, the delay time of the other relative intersections is more than that of the existed system. But from the point of the whole area, the integrated control can prevent the overspreading of the whole area because of the jammed intersection 3 which is the importang advantage of the integratd control system.

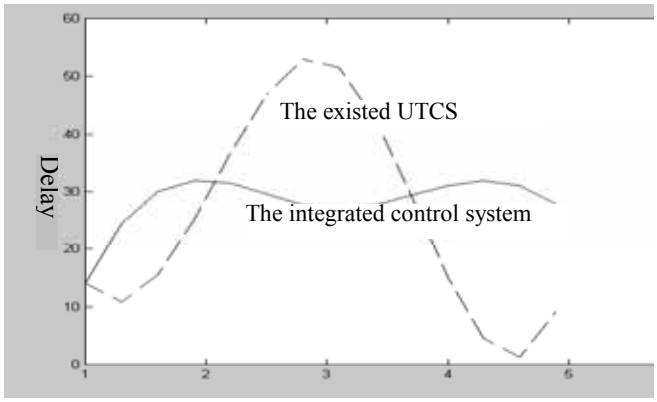

Figure 15. Delay Time of the Existed System and the Integrated System

9.CONCLUSION

In this paper, we introduce the design frame of the intelligent control integrated system, which can realize the flexible and adaptive signal control system. The first objective of this paper was to construct an intelligent control integrated system to deal with the urban traffic congestions, especially at the intersections in the period of heavy traffic. And the proposed methods are designed from the aspect of the practice and the availability such as the selection of the sub-area and all of the input data coming from the factual collection, which is agreed with the ITS industrialization policy. Moreover, we also consider the bus-priority problem in order to adapt to the situations of China.Finally, through the simulation analysis results, the system developed in this paper curtails the total intersection delay time. Therefore, a conclusion can be drawn that the system introduced in this paper is practical and effective.

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