Recommendation of the Most Appropriate Control Agents for an Urban Traffic Control System Based on Evaluation

Shuangshuang Li, Cheng Chen, Qingming Yao, Xiangying Liu

***Abstract*—Multi-agent control method is an important approach for urban traffic control system. It is noted that, for a real traffic control system, each control agent cannot meet control requirements well under different traffic states. How to recommend the most appropriate control agents to a multi-agent urban traffic control system is a crucial problem. In order to solve this problem, we use the historical traffic flow of an intersection to test the performance intervals of every control agent offline. Then we predict the traffic flow on the basis of the historical traffic flow. According to the performance intervals of every control agent and the predicted traffic flow, we recommend the most appropriate control agents to the intersection. In particular, we use the pattern recognition algorithm (PRA) and the weighted pattern recognition (WPRA) to predict the traffic flow respectively. The results of the experiments show that the control agent recommendation system performs better than the original control system.**

I. Introduction

The urban traffic control system, like power control system, urban sewage distribution control system, etc. is usually large in size, has many actuators and sensors, and exhibits complex dynamics. Single control method is difficult to meet the control requirements of urban traffic control system. For this reason, urban traffic control system typically has to be operated using a multi-agent and distributed control approach [1-9]. In such an approach the urban traffic control system consists of multiple control agents. It is easy to see that, for a real traffic control system, the performance of each control agent is not always good. So it is necessary to recommend the most appropriate control agents to the multi-agent urban traffic control system. Single intersection is the basic components of the traffic network. When we want to study the control agent recommendation system of a traffic network, it will play a fundamental role to study the control agent recommendation system of a single intersection.

Control agent recommendation in a multi-agent urban traffic control system is unlike item recommendation in E-commerce. The recommendation in E-commerce is all about predicting the patterns of users' taste and using them to discover new and desirable things you didn't already know about. These patterns stand for people tend to like things that are similar to other things they like. For example, if a stranger asks you whether you think she likes the Harry Potter VII film, you might have nothing better than a guess. However, if she tells you she loved the first six films in the series, you'd be shocked if she didn't like the seventh as well. On the contrary, if she says she hated the films, or asks. "What's the film?" you'd rightly guess the seventh film is not on her favorites list. We can see that this recommendation is done by computing a set of previously expressed preferences, in order to recommend items that are likely of interest to a user. The recommendation in an urban control system must know all "users' preferences" and using them to give a recommendation to the control system. The "users' preferences" stand for the performance of the control agents. Unlike the recommendation in E-commerce, the recommendation in an urban control system couldn't predict the one control agent's performance by other control agents' performance. Even there are some relationships between them. We can see that this recommendation is done by testing the performance of every control agent and predicting the traffic flow, in order to recommend the most appropriate control agents to the multi-agent traffic control system.

To determine which control agents to recommend, it is the major requirement for control agent recommendation system to have the performance of every control agent. That is to say, we should know the evaluation of control agents. There are many evaluation indices to evaluate a control agent, such as the without waiting for passing rate, total numbers of vehicles passing, total mean speed and total mean time delay. In this

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paper we use these four indexes to evaluation the performance to the control agents. The control agent recommendation system should have the ability to make and continuously update predictions of traffic flows and link times for several minutes into the future using real-time data. With this ability the control agent recommendation system can give a proactive control to the urban traffic. So we use two methods which called pattern recognition algorithm (PRA) [10] and the weighted pattern recognition algorithm (WPRA) [12] respectively to predict the traffic flow. Compared to PRA, WPRA predicts the future traffic flow by taking the time information into account [12].

In this paper, in order to obtain the evaluation of the control agents, we test the every control agent's performance in *Paramics*[13] microscopic simulation software. Based on the evaluation of control agents and the predicted traffic flow, the most appropriate control agent which suited for the current traffic state could be recommended to the multi-agent urban traffic control system. Experimental results show that the control performance of the control agent recommendation system performed better than that of the original control system.

Compared to the original control system, the control agent recommendation system is more intelligent and has self-adaptive function. On one hand, this is because the original system treats different state of traffic flow with the same control strategy. However, the same control strategy cannot meet the control need for all state of traffic flow. On the other hand, the control agent recommendation system can recommend the most appropriate control agents to the intersections according to the evaluation of control agents which is tested out in different state of traffic flow state. So the control agent recommendation system can deal with different situations by using the most appropriate control agents which are recommended by the system.

The structure of the paper is organized as follows. After introducing the urban traffic control system, control agent recommendation, we describe the architecture of control agent recommendation in Section 2, which contains the difference between the control algorithms and control agents, simulation platform, traffic flow data set and control agents' performance test. Section 3 reports the experimental results on the performance of the recommendation system, and gives a performance comparison among recommendation system and the original control system. In Section 4 we conclude the paper and discuss some orientations about future work.

II. CONTROL AGENT RECOMMENDATION ARCHITECTURE

The general structure of the control agent recommendation system is shown in Fig. 1. Here, the control agent recommendation system is divided into two parts: the online processing section and the offline processing section. The offline processing section contains four parts and its main role is to test the performance of control agents which is the basis of recommendation algorithm. In this section, after building the intersection network model of an actual intersection in traffic simulation software platform and choosing historical traffic flow data, the performance of control agents is tested. The performance of control agents are the input of the recommendation algorithm, whose main function is to predict the traffic flow and make a recommend to the intersection. The online processing section consists of three parts. The input of this section is historical traffic flow data, performance of control agents and the real-time traffic flow data. According to the real-time traffic flow and the historical traffic flow data, the algorithm can forecast the current traffic flow. Then the control agent recommendation system gives a real-time recommendation to the intersection online on the basis of the predicted traffic flow and the performance of control agents.

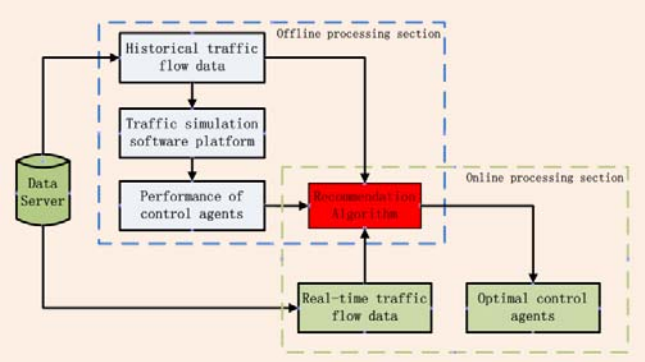

Fig.1. Architecture of agent recommendation

A. *Control algorithms and control agents*

It is necessary to give a simple introduction of the control algorithms and the control agents before testing the performance of the control agents. The definition of control algorithms is the mathematical representation of executive function. Compared to control algorithms, control agents have some advantages as follows: (1) Control agent has more mobility. One control agent can provide control service for two or more controlled object simultaneously. (2) One control agent can communicate with others on the same or different platforms. (3) Control agent has more security by considering the issue and recovery.

B. *Simulation platform*

We use *Paramics* microscopic simulation software to test the control agents' performance. "*Paramics* is a widely used microscopic traffic simulation tool. It has a large set of functionalities that can be used to simulate and evaluate various policies and control strategies and their effects on the transportation system, such as vehicle delays and emissions. Application Programming Interface (API) makes it have the ability of overriding or extending the default models such as car following, lane changing, route choice. The modelers can test their own models and incorporate customized functionalities using API" [14].

C. *Traffic flow data set*

In order to test the control agents' performance, it is

necessary to prepare the traffic data. The traffic data were

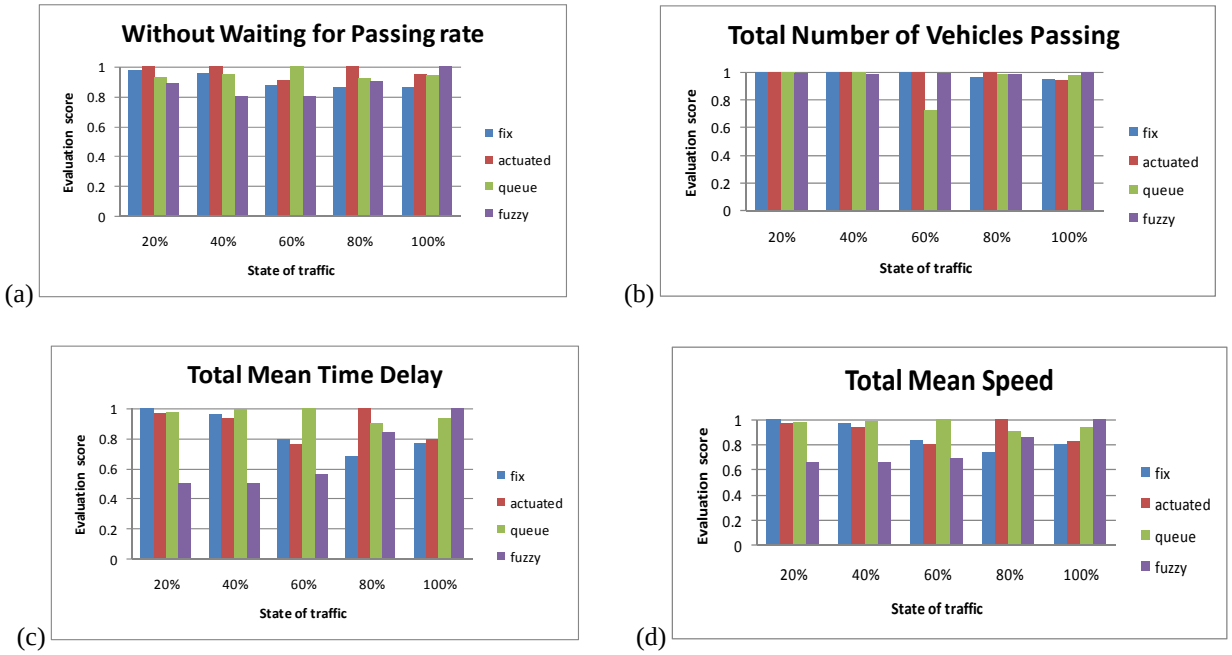

Fig.4. The four indexes for the four control agents. The panels represent (a) the without waiting for passing rate, (b)the total number of vehicles passing, (c)the total mean time delay and (d)the total mean speed of the four control agents

collected at a site monitored by the Center for Intelligent Control and Systems Engineering (CICSE) of Institute of Automation Chinese Academy of Sciences (CASIA). The site chosen within CICSE is located on Suzhou City, Jiangsu Province, China. This is a five-lane road and its number is 103, called Feihu Intersection, as shown in Fig. 2. From this site, a database of one month of aggregate 5-minute traffic volumes was assembled from May 1 to 31, 2010. The data set contains very few periods of missing observations, where data is not available for up to 5 minutes. We divided the historical traffic flow data into two parts: a search data set and a test data set. We used the data from May 1 to May 30 as an estimation data set and the data of May 31 as a test data set.

Fig.2. Spatial location of study site

D. The process of testing control agents performance

We chose four commonly used control agents to do performance testing. They are “fix”, “actuated”, “queue” and “fuzzy”. The process of testing performance of control agents is divided into the following four steps:

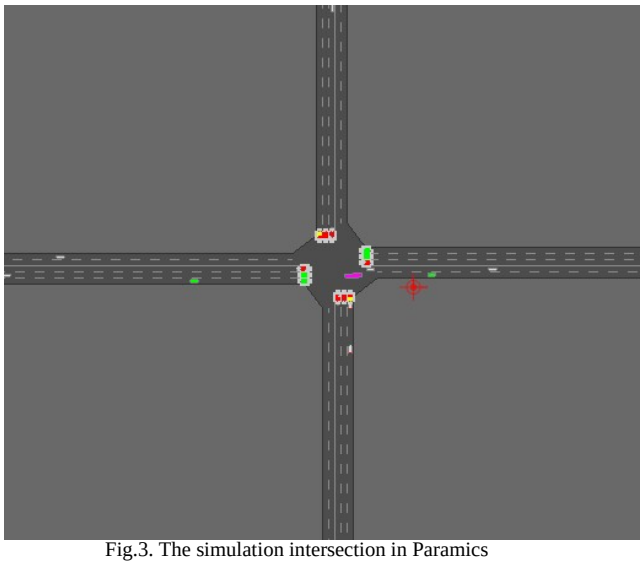

Fig.3. The simulation intersection in Paramics

- Step 1: Build actual intersection network model in the traffic simulation platform. A PARAMICS micro-simulator is used to simulate this intersection network, as shown in Fig. 3.
- Step 2: Extract the historical traffic data form database. According to the ratio of maximum traffic data, the test data is divided into five intervals:0～20％, 20%～40%, 40%～60%, 60%～80%, 80%～100%. Test the four control agents one after another and get the evaluation scores which are the normalized without waiting for

passing rate, total number of vehicles crossing, total mean speed and total mean time delay of each control agent, as shown in Fig. 4.

- Step 3: Weight the four indicators in step 2 and get the fitness of the control agents, as shown in Fig. 5.
- Step 4: Obtain the most appropriate performance intervals of each control agent.

According to the fitness of four algorithms, we get the most appropriate performance intervals of every agent, as shown in Table 1.

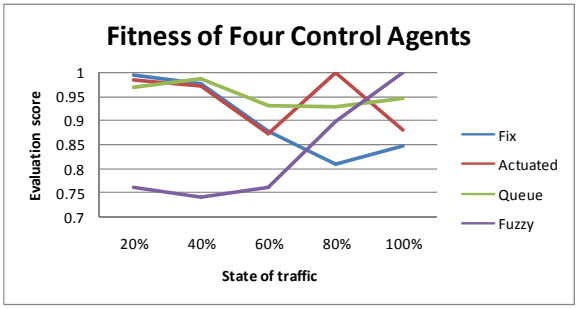

Fig.5. The fitness of four Control Agents

TABLE I
THE MOST APPROPRIATE PERFORMANCE INTERVALS OF EVERY CONTROL AGENT

Traffic flow intervals	0-35%	35%-70%	70%-90%	90%-100%
Control agents	Fix	Queue	Actuated	Fuzzy

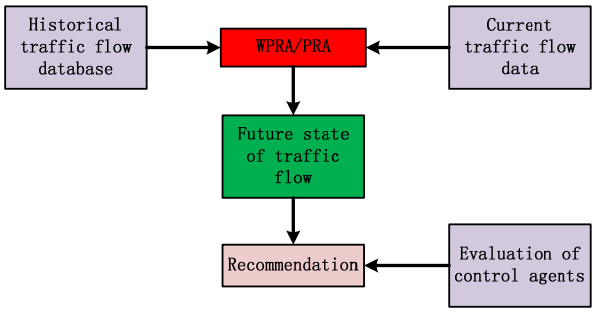

Fig.6. The process of recommendation

III. RECOMMENDATION

The state of traffic includes the mean speed, volume and occupancy in the traffic roads. In the paper the future state of the traffic flow stands for the volume of the intersections in the next one or several periods. In order to recommend the most appropriate control agents to the intersection, Not only do we need the evaluation of control agents, but also we need to know the future state of the traffic flow. This is to say, the recommendation system should have the ability to predict the traffic flow. In this paper, we use pattern recognition algorithm (PRA) [10] and the weighted pattern recognition algorithm (WPRA) [12] respectively to forecast the traffic flow. The input of WPRA and PRA is the historical traffic flow data and the current traffic flow data, as shown in the Fig. 6. The traffic control system can give a recommendation according to the predicted future state of traffic flow and the evaluation of control agents.

IV. EXPERIMENTS

The performance of online process section in the agent recommendation architecture presented in this paper was evaluated using a simulated road network in Feihu Intersection. We measured the numbers of actual and predicted traffic flow in every control agent performance interval and we report the ratio of the error between them to the actual numbers, which we called the recommendation error rate. We compared the recommendation error rate of WPRA with that of PRA [10]. In the end, we compared the total mean speed during different time intervals of control agent recommendation system with original control system. The actual traffic flow of Feihu Intersection is as shown in Fig. 7 and the maximum vehicle of this intersection is 552.

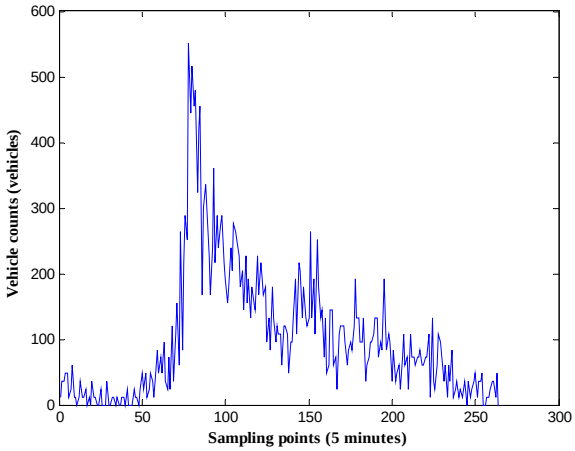

Fig.7. The traffic flow of Feihu Intersection in May 31

TABLE II
COMPARISON OF THE RECOMMENDATION ERROR RATE OF TWO ALGORITHMS

Agent Performance Intervals	Actual Numbers	WPRA Numbers	PRA Numbers	WPRA(PRA) Recommendation Error Rate
0～35%	226	221	209	2.21%(7.52%)
35%～70%	31	36	48	16.13%(54.84%)
70%～90%	5	6	4	20%(20%)
90%～100%	2	1	3	50%(50%)

From Table 2 we can find that recommendation precision of WPRA is better than that of PRA. In Fig. 8, we can see that the majority of the traffic flow in May 31 at Feihu intersection is in the agent performance interval: 0～35%. So we compare the total mean speed of the Fix agent with that of the recommendation system. In the Fig. 8, it is shown that the performance of the control agent recommendation system outperformed that of the “Fix” agent during the heavy traffic flow. During the light traffic condition, the recommended control agent is “Fix” control agent which is the same as the original control agent. So there is little difference between the mean speed of the control agent recommendation and that of the original system.

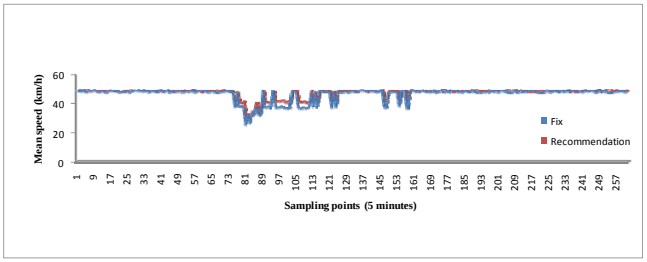

Fig.8. Total mean speed of the Fix and Recommendation

V. Conclusions and Future Studies

In this paper, on one hand, while the performance of the control agents discussed in this research does significantly stand for a kind of performance index, it does not equal the performance of the four control agents. For example, the parameters for the fuzzy control agent are too difficult to adjust in order to obtain a good performance of fuzzy control agent. We only work with a set of parameters, and certainly not the most appropriate one. On the other hand, we compare the mean speed of the "Fix" and the recommendation system. The results have shown that the recommendation system outperforms the original system which uses the "Fix" agent only.

In the future we would like to extend our method to the case with more than ten intersections. When we want to give a recommendation to an area where there are more than ten intersections, we should also consider the relationship of these intersections which may provide some information to help us to give a recommendation to this area.

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References

[1] F.-Y. Wang, "Agent-Based Control for Networked Traffic Management Systems," *IEEE Intelligent Transportation Systems*, vol.20, no. 5, September/October, 2005, pp.92-96.

[2] X.M. Liu and F.-Y. Wang, "Study of City Area Traffic Coordination Control on The Basis of Agent," *The IEEE 5th International Conference on Intelligent Transportation Systems*, Singapore, September 2002, pp. 758-761.

[3] P.G. Balaji and D. Srinivasan, "Multi-Agent system in urban traffic signal control," *IEEE COMPUTATIONAL INTELLIGENCE MAGAZINE*, vol.5, no.4, November, 2010, pp.43-51.

[4] F.-Y. Wang and C. H. Wang, "Agent-based control systems for operation and management of intelligent network-enabled devices," *Proceedings of the IEEE International Conference on System*, Man and Cybernetics, 2003, vol. 5, pp. 5028-5033.

[5] R.R. Negenborn, B. De Schutter, J. Hellendoorn, "Multi-agent model predictive control for transportation networks: Serial versus parallel schemes," *Engineering Applications of Artificial Intelligence*, vol.21, no.3, pp. 353-366.

[6] Z.J. Li, F.-Y. Wang, Q.H. Miao and F. He, "An urban traffic control system based on mobile multi-agents," *IEEE international Conference on Vehicular Electronics and Safety*, 2006, pp. 103-108.

[7] Burmeister. B., Haddadi. A., Matylis. G., "Application of multi-agent systems in traffic and transportation," *IEEE proceedings. Software engineering*, Feb 1997, vol. 144, no. 1, pp.51-60.

[8] X. Chen, Z.S. Yang, H.Y. Wang, "A Multi-agent Urban Traffic Control System Cooperated with Dynamic Route Guidance," *Proceedings of the 2006 International Conference on Machine Learning and Cybernetics*, 2006, vol. 2006, pp.330-335.

[9] R.S. Chen, D.K. Chen, S.Y. Lin, "ACTAM: Cooperative multi-agent system architecture for urban traffic signal control," *IEICE Transactions on Information and Systems*, January 2005, vol.E88-D, no.1, pp.119-126.

[10] T. Kim, H. Kim and D.J. Lovell, "Traffic Flow Forecasting: Overcoming Memoryless Property in Nearest Neighbor Non-Parametric Regression," *Proceeding of the 8th International IEEE Conference on Intelligent Transportation System*, Vienna, Austria, September 13-16, 2005, pp. 965-969.

[11] G.A. Davis and N.L. Nihan, "Traffic flow forecasting: comparison of modeling approaches," *ASCE Journal of Transportation Engineering*, vol. 117, no. 2, 1991, pp.178-188.

[12] S. S. Li, Z. Shen, F.-Y. Wang,"A Weighted Pattern Recognition Algorithm for Short-Term Traffic Flow Forecasting," *9th IEEE International Conference on Networking, Sensing and Control*, Accepted.

[13] Quadstone Paramics Ltd, Introducing Paramics, 2011, Available: http://www.paramics-online.com

[14] K. Ozbay, S. Mudigonda and B. Bartin, "Development and Calibration of an Integrated Freeway and Toll Plaza Model for New Jersey Turnpike using Paramics Microscopic Simulation Tool," *Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems*, Vienna, Austria, September 13-16,2005, pp.1165-1170.