2012 15th International IEEE Conference on Intelligent Transportation Systems
Anchorage, Alaska, USA, September 16-19, 2012

A Survey of Urban Traffic Signal Control for Agent Recommendation System

Cheng Chen, Fenghua Zhu, Yunfeng Ai

Abstract— **Dynamic changes and uncertainty in traffic environments directly spawned lots of strategies about traffic signal control (TSC). Meanwhile, the differences in the traffic environment and demand of control have a significant impact on the performance of strategies about TSC. In order to enable dynamic selection of the most appropriate TSC agents for each specific traffic state in urban traffic transportation system, we firstly propose a survey about urban TSC, which helps us to understand the characteristics of TSC strategies. This survey focuses on the traffic environment about the application of TSC and the demand of TSC. Then, based on the aforementioned survey, we propose one recommendation mechanism for agent-based distributed and adaptive platform for transportation systems to adapt to traffic dynamic characteristic.**

I. Introduction

Traffic signal control (TSC) has a long history, which began in 1864 that policemen use semaphore to guide the traffic in London. In 1914, the first electric traffic signal device was installed in Cleveland, Ohio, USA to complete the leap from semaphore to electrification. After that, TSC kept continuously developing. With the acceleration of urbanization and the popularity of vehicles, the contradiction between limited road resource and increasing number of cars draw the attention of society. Considering the product of this contradiction, like traffic congestions, environmental pollution and so on, people need to find out reasonable methods of road resource allocation to alleviate this conflict. As one effective method of road resource allocation, TSC has drawn sufficient attention. The theoretical research work about the optimization of TSC could date back to the mid-20th century [1]. Meanwhile, the actual TSC also develop from single points to systematic direction with the emergence of several generations of traffic management systems, like TRANSYT, SCOOT, SCATS, and so on. These traffic management systems not only contains the TSC for intersections, but also the information fusion and coordination strategies for the intersection, the traffic flow forecasting and inducement functions etc. However, TSC for intersections is still one very important and basic part of the whole system. According to the characteristics about the environment of intersection and traffic management systems, finding out a matching TSC algorithm for each intersection is significant to the optimization of the entire system. Hence, the surveys about TSC are meaningful. In [2] and [3], authors give surveys about intelligent methods in TSC respectively. They help readers to grasp the latest technologies of artificial intelligence in the TSC area. Although in [3], the methods are introduced apart by three types of road: surface way, ramp and corridor. However, these surveys only pay attention to the methods of solutions for the traffic problem, like fuzzy, artificial neural network, reinforce learning and so on. They lack the detail description about the application environment of methods. As shown in the (a) of Fig.1, the process of research has three phases: identify and describe problem, clarify the objectives, solve problem. The identification and description about the problem help us to understand the similarities and differences of the problem with other problems in a rational and generally recognized way, like making some definitions and assumptions. According to the understanding about characteristics of this problem, the concrete goal of research work could be determined. This concrete goal is not a vague term, like the improvement of performance, but the melioration about some specific indicators. With these two phases, researchers can begin to find out the reasonable solutions and users can realize the limitation of these solutions to solve the problem. Therefore, the first two phases are the same important as the third phase.

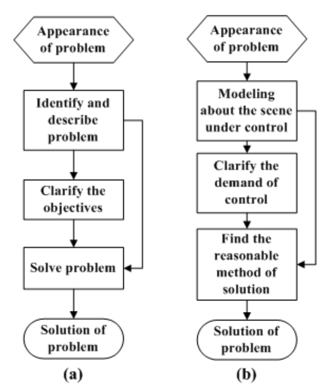

Fig. 1. The flowchart about the process of general research (a) and the research on TSC (b).

We define the research of TSC as follows: in one special traffic scene, researchers use some method to improve the traffic state than the original control method. Hence, as shown in the (b) of Fig.1, the research of TSC also has three phases: modeling about the urban traffic scene under control,

This work was supported in part by NSFC 60921061, 70890084, 90920305, 90924302, 60904057, 60974095; CAS 2F09N05, 2F09N06, 2F10E08, 2F10E10; 2F11D01.

Cheng Chen, Fenghua Zhu are with the State Key Laboratory of Management and Control for Complex Systems, Chinese Academy of Sciences, Beijing, 100190, China. They are also with Dongguan Research Institute of CASIA, Cloud Computing Center, Chinese Academy of Sciences, Songshan Lake, Dongguan 523808, China. (e-mail: chengchen.cas@gmail.com, fenghua.zhu@ia.ac.cn). Yunfeng Ai is with the College of Computing and Communication Engineering, Graduate University of the Chinese Academy of Sciences, Beijing 100049, China (e-mail: aiyunfeng@gmail.com).

clarify the demand of control, find out the reasonable method of solution. Through these three phases, TSC can calculate out reasonable parameters for signal timing, like cycle length, split and offset, to meliorate our urban traffic environment.

In this paper, we firstly make a survey about the urban traffic scene under control and the demand of control respectively in Section II and III. Then, according to the aforementioned content, we propose a recommendation mechanism for TSC agents in agent-based distributed and adaptive platform for transportation systems (aDAPTS) [4] in Section IV. At last, one conclusion will be given in Section V.

II. MODELING ABOUT TRAFFIC SCENE UNDER CONTROL

Modeling about the scene under control helps us to understand the characteristics about the problem of TSC, like constraints and given context. These characteristics directly impact on the goal and method of TSC. The content of modeling about the scene under control includes four parts: modeling about controlled intersection, type of detected traffic information, type of TSC system, and traffic state of intersection.

A. Modeling about Controlled Intersection

The modeling involves the location and physical shape of intersection. From Wikipedia, an intersection is a road junction where two or more roads either meet or cross at grade (they are at the same level). The location and physical shape of intersection has impact on the traffic priority of roads. In traffic engineering, the location has directly impact on the TSC of intersections. On the freeway, the intersection is called as highway ramp [5]. TSC of highway ramp is called as ramp meter [6]. Among the roads of ramp, the road of freeway is dominant. Hence, the basic goal of ramp meter is to keep the freeway having a more smooth throughput [7]. The most common intersection is on the surface street of the city. The traffic priority of roads on this intersection is equal from the viewpoint of location. However, the traffic priority can also be influenced by other elements, which will be mentioned in the following part. Besides, the intersection on the corridor, which is the surface road beside the freeway called as the side way. For a special location, the TSC about intersections on the corridor should take the ramp into consideration. And this is different from other intersections on the urban surface road. Similarly, many researches in TSC focus on the physical shape of intersections, including the quantity of related roads, the number of lanes on these related roads, the directional characteristics of related road. From the viewpoint of the quantity of related roads, intersection can be divided into several types, like two-way, three-way (T-junction), four-way (Crossroad) and so on. Considering that all the ramps are two-way type, two-way model of intersection is special. Besides ramps, green wave on arterial road is also a hot topic in the TSC research of two-way model of intersection [8]. Begin from three-way model of intersection, researches generally focus on the optimization about some indicators of control performance. Specially, the illustrated model of intersection in [9] is unusual, which is an eight-way intersection. To some extent, the number of lanes on these related roads also impacts on the choice about the goal and method of TSC. In traffic Engineering, the urban surface roads are consisted of arterial roads, collectors and local streets. Generally speaking, the numbers of the links on these roads decrease obviously with the above order. Different types of roads has different traffic priority. Therefore, according to the intersections which have different types of road, their TSCs vary from each other. In [10], by controlling the traffic flow access to the freeway, the goal about the TSC of on-ramp is to make full use of the traffic capacity of freeway and make the distribution of traffic flow on the freeway be reasonable. However, the goal about the TSC of off-ramp is to prevent the queue on the off-ramp being too long or one traffic flood leaving from the freeway to cause a traffic congestion of related intersection on corridor. Therefore, the direction is also one characteristic need to be considered.

B. Type of Detected Traffic Information

As one major collector of real-time traffic information, the detectors are responsible for providing the input of TSC algorithms. Hence, they are indispensable in the TSC. In [11], authors survey technologies of detection. These technologies are divided into point detectors, above-ground detection and vehicle tracking. In [12], according to influence of the installation and upkeep about the detector on actual traffic, all the detectors are classified into intrusive sensors and non-intrusive sensors. We classify the technologies of detection as active detection and passive detection. The technologies of active detection make use of the device on the vehicle, like the technology of V2I, GPS and so on. The main disadvantage of active detection is the requirement that all vehicles need to have appropriate equipment. On the contrary, the technologies of passive detection only take vehicles as the objects to be detected. The passive detection technologies also can be classified as under-ground detection and above-ground detection. Under-ground detection, such as inductive loops, is limited by the location of detectors. The above-ground detection includes the video image processing, microwave radar based detection system and so on. As mentioned in [11], the video image processing can offer the prospect of more detailed information. The level of detail depends on the sophistication of the image processing that is undertaken. However, traffic control algorithms of TSC only concern about the variables of input and their precision detected by the technologies of detection rather than these technologies themselves. If the field detector cannot provide or synthesize the information required by control algorithms, control performance of TSC will greatly deteriorate, even that cannot be used. According to the time stamp of information, the information required by control algorithms can be divided into historical and real time information. Historical traffic information is converted from real time information by storage, analysis and synthesis. Hence, if the real time information for the conversion can be collected,

TABLE I

THE OUTPUT ABOUT DIFFERENT TYPE OF DETECTOR

Technology	Output Data[1]					
	count	presence	speed	Occupancy	Classification	Detection Zone Data
Inductive loop	Y	Y	Y[2]	Y	Y[3]	N
Magnetometer (Two-axis fluxgate)	Y	Y	Y[2]	Y	N	N
Magnetic(Induction or search coil)	Y	N	Y[2]	Y	N	N
Microwave radar	Y	Y[4]	Y	Y[4]	Y[4]	Y[4]
Infrared	Y	Y	Y[5]	Y	Y[6]	Y[6]
Ultrasonic	Y	Y	N	Y	N	N
Acoustic array	Y	Y	Y	Y	N	Y[7]
Video image processor	Y	Y	Y	Y	Y	Y

[1] Y represent this kind of information can be acquired by this type of detector; N has reverse meaning.
[2] Speed can be measured by using two sensors a known distance apart or by knowing or assuming the length of the detection zone and the vehicle.
[3] With specialized electronics unit containing embedded firmware that classifies vehicles.
[4] From microwave radar sensors that transmit the proper waveform and have appropriate signal processing.
[5] With multi-detection zone passive or active mode infrared sensors.
[6] With active mode infrared sensor.
[7] Models with appropriate beam forming and signal processing.

historical traffic information can be acquired. We can focus on the real time information provided by detectors. As we known, the type of information is determined by the type of detector. According to the content of [12], table I lists all type of output data provided by different kinds of detectors. Therefore, as we know the type of detector installed in intersection, the kind of TSC can be implemented is known.

C. Type of TSC System

Control in single point mode is the pioneer. Nowadays, in most of the small and medium cities, for lacking of the fund for transportation construction, it is still a popular control mode. For example, in [13], the city of Macaé lacks of wired communication between roadside controllers and the central control room. However, for the complexity of traffic environment, especially in metropolises, the systematization of TSC becomes an inevitable trend. Hence, many algorithms of TSC rely on the information of coordination and the instruction from remote control center. Without the help of information provided by the whole system (or can be said as only using the local information collected by the detector in local intersection), TSC is difficult to acquire a satisfied control performance. Hence, an inappropriate system will wash the performance of some special TSC strategies down.

In [14], two topological structures of agent-based traffic control system are given, which are TRYS and $TRYSA_2$. In TRYS, the sharing of traffic information is centralized. Generally speaking, there is one coordinator to be responsible for the exchange of information. The characteristic of this topological structure is described as follows: although it may not be able to find the optimal solution in a controlled time, finding out a feasible solution is possible. Hence, it has a good real-time performance. Differently, the sharing of traffic information in $TRYSA_2$ is decentralized. It also can be called as self-organized. Without a unified management for the exchange of information, the users of information need to directly contact with the providers of information. Hence, adding a new intersection in $TRYSA_2$ is easy than TRYS. However, this kind of system has the risk about being unable to get a solution in a controlled time. Centralized and decentralized coordination modes are also common in other TSC systems. For example, in [15], the architecture about the organization of multiagent is decentralized. However, RHODES [16], which has a hierarchical system architecture, is a representative of centralized coordination mode.

D. Traffic State of Intersection

The purpose about the implementation of one kind of TSC is making traffic state of intersection better than the one not under the control or under other control methods. Time of Day (TOD) control technology segments one day into several control periods based on different traffic states of one intersection [17]–[19]. Hence, in different control period, we implement the most suitable TSC strategy to enhance the control performance of intersection. Meanwhile, many researches focus on the congestion status of intersection to develop new control strategies of TSC [20] [21]. Therefore, traffic state of intersection is an indispensable element for modeling of intersection. The content of traffic state can include the arriving rate of vehicle and length of queue on each road of the intersection. These indicators can be determined by the type of information acquired from detectors. Traffic state also can be divided into several levels by fuzzification. However, there are strategies of TSC for all traffic states, like the adaptive dynamic programming for the management of intersection.

III. DEMAND OF CONTROL

The aim of TSC is to make our travel more convenient and comfortable. However, convenient and comfortable are too abstract as the goal for the methods of TSC. Hence, the concretization about the demand of TSC always takes form of the improvement about some specific indicators of traffic performance. In [11], the authors grouped objectives of TSC into two categories: tactical ones and strategic ones. Tactical ones aim at ensuring good operation of the intersection to handle different traffic flow. Strategic ones are related with the demand of all the traffic participants, like pedestrians, environment and so on. And author showed a range of traffic management objectives can be expressed within the framework of optimal control theory, like the delay-related objectives and fuel-related objectives. These objectives actually are the specific indicators of traffic performance. We pay attention to the expression about demand of TSC, which reflects in two aspects: form and content. From the view of form, the demand can be classified into two basic classes: single goal, multi-goals. According to different form, we detail the demand in this section.

A. Single Goal

Single goal is one relatively simple form. The evolution about demand in this form focuses on the content of goal. With the increasing number of vehicles, how to make best use of the road capacity is no doubt to be considered firstly. Researchers try their best to enhance the efficiency of the whole transport system. The average delay of vehicles in the intersection is directly related to the length about the travel time of people. With the premise of ensuring safety, shorten the travel time is the most effective way to make personal traffic experience be more enjoyable. This indicator of performance satisfies the initial traffic demand. Hence, it is one widely used indicator in many researches [22] [23]. And it also has alias as average waiting time of vehicle [24] [25]. Besides, many other indicators of traffic performance also reflect the efficiency about the use of road capacity. Hence, they are used as the objective of TSC. For example, in [26], author tries to maximize the throughput of intersection to enhance performance of TSC. However, the indicators about the average delay of vehicle and throughput may lead to a long queue in the assistant road, especially in the period of congestion. As said in [27] [28], signal timing should aim at reducing each phase's queue length. In [29], phases of TSC are seen as players in a cooperation game. The payoff matrix of the game is composed of the queue length in each phase. The indicator about queue length is more appropriate for the period of congestion. However, the efficiency about the use of road capacity is not very outstanding in the period of normal. In [30] [31], reserve capacity is used as the control objective to optimize signal timing. The degree of saturation is also a widely used objective of TSC in [32]. At the same time, with the development of society, people not only concern the efficiency of transport system and feeling of travelers, but also try to make our transportation to be friendly to other members of society, like pedestrian and environment. In [33] [34], pedestrian-friendly is the core of paper. In [35], environment-friendly TSC also draw attention. Some of these single objectives are related, others has a certain degree of conflict. With deepening about the understanding of traffic influence on the society, the demand of people is not unitary. Hence, TSC has multi-goals attract our attention.

B. Multi-Goals

How to combine multiple control objectives in the process of traffic control is the focus of multi-goal TSC. One way is to mix several sub-goals into one overall goal. The methods of this way have weighted method, multiplication method, and intelligent method. The other way is to achieve different goals in different stages or periods of control, such as cascade mode and multi-periods method. In [36], the weighted method combines the delay time and parking number two indicators by assigning different weights. In [37], the three objectives are also using the method of weighted to merge into one objective function. What's extraordinary, the three sub-objectives has an order. However, the assignment of weight of each sub-objective has a special way, which makes the former objectives dominate the later ones. Hence, the effectiveness of this weighted method in [37] is similar to cascade mode. The mathematical expression of weighted method can be expressed as follows:

$$TotalGoal = w_1 * Goal_1 + w_2 * Goal_2 + \cdots + w_n * Goal_n \quad (1)$$

where $Goal_1, Goal_2, \cdots, Goal_n$ are sub-goals, which sometimes are normalized values. They have the same meaning in the the following formulas of this section. The sub-goals in the weighted method can be different indicators of performance, but also can be the same indicator on different objects. In [32], all the sub-goals are the queue length of different roads on the intersection. Hence, the weight of each sub-goal is determined by the priority of road.

Multiplication method is also one effective method for combination of sub-goals. In [38], author takes the number of passing vehicles multiplied by the additional vehicle delay as the reward of Q-learning. The mathematical expression is shown as follows:

$$TotalGoal = Goal_1 \times Goal_2 \times \cdots \times Goal_n \quad (2)$$

Besides, intelligent method can be used. In [39], author proposes the conception of "urgency degree", and uses fuzzy inference system to calculate the urgency degree of each phase. Then, for the goal to maintain the urgency degree of each phase at a low value, green phase is given to the phase that has the maximal urgency degree. Maintaining all the urgency degrees of each phase at low value is the overall goal. And this overall goal is composed of several detector values, such as waiting time of pedestrian and vehicle, length of queue and so on.

It is possible that multi-goals are processed respectively. In the cascade mode, people will find the solution of one sub-goal in the solution of other goals. The mathematical expression is shown as follows:

$$TotalGoal = Opt\{Goal_1(Opt\{Goal_2(\cdots Opt\{Goal_n\} \cdots)\})\} \quad (3)$$

where $Opt(\cdot)$ represents the operation of optimization. In [40], author tries to improve the traffic quality and reduce emission at the intersection. During the running of TSC, the possible solutions about improvement of traffic quality are selected out firstly. Then, the fitness of solutions will be calculated based on emission. In [41], Pareto ranking method is used for multi-goals problems. According to the priorities of sub-objectives, engineers can pick out the reasonable solution from the optimal solution set of Pareto ranking.

Besides, as mentioned in the section II, the traffic scene, especially the traffic state of intersection, is mutative. Hence, according to different traffic scene, the demand will vary. In normal traffic state, average delay of vehicle may be the choice. However, in some extreme traffic states, like the congested state and the unobstructed state, taking the minimization of traffic travel time as the target of TSC is difficult to achieve a satisfactory performance. When the traffic state is in congestion, the most important aim of TSC is to keep drivers from irritability. Too long waiting queue in any direction of the intersection will lead to the deterioration about the feeling of traveler. In [42] [43], balance of vehicle queue became the goal of TSC. On the contrary, in the unobstructed state, few cars are on the road. It is hard to improve many indicators of performance by adjustment of control mode. Hence, in [44], author can pay attention to the energy consumption and air pollution of transportation. And a high non-stop pass rate is chosen as the demand of TSC to reduce re-start phenomena of vehicles in the intersection. Hence, multi-periods method is necessary. And it can be used with the Time of Day (TOD) control technology. The mathematical form can be expressed as follows:

$$TotalGoal = \begin{cases} Goal_1 & Restriction_1 \\ Goal_2 & Restriction_2 \\ \vdots & \vdots \\ Goal_n & Restriction_n \end{cases} \quad (4)$$

where the restriction in the equation is a description about the traffic scene, which takes the corresponding sub-goal.

IV. RECOMMEND MECHANISM

According to the aforementioned survey, there is no TSC strategy that can handle all kinds of dynamic traffic environment. These strategies have their own advantages and limitations. The research about the dynamic selection of the most appropriate agents for each specific traffic state in urban traffic transportation system is necessary. In [45], we begin to explore how to construct one reasonable recommendation system for TSC agent for urban hierarchy traffic management systems. The goal of our recommendation system is to enable the dynamic selection of control agent for transportation system. As shown in Fig.2, based on our survey on TSC, our recommend system is one kind of hybrid system which consists by one content-based recommendation system and one collaborative filtering recommendation system. The mode of combination is cascade: We firstly use content-based recommendation system to get a coarse result, which always contains several feasible TSC agents. Then, this coarse result will be further processed by collaborative filtering recommendation system to get the most suitable agent has the highest score for traffic management systems. Both of the two recommendation system will be detailed in the following part of this section. And in the last part of this section, we will give an illustration about the effectiveness of traffic management system based on mobile TSC agents to show its superiority.

A. Content-based recommendation system

In this sub-system, the demand of user finds the suitable set of agents by decision tree. The demand of user will illustrate the intersection that need for a suitable TSC agent in

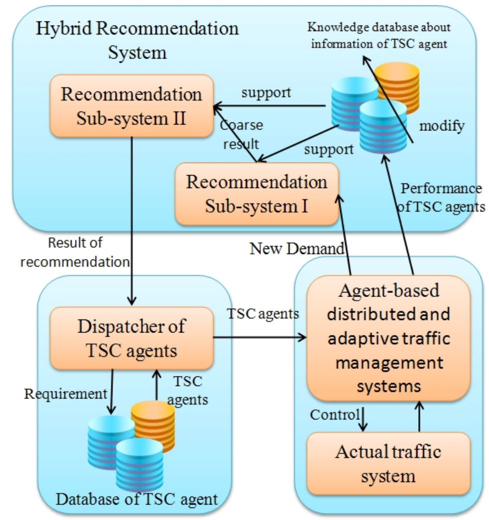

Fig. 2. Overview of the main functional elements in the recommendation system and its related system

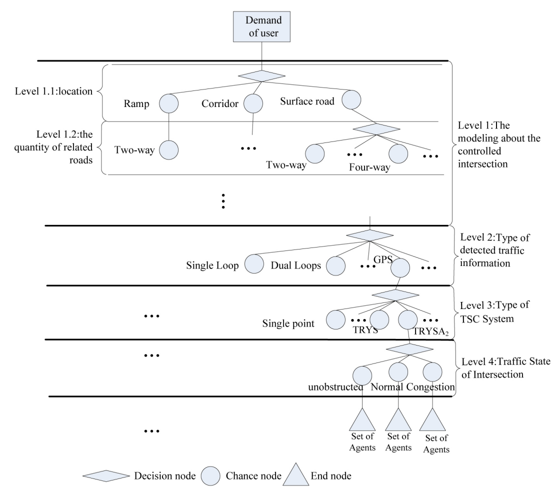

Fig. 3. Overview of the decision tree in the content-based recommendation system

detail. As the input of decision tree, it depicts the detail traffic environment of this intersection. In Fig. 3, the whole decision tree has four levels, which correspond directly to modeling about the scene under control. Meanwhile, the $level1$ has its own sub-levels to identify the model of intersection in detail. Generally, each level of decision tree has decision node and chance node to clarify the type of intersection. However, there are exceptional cases. For example, ramp must be one intersection in two-way model. There is no need to make a decision. Hence, there is no decision node on the branch of ramp in $level1.2$. Through the decision tree, the demand of user will arrive at one end node of the tree. End nodes record all feasible TSC agents for this type of intersection. In the early stage about the establishment of information database for TSC agents, some records of end node may be only one identification number of TSC agent. The worse situation is an empty set. Under this situation, the system will terminate the whole recommendation process and return result of this sub-system directly. With the enrichment of database, this sub-system will return a set of TSC agents. Hence, collaborative filtering recommendation system is indispensable to help us to find out the most appropriate TSC agent.

B. Collaborative filtering recommendation system

The second sub-system employs the user-based collaborative filtering recommendation mechanisms. According to the similarity between the target user and the reference users in record, user-based collaborative filtering recommendation system make use of the existing scores about the merchandize to estimate the preference value of target user on the merchandize. Different intersections in urban traffic system are users of our recommendation system. The merchandize of recommendation system is TSC agent. Hence, our system needs to have a certain amount of record about the evaluation of intersections on TSC agents to prevent the first-rater problem. The problem-solving approach is to make use of the platform of Artificial Transportation Systems (ATS) [46] to model several virtual intersection scenes as virtual users. These virtual users are treated as reference users. According to the understanding about the demand of traffic control in the section III, we use the combination about several indicators of performance to evaluate the preference value of different TSC for intersections, which are traveler satisfaction, environmental satisfaction and pedestrian satisfaction. The concretization about indicators is shown as follows. Traveler satisfaction is reflected by the average delay of vehicle and the maximum queue length of target intersection. Environmental satisfaction contains two indicators: the emission about CO and NO_X. Pedestrian satisfaction is dominated by the average waiting time of pedestrian. All indicators are artificially set the minimum and maximum value. When the value of sample is out of range, we handle them as the boundary value. Then, all the values of indicators are normalized to the range from zero to one. Under different reference intersection scenes, the mode of calculation about preference value is assigned by engineers. Based on sampled values about the indicators of performance, the mode of calculation can be weighted method, multiplication method, and so on, which are detailed in the section III. With one demand of user, what should be noted is that the used mode of calculation for the reference values of different TSC agents must be the same. And the preference value of different TSC agent is called as $Score_{id}$. The "id" is the identification of the TSC agent in the system. The mathematical expression of $Score_{id}$ is shown as follows:

$$Score_i = sim_{i_{max}} * Score_{i_{max}} + sim_{i_{min}} * Score_{i_{min}} \tag{5}$$

where $Score_i$ is the preference value of the TSC agent for target intersection whose identification number is i. The sim is the similarity between two users. $Score_{i_{max}}$ and $Score_{i_{min}}$ are preference value of the TSC agent for two most similar intersections to target intersection. Each single intersection in our road network has its own corresponding physical intersection model. Hence, the indicators used for the measurement about the similarity of intersections are the arriving rate of vehicle and the length of queue on each road of the intersection. Then neighborhood-based algorithm are designed to calculate the similarity between two users, produces a prediction for the user taking the weighted average of all the ratings. According to the traffic state in the target intersection, we need to find out two most similar intersection scenes: one is denoted as i_{max}, the other one is i_{min}. The values of indicators in i_{max} are larger than the ones in i. And the i_{min} is reverse. The mathematical expression of similarity is shown as follows:

$$\begin{aligned} sim_{i_{max}} &= \frac{\vec{i}\cdot\vec{i}_{max}}{\|\vec{i}\|\|\vec{i}_{max}\|}\prod_{j=1,\cdots,n}\frac{\vec{i}_j-\vec{i}_{min_j}}{\vec{i}_{max_j}-\vec{i}_{min_j}} \\ sim_{i_{min}} &= \frac{\vec{i}\cdot\vec{i}_{min}}{\|\vec{i}\|\|\vec{i}_{min}\|}\prod_{j=1,\cdots,n}\frac{\vec{i}_{max_j}-\vec{i}_j}{\vec{i}_{max_j}-\vec{i}_{min_j}} \end{aligned} \tag{6}$$

where $\vec{j}$ represents the intersection scene, which is the vector in the space of indicators. j is the identification number of the indicator for measurement about the similarity.

As shown in Fig.2, with the predicted score of the agents, the most suitable control agent is the one who has the highest score and will be recommended to the traffic management system. Meanwhile, the performance of TSC agent for the management in actual traffic system will be successively returned to recommendation system to enrich the database of reference users. In [47], we have given a certification about the superiority of traffic management system based on mobile TSC agents.

V. Discussion and Conclusion

Up to now, lots of strategies for TSC are developed. However, most of them still remain on the paper. It is a huge waste of social resources. To utilize of them, it has two steps. The first step is to solve how to put them into use. Mobile agent technology can do well. The second one is to explore the potential of these strategies and make a full use. We attempt to use recommendation system for TSC agents to realize the second step. Recommendation system for agents is one sub-system in aDAPTS. In order to propose a reasonable system, we survey the status about the research of TSC. Modeling about the traffic scene under control and demand of control is the focus of this survey. Based on the survey, we detail the cascade recommendation mechanism in our system.

References

[1] F. Webster, *Traffic signal settings*, ser. Road research technical paper. H. M. Stationery Off., 1958.

[2] Z. Liu, "A survey of intelligence methods in urban traffic signal control," *IJCSNS International Journal of Computer Science and Network Security*, vol. 7, no. 7, pp. 105–112, July 2007.

[3] D. Zhao, Y. Dai, and Z. Zhang, "Computational intelligence in urban traffic signal control: A survey," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. PP, no. 99, pp. 1 –10, 2011.

[4] F.-Y. Wang, "Agent-based control for networked traffic management systems," *Intelligent Systems, IEEE*, vol. 20, no. 5, pp. 92 – 96, sept.-oct. 2005.

[5] L. Zhao, "Freeway ramp control based on interval ttype-2 fuzzy inference system," in *Intelligent Control and Information Processing (ICICIP), 2010 International Conference on*, aug. 2010, pp. 574 –579.

[6] H. M. Zhang and S. G. Ritchie, "Freeway ramp metering using artificial neural networks," *Transportation Research Part C: Emerging Technologies*, vol. 5, no. 5, pp. 273 – 286, 1997.
[7] H. Hadj-Salem, J. Blosseville, and M. Papageorgiou, "Alinea: a local feedback control law for on-ramp metering; a real-life study," in *Road Traffic Control, 1990., Third International Conference on*, may 1990, pp. 194 –198.
[8] L. A. Yardeni, "Algorithms for traffic-signal control," *IBM Systems Journal*, vol. 4, no. 2, pp. 148 –161, 1965.
[9] J. Wei, A. Wang, and N. Du, "Study of self-organizing control of traffic signals in an urban network based on cellular automata," *Vehicular Technology, IEEE Transactions on*, vol. 54, no. 2, pp. 744 – 748, march 2005.
[10] D.-w. Chen, L.-X. Li, X.-M. Liu, X.-Y. Gong, and F.-Y. Wang, "An overview on urban freeway traffic control and its prospect," *Information and Control*, vol. 31, pp. 341–345, Aug. 2002.
[11] H. BG, "Objectives, stimulus and feedback in signal control of road traffic," *Journal of Intelligent Transportation Systems*, vol. 8, pp. 63–76, 2004.
[12] L. E. Y. Mimbela, *Summary of vehicle detection and surveillance technologies used in intelligent transportation systems*. Federal Highway Administration, Intelligent Transportation Systems Joint Program Office, 2000.
[13] W. Kraus, F. de Souza, R. Carlson, M. Papageorgiou, L. Dantas, E. Camponogara, E. Kosmatopoulos, and K. Aboudolas, "Cost effective real-time traffic signal control using the tuc strategy," *Intelligent Transportation Systems Magazine, IEEE*, vol. 2, no. 4, pp. 6 –17, winter 2010.
[14] J. Hernández, S. Ossowski, and A. García-Serrano, "On multiagent coordination architectures: A traffic management case study," in *Proceedings of the 34th Annual Hawaii International Conference on System Sciences (HICSS-34)-Volume 3 - Volume 3*, ser. HICSS '01. Washington, DC, USA: IEEE Computer Society, 2001, pp. 3036–.
[15] B. Gokulan and D. Srinivasan, "Distributed geometric fuzzy multiagent urban traffic signal control," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 11, no. 3, pp. 714 –727, sept. 2010.
[16] P. Mirchandani and F.-Y. Wang, "RHODES to intelligent transportation systems," *IEEE Intelligent Systems*, vol. 20, pp. 10–15, January 2005.
[17] X. Wang, W. Cottrell, and S. Mu, "Using k-means clustering to identify time-of-day break points for traffic signal timing plans," in *Intelligent Transportation Systems,Proceedings. IEEE*, sept. 2005, pp. 586 – 591.
[18] S. P. Y. I. Park, B. and D. Lee, "Optimization of time-of-day breakpoints for better traffic signal control," *Journal of the Transportation Research Board*, pp. 217–233, 2004.
[19] J. Lee, J. Kim, and B. Park, "A genetic algorithm-based procedure for determining optimal time-of-day break points for coordinated actuated traffic signal systems," *KSCE Journal of Civil Engineering*, vol. 15, no. 1, pp. 197–203, Jan. 2011.
[20] C. Wei, W. Dianhai, C. Yuguang, Y. Manrong, and L. Xuemin, "Research on signal control methods of traffic bottlenecks in city road network," in *Intelligent Systems, 2009. GCIS '09. WRI Global Congress on*, vol. 3, may 2009, pp. 450 –454.
[21] A. K. Rathi, "A control scheme for high traffic density sectors," *Transportation Research Part B: Methodological*, vol. 22, no. 2, pp. 81–101, 1988.
[22] W. Wu, W. Min, and X. Sai, "A traffic signal control method based on large phase using fuzzy system and ga," in *Fuzzy Systems and Knowledge Discovery, 2009. FSKD '09. Sixth International Conference on*, vol. 4, aug. 2009, pp. 530 –534.
[23] S. Barzegar, M. Davoudpour, M. Meybodi, A. Sadeghian, and M. Tirandazian, "Traffic signal control with adaptive fuzzy coloured petri net based on learning automata," in *Fuzzy Information Processing Society (NAFIPS), 2010 Annual Meeting of the North American*, july 2010, pp. 1 –8.
[24] L. Chun-Gui, W. Meng, S. Zi-Gaung, L. Fei-Ying, and Z. Zeng-Fang, "Urban traffic signal learning control using fuzzy actor-critic methods," in *Proceedings of the 5th international conference on Natural computation*, ser. ICNC'09. Piscataway, NJ, USA: IEEE Press, 2009, pp. 368–372.
[25] D. Renfrew and X.-H. Yu, "Traffic signal control with swarm intelligence," in *Natural Computation, 2009. ICNC '09. Fifth International Conference on*, vol. 3, aug. 2009, pp. 79 –83.
[26] S. Mikami and Y. Kakazu, "Self-organized control of traffic signals through genetic reinforcement learning," in *Intelligent Vehicles '93 Symposium*, jul 1993, pp. 113 –118.
[27] L. Zhang, "Speed-based two-way traffic signal timing control using ga," in *Natural Computation, Fifth International Conference on*, vol. 5, aug. 2009, pp. 408 –412.
[28] P. Balaji, X. German, and D. Srinivasan, "Urban traffic signal control using reinforcement learning agents," *Intelligent Transport Systems, IET*, vol. 4, no. 3, pp. 177 –188, september 2010.
[29] T. Linglong, Z. Xiaohua, H. Dunli, S. Yanzhang, and W. Ren, "A study of single intersection traffic signal control based on two-player cooperation game model," in *Proceedings of the 2010 WASE International Conference on Information Engineering - Volume 02*, ser. ICIE '10. Washington, DC, USA: IEEE Computer Society, 2010, pp. 322–327.
[30] G. Improta and G. E. Cantarella, "Control system design for an individual signalized junction," *Transpn Res.*, vol. 18B, pp. 147–167, 1984.
[31] M. K., "Calculation of optimum fixed-time signal programs," *Transportation and Traffic Theory*, pp. 179–198, 1987.
[32] T. (2000), "Highway capacity manual," in *Transportation Research Board, National Research Council, Washington, D.C., U.S.A. (HCM 2000)*, April 2004.
[33] H. N. McLeod, F.N. and B. Rajbhandari, "Improving traffic signal control for pedestrians," in *Proceedings of the 12th International Conference on Road Transportation Information and Control*, April 2004, pp. 268 –277.
[34] A. Shende, M. Singh, and P. Kachroo, "Optimization-based feedback control for pedestrian evacuation from an exit corridor," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 12, no. 4, pp. 1167 –1176, dec. 2011.
[35] F. I. G. R. B. W. Hallmark, Shauna L, "Assessing impacts of improved signal timing as a transportation control measure using an activity-specific modeling approach," in *Transportation Research Record No. 1738, Energy, Air Quality, and Fuels*, 2000, pp. 49 –55.
[36] Y. Qian, C. Wang, H. Wang, and Z. Wang, "The optimization design of urban traffic signal control based on three swarms cooperative-particle swarm optimization," in *Automation and Logistics, 2007 IEEE International Conference on*, aug. 2007, pp. 512 –515.
[37] P. Lertworawanich, M. Kuwahara, and M. Miska, "A new multi-objective signal optimization for oversaturated networks," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 12, no. 4, pp. 967 –976, dec. 2011.
[38] L. Yongquan and C. Xiangjun, "Study on traffic signal control based on q-learning," in *Fuzzy Systems and Knowledge Discovery, 2009. FSKD '09. Sixth International Conference on*, vol. 3, aug. 2009, pp. 581 –585.
[39] W. Wei and M.-J. Wang, "Fuzzy-moga-based traffic signal control at intersection," in *Machine Learning and Cybernetics, 2003 International Conference on*, vol. 1, nov. 2003, pp. 639 – 644 Vol.1.
[40] S. Zhou, X. Yan, and C. Wu, "Optimization model for traffic signal control with environmental objectives," in *Fourth International Conference on Natural Computation*, vol. 6, oct. 2008, pp. 530 –534.
[41] L. Conglin, W. Wu, and T. Yuejin, "Traffic variable estimation and traffic signal control based on soft computation," in *in Intelligent Transportation Systems, The 7th International IEEE Conference on*, oct. 2004, pp. 1045 – 1050.
[42] W.-H. Lin, H. K. Lo, and L. Xiao, "A quasi-dynamic robust control scheme for signalized intersections," *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, vol. 15, no. 1, pp. 223–233, Jan. 2011.
[43] H. Shimizu and H. Mashiba, "Signal control of two-way traffic arterials," in *SICE 2000. Proceedings of the 39th SICE Annual Conference. International Session Papers*, 2000, pp. 301 –306.
[44] C. Li and S. Shimamoto, "A real time traffic light control scheme for reducing vehicles co2 emissions," in *Consumer Communications and Networking Conference (CCNC), 2011 IEEE*, jan. 2011, pp. 855 –859.
[45] C. Chen, S. S. Li, B. Chen, and D. Wen, "Agent recommendation for agent-based urban-transportation systems," *Intelligent Systems, IEEE*, vol. 26, no. 6, pp. 77 –81, nov.-dec. 2011.
[46] F.-Y. Wang, "Parallel control and management for intelligent transportation systems: Concepts, architectures, and applications," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 11, no. 3, pp. 630 –638, sept. 2010.
[47] C. Chen and Z. Li, "A hierarchical networked urban traffic signal control system based on multi-agent," in *accepted, 9th IEEE International Conference on Networking, Sensing and Control*, April 2012.