An Urban Traffic Simulation System Based On Multi-agent Modeling

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Abstract: The compute simulation technology plays a key role in developing Intelligent Transportation System (ITS). The agent-oriented technology provides the advantage in modeling the system and reflecting the ITS components' interactive and self-managing behavior than the conventional simulation technologies. In this paper, a multi-agent traffic simulation system is presented and implemented in NetLogo platform. In this system, the urban traffic components including the vehicles, road sections, intersections are abstracted to agent models. Each agent has the basic abilities of obtaining knowledge, autonomy, interaction and communication. In the road agent model, the traffic flow forecasting ability is integrated to induce vehicle agents' action and help intersection agent control the traffic signal. Each intersection agent is the abstracted model of the signal controller and the traffic situation of intersection. In each intersection agent model, the signal control function is implemented by analyzing the real-time and predicted traffic flow information from the interaction with related road agents. Simulation result shows that the proposed multi-agent traffic system performs well in reflecting the evolution of dynamic traffic system's behavior. Besides, it shows the advantage in reducing the vehicles' delay time of the road network by the interaction-based signal control function of the intersection agent.

Key Words: Multi-agent system, traffic simulation, signal control, NetLogo

1 INTRODUCTION

Traffic congestion is a crucial problem affecting the quality of life in the modern urban areas. The immediately obvious solution is to enhance the capacity of urban road network by building more new roads or increasing the number of lanes in one road, but this rarely works to reduce long-term congestion. Therefore it is paid much attention to improve traffic transportation efficiency for alleviating traffic congestion in urban areas. Consequently, Intelligent Transportation System (ITS) [1, 2] emphasizing the integrated optimization in views of system, control and information science, has got comprehensive development. However, in real world, ITS designers don't have enough knowledge to evaluate the performance before the overall system is completed. The traffic simulation is assumed to be a valuable approach to help ITS designers determine the effects of suggested traffic schemes, without the need of changing the real traffic network.

The conventional simulation technology is procedure-oriented or object-oriented. The procedure-oriented simulation methods mainly pay more attention to simulate the procedure of traffic system's operation by sequential programming. But the simulation methods aren't good at modeling the traffic components. The traditional object-oriented simulation technology shows more advantage in modeling abstraction layer for the distributed transport system and organizing the structure of traffic elements, such as roads, vehicles, signal controllers. In terms of the particular model, some conventional methods such as microscopic following model for vehicles, cell transmission model are helpful to analyze microscopic traffic states and show the randomness of traffic system well. However, these conventional simulation technologies and traffic models pay little attention to the autonomy and interaction of traffic elements and show little intelligent interactions between traffic models in distributing interactive system. To research the intelligent feature of complex system, the agent-based technology is proposed in the field of artificial intelligence. In [3], the agent-based modeling methods are further used in the traffic system. It shows that the agent-based technology is helpful to analyze the effect of different light plans on average for the ITS. In [4], the agent-based technology is used in studying the effect of proactive braking on traffic flow and road throughput in the traffic system. All these work in [3, 4, 5] shows that the agent-based traffic simulation is greatly helpful to study the dynamic traffic system's behavior and show the autonomy and interaction of traffic elements better than the conventional traffic models.

In this paper, we focus on the traffic simulation system by analyzing the agent model for the traffic components, such as the road section, intersection, vehicles. In each intersection agent model, the signal control function is implemented by analyzing the real-time and predicted traffic flow information from the interaction with related road agents. Simulation results in NetLogo show that the multi-agent system performs well in dynamic traffic control adaptively and can reflect the evolution of dynamic traffic

This work is supported by Fond National Engineering and Research Center For Mountainous Highways (GSGZJ-2014-07), Scientific Research Innovation Capacity Special Funds Of China (2014EG124042).

978-1-4799-7016-2/15/$31.00

system's behavior. It also shows that the interaction-based signal control function is better to reduce the delay time of vehicles in the presented multi-agent traffic simulation system.

The outline of this paper is organized as follows. In Section 2, the related knowledge about the agent and NetLogo platform is introduced. Section 3 describes the agent models for traffic components. Section 4 shows the implemented traffic simulation system in NetLogo. Finally, Section 5 concludes the paper.

2 Agent-Based Simulation and NetLogo Platform

Agent-based simulation is a computer technique simulating a system whose main components are agents. In complex distributed traffic system, the agent can be considered as the abstracted intelligent model for one task or one system's component, owing the basis abilities of object-oriented, autonomy, reactivity, interaction and cooperation. The object-oriented feature means that the actions of agent serve its own goals. The agent's goal can be given by programming in order to make agent obey some fixed rules. Besides, the agent's goal can be changed dynamically according the given task from system during the running time. The autonomy means that the agent model can control its own behavior space and properties according to the goal and intention by itself. The ability of reactivity makes the agent obtain the environment information and adapt some related actions correspondingly. The agent can update its knowledge and improve itself by adapting to the environment. The ability of interaction and cooperation allows agent finishing some system's task by communicating and cooperating with other agents.

In the structure of one agent model, four aspects should be included: sensor for obtaining the environment information, knowledge base for expression and learning strategies, processor for handling events in the system, communicator for interaction and cooperation with other agents. In the working mechanism, an agent can be informed for the change of dynamic environment by its own sensor. Then, the agent can solve related problem for its goal or task by its own knowledge and learning strategies in the processor. Thus, the autonomous control for the agent's own behavior can be implemented by the solution of its goal. The information one agent owes can be exchanged with other related agents by the communicator to implement the common task in the complex system.

In this paper, we use agent-based simulation to model the traffic main components and develop the multi-agent traffic system in NetLogo platform. The NetLogo Software (http://ccl.northwestern.edu/netlogo/) is a proper multi-agent programmable environment for modeling complex phenomena including social, medical, etc, which runs dynamically over time. Netlogo is purely written in JAVA language and can run any operation platform that supports JAVA. In this software, modelers can give instructions to hundreds or thousands of "agents" indenpendently.

In the Netlogo platform, there are four kinds of basic agents used: patches, turtles, links and the observer. Patches are the stationary agents for modeling the environment and constitute the two dimensional grids, called "Word". Turtles are the set of agents with their own property, intention and behavior space. Links are used to make connections between turtles. The observer is a system manager which can observe everything and command any agent in the environment. Any agent model for the application system can be derived by programming from these four kinds of basic agents.

3 Multi-Agent System Model

3.1 Vehicle Agent

In the urban traffic system, the vehicles are active frequently and highly autonomous subjects in the traffic system. Therefore, the vehicles are the important components reflecting the system's dynamism and effecting the state of road network. A vehicle agent is generally modeled as the combination of the driver's characteristics and the vehicle's characteristics. The brief structure for one vehicle agent is modeled as shown in Fig.1.

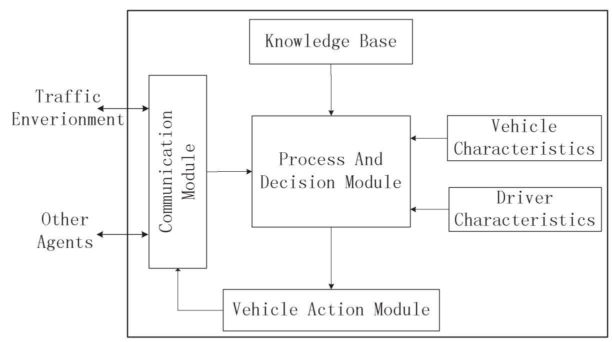

Fig.1 the structure for vehicle agent

Each vehicle agent in the structure is made up of six modules: the vehicle's characteristics, driver's characteristics, the communication module, the process and decision module, the vehicle's action module, the agent-own knowledge base module. The vehicle's characteristics module includes the basic property and static performance of one vehicle, such as the vehicle type, color, location, speed, direction, the ability of acceleration and deceleration. The driver's characteristics module reflect the driver's feature, including the driver type, intention, reaction time, the accepted speed limitation, the max acceleration or deceleration abilities. The vehicle's action module provides some ways the vehicle can adopt, such as the acceleration action, the deceleration action, turning behavior. The process and decision module helps the vehicle agent process the traffic data from the environment and make the decision what action the agent should take, such as stopping, speed up, slow down, whether or not change the direction. The communication module provide the communication way between the vehicle agent and other agents or traffic environment, such as roads, traffic light, intersection, other vehicles. On the one hand, the communication module makes the vehicle agent obtain traffic environment, such as the traffic flow in front of the vehicle, the traffic flow following the vehicle, the state of traffic light in the intersection, the road condition (snowy, icy, wet, dry), the number of cars on the road and the traffic state of road network. On the other hand, the communication module informs other agents some states about the vehicle agent, such as the location in the road network, the current speed, the turning intention.

3.2 Road Agent

In the traffic system, road agent is generally modeled to gather the real-time traffic flow information and inform vehicle agents and intersection agents the state of road's traffic state. The brief structure for the road agent is modeled as shown in Fig.2. Each road agent in the structure is made up of six parts: the road properties, the knowledge base, the sensors module, the process and state evaluation module, the information publish module, the communication module.

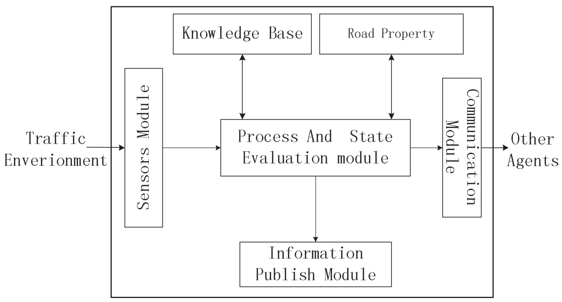

Fig.2 The structure for road agent

The road agent can record its characteristics in the road network by initializing and updating its properties, generally including the location in the network, the road length, the number of the lane in the road, the width of lane, the capacity for vehicles, the link with other roads and the traffic state of the road. The knowledge base can provide some methods and parameters for the process and state evaluation module. The sensors module can be used to gather and monitor the real-time basic traffic information from the interactive actions between road agent and vehicle agents by communication. Thus it can provide traffic basic data for the process and evaluation module, including the number of vehicles, the location of the vehicles, the vehicle speed and the state of vehicles. In the process and state evaluation module, the basic information of vehicles are processed further for evaluating the road's traffic state and forecasting the traffic flow. The module can make the road agent calculate the average speed of vehicles, the road load ratio (the ratio between the number of vehicles and the road's capacity), and provide some predicted traffic flow information for the intersection agent. Thus, the traffic state (congestion or smooth) for the road can be distinguished by combining the processed traffic information and the threshold for congestion in the knowledge. The information publish module is used to show the real-time vehicle information, the predicted traffic flow and traffic state in the road for inducing vehicles' action.

In the process and state evaluation module, the short-time traffic flow forecasting function of road agent is important for the signal control function of intersection agent, which is introducing in Section 3.3. The short-time traffic flow in the future can be forecasted based on the current and history traffic data by some prediction methods, such as the approach based on the neural network [6][7], the approach based on Markov chain model[8], the approach based on Bayesian time-series model [9]. In this paper, the double exponential smoothing approach, which is based on time series model, is applied in realizing the function for each road agent.

In the double exponential smoothing prediction process, firstly, the single exponential smoothing values for the road's traffic flow should be calculated at time t by the smoothing statistics in Eq(1). In Eq(1), $S_t^{(1)}$ is the single smoothing at time t, x_t is the number of cars at time t in the corresponding road obtained by the interaction between the road agent and vehicle agents, α is the smoothing coefficient given by the system initialization.

$$\begin{aligned} S_t^{(1)} &= \alpha x_t + (1-\alpha)S_{t-1}^{(1)} = \alpha x_t + \alpha(1-\alpha)x_{t-1} + \alpha(1-\alpha)^2 x_{t-2} + \\ &\cdots + \alpha(1-\alpha)^{t-1} + \alpha(1-\alpha)^t S_0^{(1)} \end{aligned} \tag{1}$$

The double exponential smoothing values $S_t^{(2)}$ is calculated based on the single exponential smoothing values as shown in the Eq(2).

$$S_t^{(2)} = \alpha S_t^{(1)} + (1-\alpha)S_{t-1}^{(2)} \tag{2}$$

After double exponential smoothing values at time t is calculated based on the history traffic flow data, the traffic flow can be predicted in the next signal period by Eq(3), where, $\hat{x}_{t+\tau}$ is the predicted traffic flow, τ is the prediction time interval

$$\hat{x}_{t+\tau} = S_t^{(2)} \tag{3}$$

In the signal control approach of intersection agent, the time interval is 1 and the time for updating signal parameter is chosen in the beginning of next signal period. Thus, the predicted history traffic flow from the current period can be used to determine the signal timing plan in the next period.

3.3 Intersection Agent

In the traffic system, the intersection agent is abstracted as the model of the signal controller and the traffic situation in the intersection. The intersection agent is the key to undertake the traffic control task and make assignment for the traffic jam in the road network. Particularly, the intersection agent can make a link for different road agents in the network. Besides, it can control and induce vehicles into another road section from one road via the management for the signal light.

Each intersection agent in the structure mainly includes the intersection properties, the evaluation module for the intersection's traffic state, the traffic information public module, the signal controller module, the knowledge base and the communication module. As the part of the roads, the properties of the intersection agent generally includes the type and location of intersection in road network, the intersection's size, the serial number in the intersection groups, the traffic conditions of the intersection, whether the signal lights are equipped, the ability for the signal controller, and the capacity ability for the traffic flow. In the evaluation module, the traffic flow parameters and the road's traffic state are obtained firstly by the interaction between the intersection agent and different related road agents, which is linked with the intersection. The evaluation module can make a decision whether the intersection can work normal according to the situation of the related roads. The intersection agent informs the traffic manager via the communication module if the number of roads with congestion state exceeds the threshold for defining the normal working state in the knowledge base. The traffic information public module is used to publish the real-time road information related to the intersection. Thus it can induce vehicles' action for the right path. The signal controller module is used to control the traffic lights according to the signal parameters, including the color state, the green time, the red time and the signal period in the signal lights. In this module, a particular solution is proposed and applied for the intersection agent to adjust the green ratio adaptively based on the interaction between the intersection agent and road agents.

For the signal controller module of each intersection agent, the green ratio is made up of two parts: the basic constant value for guaranteeing the basic ability of allowing vehicles pass, and the variable values determined by the real-time and predicted traffic flow information in the related roads. The intersection and green ratio components are shown in Fig.3.

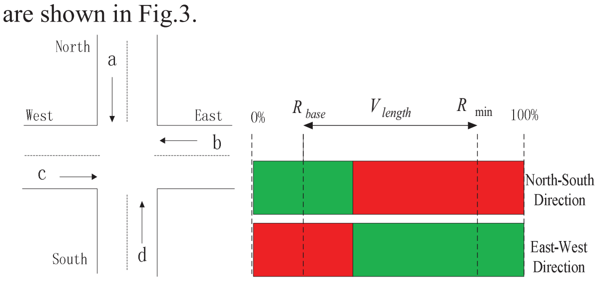

Fig.3 The intersection and the green ratio

In the Fig.3, the green ratio of signal lights in the North-South direction should be equal to the one in the East-West direction when the distribution of vehicles in different directions is balanced. Therefore, the green ratio in one direction should be changed dynamically around 50% when the balanced distribution of vehicles is broken. Thus, the maximum values $R_{\max}$ of green ratio should be restrained by Eq(4), where the R_{base} is the basic constant value, that is also the minimum value. The changeable length of the green ratio V_{length} is determined by Eq(5). The constrain condition for adjusting the green ratio is satisfied as shown in Eq(6), where, $R_{\mathrm{var}\,y}$ is the variable values of green ratio.

$$R_{\max} = 1 - R_{base} \tag{4}$$

$$V_{length} = R_{\max} - R_{base} \tag{5}$$

$$\begin{cases} 0 < R_{base} < 50\% \\ 50\% < R_{\max} < 100\% \\ 0 < R_{\mathrm{var}\,y} < V_{length} \end{cases} \tag{6}$$

In the traffic control system with double lanes, the intersection in Fig.3 is the combination of eight ramps, but the green time is effected directly by the traffic state of four entrance ramps, *a,b,c,d*. Correspondingly, the $R_{\mathrm{var}\,y}$ in the North-South direction can be determined by the traffic flow information from these four ramps. $R_{\mathrm{var}\,y}$ consists of two components in the intersection's signal controller module. One component is determined by the real-time traffic flow information as shown in Eq(7).

$$R^{(1)}_{\mathrm{var}\,y} = (R_{\max} - R_{base}) * \frac{Xa + Xd}{Xa + Xb + Xc + Xd} \tag{7}$$

Here, Xa , Xb , Xc , Xd are the real-time traffic flow at current time via the interaction between the intersection agent and the road agent *a,b,c,d*.

$$R^{(2)}_{\mathrm{var}\,y} = (R_{\max} - R_{base}) * \frac{\hat{Xa} + \hat{Xd}}{\hat{Xa} + \hat{Xb} + \hat{Xc} + \hat{Xd}} \tag{8}$$

The another component is determined by the predicted traffic flow information in Eq(8). Here, $\hat{Xa}$, $\hat{Xb}$, $\hat{Xc}$, $\hat{Xd}$ is the forecasted traffic flow of the ramp *a,b,c,d,* for the current time according to the traffic data in the last signal period. The forecasted component reflects the trend that the traffic flow changes in the different roads.

Thus, the green ratio in the North-South direction can be obtained by Eq(9). In Eq(9), W is the weight the forecasted component effects the green ratio.

$$R_g = (1 - W) * R^{(1)}_{\mathrm{var}\,y} + W * R^{(2)}_{\mathrm{var}\,y} + R_{base} \tag{9}$$

The green ratio in the East-West direction can be calculated by $R_g^{'} = 1 - R_g$. The intersection agent can control the state for the traffic lights according the green ratios and the signal period.

4 System Simulation

In this paper, the multi-agent traffic simulation system is implemented in the NetLogo platform. In this platform, the vehicle agent is generated from the basic turtle agents. The road agent and intersection agent are from the patch agents. In traffic simulation system, the interaction between turtles and patches means the relationships between vehicles and traffic environment, including roads, intersection, traffic signal controllers. The interaction between turtles shows the relationships between vehicles. The interaction between observer and any other agent means the traffic manager's control strategies for the traffic system's components. All the agents and the interactive actions form the complex dynamic traffic simulation system. The implemented multi-agent traffic simulation system is shown in Fig.4.

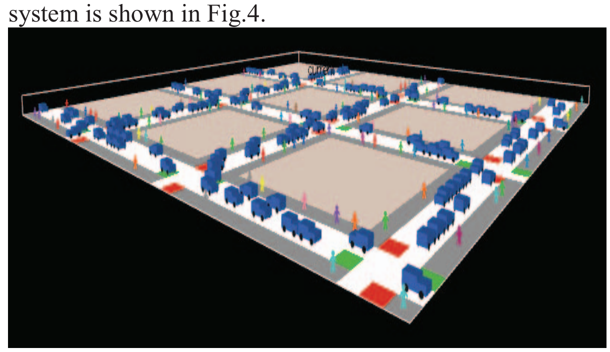

Fig.4 The multi-agent traffic simulation system in NetLogo

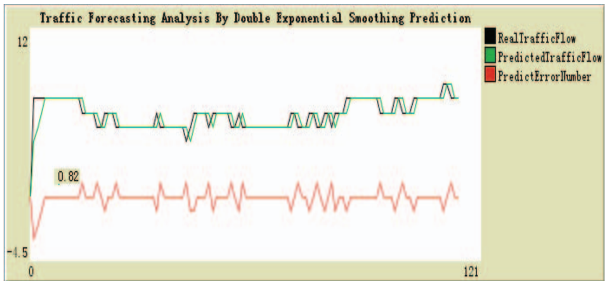

Fig.5 The traffic flow forecasting result by double exponential smoothing approach

In the traffic simulation system, the total number of vehicles in the road network is set as 160, the signal period is set as 20 seconds, the smoothing coefficient for the short-time traffic flow forecasting is set as 0.7. In these set conditions, the real traffic flow and predicted traffic flow by the forecasting approach from one road agent are shown in Fig.5. The predicted error for the number of vehicles generally changes from -1 to 1. The delay time for the synchronization between the predicted curve and the real-time cure of traffic flow changes within 2 seconds in Fig.5. It shows the forecasting result can mostly follow the change of the real-time traffic flow. Thus the forecasting result can be used to reflect the trend of traffic flow and make a contribution to the signal timing plan in the intersection.

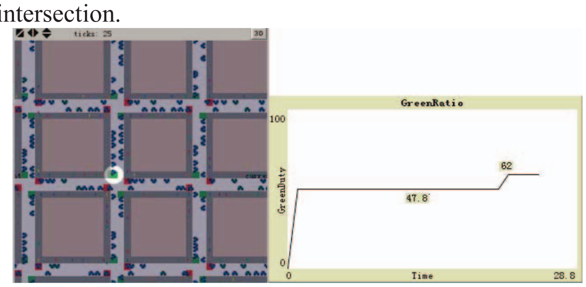

Fig.6 The traffic system and the green ratio in the observed intersection

Fig.6 shows the real-time traffic simulation system and the variation of the green ratio in the North-South direction. This figure indicates that the green ratio rises when the traffic flow increases in the North-South direction. It is helpful to the signal control adaptively for the intersection.

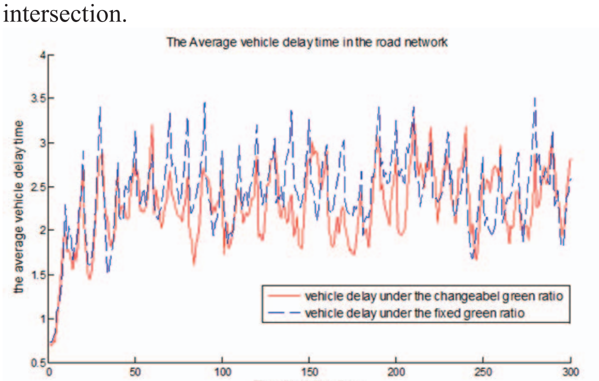

Fig.7 The comparison of average vehicle delay time under the fixed and changeable green ratio approach

To analyze the effect on the vehicles from the interaction-based dynamic signal control function of intersection agent, the experiments for comparing the average vehicles' delay time under the fixed and changeable green ratio conditions are conducted in the same road network. In each experiment, the simulation time is set as 300 seconds, the number of vehicle is 160. The green ratio is set as 50% under the fixed green ratio condition, which can't utilize the interactive information between agents. Under the other condition, the real-time and predicted traffic flow information can be used for the intersection agent to control the signal dynamicly based on the agents' interaction. The experimental result is shown in Fig.7. It shows that the average vehicle delay time under the changeable green ratio condition is smaller generally than the fixed one. In the simulation time, the total average delay time of all vehicles is 365.5040 seconds under the changeable green ratio condition, and the total average delay time under the fixed one is 388.5440 seconds. The results indicate that the interaction-based signal control function is better to reduce the delay time of vehicles in the presented multi-agent traffic simulation system.

5 Conclusion

In this paper, we presented a multi-agent traffic simulation system by the agent-based technology in Netlogo. The agent models are analyzed for the basic traffic components, such as the vehicle, the road and the intersection. The agents and the interactive actions form the complex dynamic traffic simulation system. In each road agent, the double exponential smoothing method is used to predict the short-time traffic flow and make a contribution to the signal control procedure. In each intersection agent model, the interaction-based dynamic signal control function by analyzing the real-time and predicted traffic flow information from the related road agents. The simulation part in this paper shows the dynamic multi-agent traffic simulation system. The simulation result shows that the multi-agent system performs well in controlling signal parameters adaptively and reducing the vehicle delay time by the interaction-based dynamic signal control. However, in this paper, the association for the roads from different intersection areas is not paid much attention to forecast the traffic flow for the road agent. It is the future work we should do further to improve the prediction accuracy and show better controlling performance in the multi-agent traffic system.

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