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# Multi-Agent Based Microscopic Simulation Modeling for Urban Traffic Flow

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**Abstract:** Traffic simulation plays an important role in the evaluation of traffic decisions. The movement of vehicles essentially is the operating process of drivers, in order to reproduce the urban traffic flow from the micro-aspect on computer, this paper establishes an urban traffic flow microscopic simulation system (UTFSim) based on multi-agent. The system is seen as an intelligent virtual environment system (IVES), and the four-layer structure of it is built. The road agent, vehicle agent and signal agent are modeled. The concept of driving trajectory which is divided into LDT (Lane Driving Trajectory) and VDDT (Vehicle Dynamic Driving Trajectory) is introduced. The "Link-Node" road network model is improved. The driving behaviors including free driving, following driving, lane changing, slowing down, vehicle stop, etc. are analyzed. The results of the signal control experiments utilizing the UTFSim developed in the platform of Visual Studio. NET indicates that it plays a good performance and can be used in the evaluation of traffic management and control. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Traffic simulation, Urban traffic flow, Multi-agent based system, Microscopic simulation modelling, Driving trajectory, Vehicle driving behaviors.

## 1. Introduction

The traffic system simulation is to reproduce the spatiotemporal evolution of traffic flow using the system simulation and system modeling technologies, and to investigate the traffic behavior. The traffic flow state variables changed with time and space, the relationship between the traffic flow state variables and the traffic control variables can be achieved through the traffic system simulation research. The traffic system simulation can provide technical supports for the traffic design and traffic management as well as the evaluation of the traffic influence on the environment.

According to the different levels of traffic simulation models in describing traffic systems, traffic simulation models can be divided into macroscopic, mesoscopic, and microscopic models [1]. The macroscopic simulation models investigate the relationship between velocity, density and volume by observing road network traffic flow characteristics, and describe some clustering phenomenon of traffic flow. But the description about elements, entity, behavior and their interactions in traffic system is very rough. The microscopic simulation models combine some aspects of the macroscopic models and describe the traffic various elements in great detail. In the microscopic traffic simulation, the basic unit is a single vehicle, and the vehicle microscopic behaviors such as following, overtaking and lane changing can be reproduced particularly and factually by means of computer animation. The description of mesoscopic models is between the macroscopic and microscopic models.

In recent years, the modeling and using of the microscopic traffic simulation have become more and more popular in transportation modeling [2]. An open-source microscopic traffic simulator [3] is presented which focuses on investigating fundamental issues of traffic dynamics. A microscopic simulation model (named as MITSIMLab) is developed in [4]. Burghout [5] presents a hybrid mesoscopic-microscopic model that applies microscopic simulation to areas of specific interest while simulating a large surrounding network in less detail with a mesoscopic model. Cai [6] presents the microscopic traffic simulation models by integrating the geographic information system (GIS) and microscopic traffic simulation. Chen [7] analyzes the capacity impact of weaving sections caused by exclusive bus lanes (XBLs) on urban expressways with a microscopic traffic simulation approach. A microscopic model for the study of operations at public transport stops is built in [8]. Liu [9] proposes a microscopic traffic model which is composed of a road model and a vehicle behavior model.

Traffic system is composed of people, vehicles, road and traffic environment. The traffic simulation system is a typical multi-agent-based system (MABS) [10]. Paper [11] builds a multi-agent behavioral model and designs a road traffic simulation tool able to deal realistically with road junctions. A continuous microscopic traffic simulation approach with activity-based agent behavior is introduced in [12]. Fujii [13] develops a traffic simulator named MATES based on intelligent multi-agent model and coordinative behavior model. A framework with three-level Petri net for urban traffic systems microscopic simulation based on agent is presented in [14].

In this paper, we attempt to establish a multi-agent based urban traffic flow microscopic simulation system (MAB-UTFSim). Firstly, the structure of this system including four layers is built. Then the agents in this system are modeled. We introduce the concept of driving trajectory, improve the "Link-Node" road network model, and analyze in detail the driving behaviors of drivers on the urban traffic road. Finally, we develop the UTFSim and do some experiments which reveal the good performance of this system.

## 2. Structure of the Multi-agent Based Traffic Simulation System

The structure of the traffic simulation system based on multi-agent is shown in Fig. 1.

The structure is divided into four layers:

Layer 1 is the bottom called computer environment layer, which provides the software and hardware supports for the operation of the simulation system, including the operating system, database, graphics card, etc. This layer is the carrier of the simulation system.

Layer 2 is the visual layer of simulation. The real-time running states of traffic simulation are shown in the form of 2D or 3D dynamic images. In this layer, the mapping relationship between the coordinate systems of simulation system and computer display system will be built, and the graphics and image technologies such as GDI (Graphics Device Interface), DirectX, OpenGL etc. will be used to show the running process of traffic flow simulation.

Layer 3 is the agent layer: This layer is the core of the traffic simulation system which contains all kinds of agent entities such as management agent, road agent, vehicle agent, signal agent, etc. Agents interacte with the specific communication mechanism.

Layer 4 is the human-computer interface layer. In this layer, user can customize the environment of simulation system and set the simulation parameters, the results can be provided.

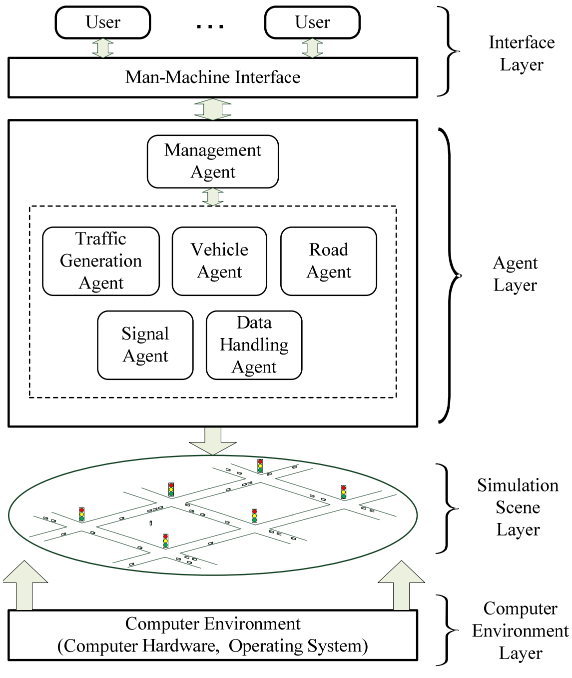


**Fig. 1.** Structure of multi-agent based traffic simulation system.

## 3. Multi-agent-based Traffic Simulation Modeling

### 3.1. Road Agent

The road is composed of nodes and links (Roads between the adjacent nodes). Node usually is a junction or intersection in the urban road. Link is composed of one or more segments which consist of several lanes. The traffic signs and markings which indicate the functions and traffic rules of each node and link attach in the road. The nodes and links as well as their traffic rules can be abstracted as the road model named classically as Node-Link model. This road model is detailed in Fig. 2.

Road agent can be composed of node agent and segment agent for the road consists of one or more nodes and segments.

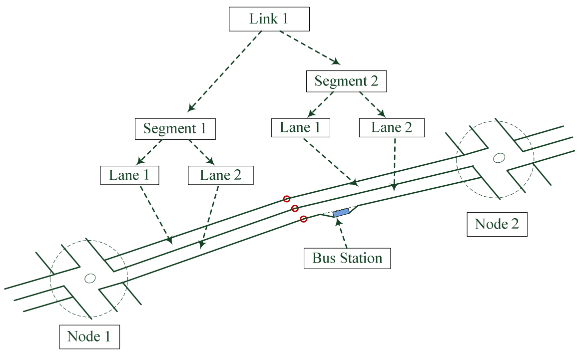


**Fig. 2.** Road model.

### 3.1.1. Driving Trajectory

In order to express the driving behavior and the constraint relationship between vehicles in the simulation road, we introduce the concept of driving trajectory (DT) which is the moving trajectory of the center projection point of the vehicle on the road. Driving trajectory can be divided into lane driving trajectory (LDT) and vehicle dynamic driving trajectory (VDDT), shown as Fig. 3.

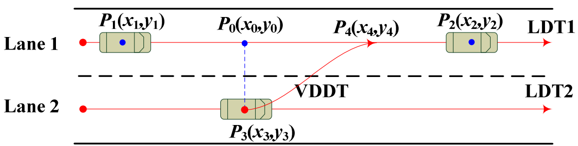


**Fig. 3.** Driving trajectory.

LDT: LDT belongs to a lane or a node and can be used to drive by the vehicles. The virtual center line of each lane is identified as LDT. The center projection point of the simulation vehicle is in the LDT. LDT is determined by the road geometry. If two lanes that belong to different node or segment are connected, the LDT of these two lanes will be end to end. Each LDT have one or more upstream LDT and downstream LDT, the end point of upstream LDT and the starting point of downstream LDT are overlapping. In Fig. 3, the LDT of Lane 1 is LDT1, and the LDT of Lane 2 is LDT2.

VDDT: The VDDT of vehicle is temporarily dynamically generated according to the driving conditions when the vehicle needs to change lane. The VDDT is a curve which joins the LDT of current lane and the LDT of neighbouring target lane. The starting point of VDDT is the vehicle's position in the LDT of current lane when vehicle starts to change lane. The end point of VDDT is in the LDT of the neighbouring target lane, and is related to vehicle speed and lane changing time.

### 3.1.2. Node

The node in the road model usually is the plane intersection which can have three-leg, four-leg or five-leg. The structure model of a typical four-leg intersection is depicted in Fig. 4.

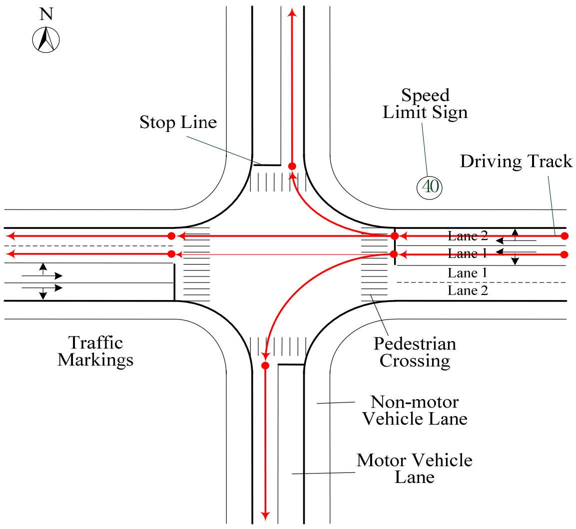


**Fig. 4.** The four-leg intersection node.

The intersection node consists of several legs and the weaving area. The leg of intersection usually is a segment from the stop line to the upstream somewhere. The vehicles come from upstream can't change lane when drive into this segment. Each lane of this segment has one LDT, as an example, the LDT of the east import lane is shown with an arrow line in Fig. 4.

The weaving area of the intersection is an area surrounded by the stop lines of all legs and the road edge. There are three traffics which come from each import lane to pass the intersection: through, left-turn and right-turn traffic. In the weaving area of the intersection, there are multiple LDT, of which the starting point is the end point of the import lane LDT on an approach to the intersection, and the end point is the starting point of the export lane LDT on another approach to the intersection.

The total number of LDT in the 4-leg intersection is as following:

$$N = N_{leg} + N_{weaving}, \quad (1)$$

$$N_{leg} = \sum_i n^i , \quad (2)$$

$$N_{weaving} = \sum_i (n^i_{through} + n^i_{left} + n^i_{right}) , \quad (3)$$

where $i$=1, 2, 3, 4, represent the four legs: east, south, west and north respectively. $N_{leg}$ is the total number of LDT of all lanes on all legs, and is equal to the total number of all import and export lanes on all legs. $N_{weaving}$ is the number of LDT in weaving area. $n^i_{through}$ is the number of lanes of through traffic. Correspondingly, $n^i_{left}$ and $n^i_{right}$ are respectively the numbers of lanes of left-turn and right-turn traffic.

### 3.1.3. Link

The link is the road between two adjacent nodes, consists of one or more segment. The segment has three types according to the segment structure: linear, curve, and linear with bus stops. The LDT of each lane on linear segment is the center line. The LDT of each lane on curve segment is also the center curve.

## 3.2. Traffic Generating Agent

The traffic on the simulation road network is generated by the traffic generating agent according to the traffic volume of each road entry. When the vehicle is generated, the parameters, such as vehicle type, geometric parameters, speed, maximum acceleration, travel route, and so on, need to be initialized. The travel route of vehicles in the simulation road network is an important parameter. If the OD trips or the destinations of each vehicle are given, the travel route can be achieved using the shortest path algorithm such as Dijkstra algorithm.

## 3.3. Vehicle Agent

The vehicle on the road is controlled by the driver, so each vehicle in the simulation system is a driver-vehicle-agent-unit (DVAU). The structure of vehicle agent is shown in Fig. 5.

Each DVAU has the following features:

1) Attributes: There are two types of attributes: static attributes and dynamic attributes. The static attributes of DVAU consist of the type, geometry, maximum speed, maximum acceleration of vehicles, and the age, driving experience, personality types (radical or steady), degree of travel emergency, reaction time of drivers, and so on. Dynamic attributes of DVAU consist of the position, speed and acceleration of vehicles.

2) Perception: The DVAU can percept the situations around such as road, other vehicles, and environment. The perception ensures the driving safety.

3) Behaviors: The behaviors of DVAU can be divided into internal behaviors and external behaviors. The internal behaviors are to adjust the changes of dynamic driving attributes which mainly include free driving, following driving, lane changing, slowing down and vehicle stop et. The external behaviors are usually the communication behaviors and interaction behaviors with other agents and the traffic environment.

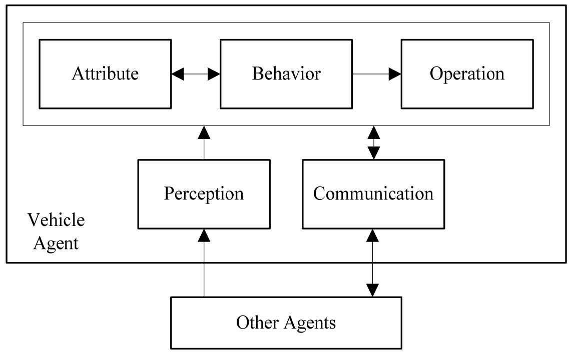


**Fig. 5.** The structure of vehicle agent.

## 3.4. Driving Behavior Model

The driving behaviors conclude free driving, following driving, lane changing, slowing down, vehicle stop, etc.

### 3.4.1. Free Driving

When the distance between the vehicle and the vehicle in front $\Delta D$ is greater than a certain threshold $\Delta D_0$, the vehicle is not affected by the vehicle in front, the free speed $V_f$ is a desired speed of drivers in free driving, and is restricted only by the structure of the road and the legal speed, influenced by the driver's driving habits and the degree of travel emergency. In the simulation system, the probability density function of $V_f$ which is a random variable is determined by the Gaussian function:

$$f(V_f) = \frac{1}{\sqrt{2\pi}\sigma} \exp(-\frac{(V_f - V_{f0})^2}{2\sigma^2}) , \quad (4)$$

where $V_f$ is the free speed of vehicle, $V_{f0}$ is the average free speed, $\sigma$ is the standard deviation.

In order to achieve the $V_f$ from Gaussian function, Eq. (4) needs to be transformed by the following equation:

$$V_f = V_{f0} + \sqrt{\sigma(-2\ln u_1)} \cos 2\pi u_2 , \quad (5)$$

where $u_1$ and $u_2$ are the independent standard uniform random number between 0 and 1 respectively.

When the speed $V$ of the vehicle is less than $V_f$, it will accelerate to the free speed $V_f$ with the acceleration $a$. Generally the acceleration is larger at low speed and is smaller at high speed that can use the following model [15]:

$$a = \begin{cases} 1.1 m/s^2, & V < 12.19\text{m/s} \\ 0.37 m/s^2, & V \geq 12.19\text{m/s} \end{cases} \tag{6}$$

### 3.4.2. Following Driving

When $\Delta D$ is less than $\Delta D_0$, the vehicle will be restricted by the vehicle in front in the case of no overtaking, the vehicle is in the following driving. The stimulus-response model is the typical representative of the following driving and is expressed as following:

$$a(t+T) = \frac{cV^m(t+T)}{\Delta D^l(t)} \Delta V(t), \tag{7}$$

where the $c$, $m$, $l$ are the constant; $T$ is the reaction time of driver; $\Delta V(t)$ is the speed difference between the leader vehicle and following vehicle at the time $t$; $\Delta D(t)$ is the distance between the leader vehicle and following vehicle at the time $t$; $V(t+T)$ is the speed of the following vehicle at the time $t+T$.

### 3.4.3. Lane Changing

Lane changing is an important behavior in vehicle driving [16]. According to the requirements of drivers, there are two types of lane changing: "Essential" and "Desirable". "Essential" is that the vehicle has to change lane to the determined target lane in a certain site. "Desirable" is that the lane changing behavior is based on the driver individual desire.

The process of lane changing is illustrated in Fig. 3. Assume $d_{ij}$ is the distance between the point $P_i$ and $P_j$, if the driving direction of LDT2 is the same as the positive direction of $X$ axis, the curvilinear equation of VDDT of vehicle 3 is as following:

$$y = \frac{d_{03}}{2} \sin\left(\frac{\pi}{d_{04}} x + x_3 + \frac{d_{04}}{2}\right) + y_3 + \frac{d_{03}}{2} \tag{8}$$

### 3.4.4. Slowing Down

Lane changing is an important behavior in vehicle.

The behavior of slowing down has three situations on non-following status: slowing down for conflict, slowing down for speed limit, and slowing down for vehicle stop.

1) Slowing down for conflict.

The conflict usually occurs in the intersection. If the two or more driving trajectories are crossed, the vehicles will conflict passing through this site. The deceleration of the vehicle before the conflict point in the driving trajectory without priority is expressed as

$$a = \frac{(v - v_{low})^2}{d_c - d_0}, \quad d_c = vT_b + d_0, \tag{9}$$

where $d_c$ is the distance to the conflict point, $d_0$ is the minimum safe stopping distance to the conflict point, $d_0 = 2m$, $T_b$ is the buffer time from the higher speed to lower, $T_b = 3.0s$, $v_{low}$ is the desired low speed in $d_0$ away from the conflict point, $v_{low} = 0s$ for the non-priority vehicles.

2) Slowing down for speed limit.

The urban road usually has the provisions of speed limit, especially on the site with bend, slope or traffic incident. If the speed $v$ of a vehicle is higher than the limit speed $v_{limit}$ of the road ahead, the vehicle needs to start slow down at the distance $d$ away from the road ahead, $d = vT_b$. The deceleration $a$ of the vehicle is described as following:

$$a = (v - v_{\lim it})^2 / d \tag{10}$$

3) Slowing down for vehicle stop.

The vehicle, which is the first one before the stop line at the signalized intersection during the red signal, or in front of which there is stop sign or queue, needs to start slow down to stop at the distance $d$ away from stop point, also, $d = vT_b$. The deceleration $a$ is described as following

$$a = v / T_b \tag{11}$$

## 3.5. Signal Agent

In the traffic signal control system, the signal of each intersection is seen as an agent named signal agent. The signal parameters, such as cycle, phase and so on, are adjusted through the perception of traffic flow at the intersection as well as the coordination and cooperation with the adjacent signal agents.

## 3.6. Communication and Coordination of Multi-Agent System

The group way is used in this traffic simulation system (shown in Fig. 6).

An agent group consists of a node agent or a segment agent, vehicle agents and signal agent in the node or segment. A group management agent is created to provide the service of communication for those agents in the agent group.

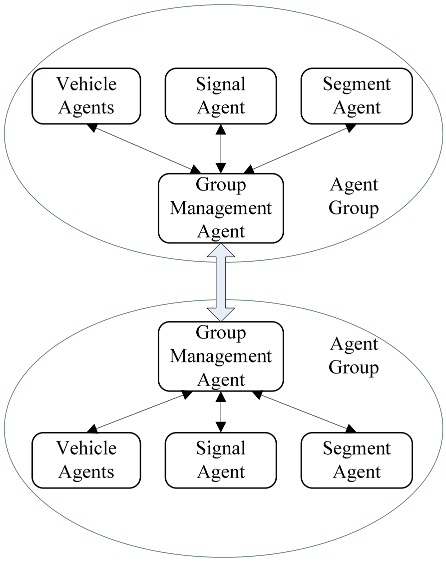


**Fig. 6.** Communication mode between agents.

## 4. Simulation Procedure

The simulation procedure (shown in Fig. 7) includes simulation parameters configuration, simulation running and analysis and output of results.

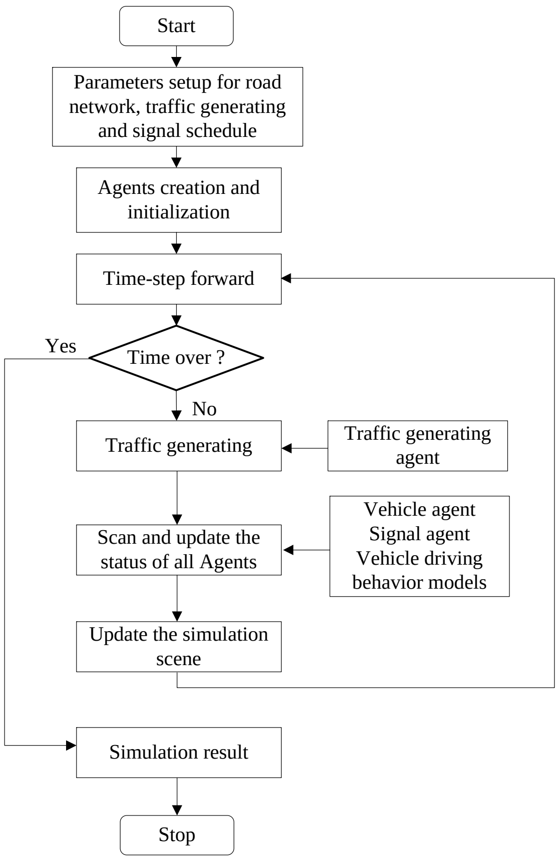


**Fig. 7**. Simulation procedure.

## 5. Experiments

The UTFSim is developed in the platform of Visual Studio. NET, a sample screen shot of UTFSim system is shown in Fig. 8.

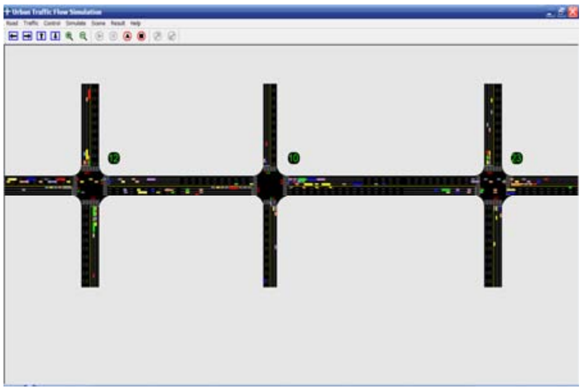

**Fig. 8.** A sample screen shot of UTFSim.

### 5.1. Signal Control Experiments of Single Intersection

The intersection for experiment is a typical four-legs signalized intersection. On each approach of this intersection, there are two through lanes, one left-turn lane and one right-turn lane, the width of each lane is 3.2 m and the length is 150 m. Lane changing which should be accomplished far away from the stop line is prohibited before the stop line of 50 m. In the signal control scheme, there are four phases, that are east west through phase, east west left-turn phase, south north through phase and south north left-turn phase.

The experiments of capacity and delay are accomplished to the intersection using the UTFSim. In the experiments of capacity, the Webster method is adopted for the signal timing, the signal cycle increases gradually from the shortest cycle. The experiments test the maximum number of vehicles passing through in various cycles, and the results are shown as Fig. 9. In the experiments of delay, the total volume of the intersection is fixed (assume 3000 *vh*/*h*, large vehicles accounted for 10 %, cars 90 %), the signal cycle increases similarly from the shortest cycle. The experiments test the mean delays of the intersection with different cycle, and the results are shown as Fig. 10.

From the simulation system, we can observe that the movement behaviors of simulation vehicles such as following, stop, accelerating and lane changing, etc., are consistent with the actual, the vehicle driving is smooth and nature. The results of capacity in Fig. 9 indicate that, in the anterior part of the curve, capacity increases more obviously with the increasing of cycle, however, in the hinder part, capacity increases very slowly. The results of delay in Fig. 10 indicate that, the delay decreases first and then increases as cycle increase, especially when the cycle is small, the delay will be very large for the capacity is less than the arrival volume. When the cycle is large, the delay increases for the long green time causes the long waiting time of the vehicles in the red phase.

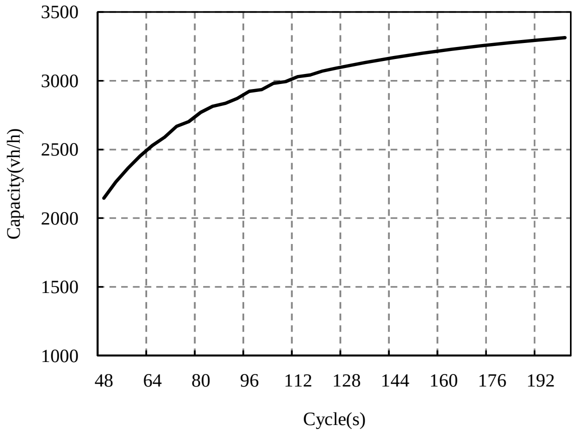


**Fig. 9.** Results of capacity.

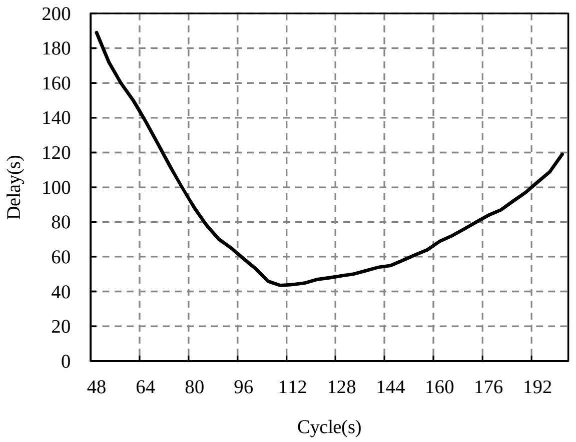


**Fig. 10.** Results of delay.

### 5.2. Signal Control Experiments of Multi Intersections

The signal control experiments of multi intersections are shown in Fig. 8. The road includes three intersections. The main road is east-west direction. In the case of three coordination control modes which are no coordination, one-way coordination and two-way coordination, the experiments are accomplished with the UTFSim. The results are shown in Table 1.

The results indicate that the mean delays of the main road with coordination control are less obviously than without coordination control, meanwhile, the mean delays of whole road decline. The two-way coordination is better than the one-way coordination in declining the mean delay of the main road.

**Table 1.** Delay in the simulation for multi intersection.

| Coordination control mode | The mean delay of the main road (s) | The mean delay of whole road (s) |
|---|---|---|
| Without coordination | 106.8 | 71.5 |
| One-way coordination | 76.3 | 62.8 |
| Two-way coordination | 66.9 | 56.7 |

## 6. Conclusions

An urban traffic flow microscopic simulation system (UTFSim) is established based on multi-agent which can describe the relationships and interactions between vehicles, vehicles and traffic facilities. The urban traffic simulation system consists of four layers: computer environment layer, visual layer, agent layer and human-computer interface layer. This paper presents an improved Node- Link road network model which the driving trajectory is introduced and divided into LDT and VDDT. The vehicle agent model is built based on the analysis of driving behaviors such as free driving, following driving, lane changing, slowing down, vehicle stop, etc. The UTFSim is developed in the platform of Visual Studio. NET. The experiments of signal control at single and multi intersections are performed using UTFSim, and achieve good performance.

## Acknowledgments

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