

Research Overview on Vehicular Ad Hoc Networks Simulation

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Abstract

The research contents of the VANET simulating involve in computer, traffic engineering, statistics, psychology, etc., presenting a multidisciplinary tendency. Started from the researching significance and contents of the VANET simulation, this paper introduced the development history and research status of VANET simulation, classified the VANET simulators, introduced and compared typical VANET simulators.

Keywords: *VANET Simulation; intelligent automotive fields; traffic stream models; car following models*

1. Introduction

Vehicular Ad Hoc Networks (VANET) has gradually become a hot research topic in wireless network and intelligent automotive fields.

VANET is a new mobile wireless ad hoc network operates on road, which supports multi-hop wireless communication between vehicles, and vehicles and roadside communication facilities. VANET owns highly application prospect and research value, which is not only capable of realizing safety forewarning and assisting driving, but supporting road traffic information searching, expressway toll payment, and voice & video communication between vehicles. VANET [1] is an extremely special mobile ad hoc network, as the vehicle is the mobile object, which differs from the traditional wireless ad hoc network. As for mobile ad hoc network, VANET has adverse factors (such as road limitation, high-speed mobile node) and favorable factors (such as rich external information, without energy limitation), thus the protocol of the traditional mobile ad hoc network cannot be applicable to VANET very well, and new protocol mechanism should be explored. The field tests of VANET generally need a large number of vehicles and personnel (drivers and computer operators) to obtain significant results. The field tests are costly, as it needs to rent or purchase vehicles and communication devices, and experimenters are to be hired as well. If the field test is conducted in high-speed conditions, the experimenters may face potential dangers, such as vehicle or pedestrian collision. In addition, it is difficult for the experimenters to accurately control and repeat one field test, which is unfavorable for debugging and improving the performance of a new protocol or application program. Therefore, conducting research by VANET simulation tool become an effective technological means.

The below discussed the development history and research status of VANET simulation, analyzed and compared the existing VANET simulators, and summarized the existing problems of VANET simulation and future development prospect.

2. The Development History of VANET Simulation

The VANET simulation includes two major kinds: one is network simulation, which refers to building statistic model of network devices and network link to simulate the transmission of network flow, so as to obtain network performance data as required by network design or optimization to test all kinds of networking protocols. Another one is vehicle and traffic simulation, which refers to building system simulation model to simulate the driving behavior and vehicle moving, so as to obtain the information of vehicle and road condition. At present, the two kinds of simulations are mature. The typical network simulators are NS-2 [2], OPNET [3], OMNet++ [4], etc. and typical traffic simulators are CORSIM, VISSIM, SOMO [5], etc. Before the emergence of VANET, the network simulator is mainly used for researching the networking protocol, and the traffic simulator is mainly used for researching traffic engineering. The two independently and parallelly developed in their individual fields. In VANET simulation, it is not suitable to independently use network simulator or traffic simulator, as network simulator provides goods testing platform for designing and evaluating the networking protocol, but it cannot provide the vehicle mobility information that required by the vehicular communication, while traffic simulator can provide accurate vehicle mobility model, but cannot provide multi-layer communication protocol that required by the vehicular communication. VANET simulation cannot directly use these two tools (the files containing vehicle mobility trace produced in the traffic simulator cannot be directly used by the network simulator) as they differ in formats and corresponding interfaces are not available. With the emergence and popularity of the VANET, the researchers found that in the VANET simulation, the network simulator and the traffic simulator are interconnected. For example, in the simulation of upper layer application, when one vehicle is detected with danger or traffic jam, the vehicle will send the warning information to the neighbor vehicles through network simulator. It is bound to change the moving trace of the related vehicles in the traffic simulator, and the changed trace will influence the network topology and route in the network simulator. Therefore, in the VANET simulation, network simulator and traffic simulator should be integrated.

2.1. Mobility Model of VANET Simulation

Vehicle mobility is an obvious feature of VANET. It is very important to select a mobility model in line with the real situation to describe the vehicle mobility mode when designing, analyzing or evaluating a VANET based system or protocol, as the mobility of the vehicle has the direct bearing on the changing of its topological structure, as well as the handling capacity, transmission delay, route effectiveness, etc. of the entire network. In the research of the VANET simulation, the selection of mobility model and its parameters is of great significance on the simulation results.

2.1.1. Classification of the Vehicle Mobility Models: According to the different details of traffic flow described, the vehicle mobility models can be classified as macroscopic, mesoscopic and microscopic. The macroscopic model takes the traffic flow as a whole, and approximately as a continuous flow. It describe traffic flow by the macroscopic parameters of the traffic, such as speed, density, flow of vehicles, and do not describe the details, such as lane change. Mesoscopic model takes the queue constituted of a number of vehicles as a unit, which is capable of describing the inflow and outflow of certain road sections and nodes of the queue, and can simply and approximately describe the lane change information of the vehicles. Microscopic model takes the traffic flow of single vehicle as the basic unit, which is

capable of relatively truly reflecting vehicle's microscopic behavior, such as car following, overtaking, lane changing, etc. In VANET simulation, Microscopic model can better truly reflect the mobility situation of single vehicle and interaction between vehicles, thus which can be used to accurately reappear the actual traffic condition on computer. There are three kinds of methods in building mobility models in VANET simulation. One is synthetic model, *i.e.* to confirm the current location of the vehicle in the process of simulation through real-time computing by means of certain specific rules or formulas according to parameters of the vehicle, such as its former location. It covers all mathematical model-based methods. Synthetic model can be further divided into stochastic models, traffic stream models, and car following models. Stochastic model means to select random path and speed to move on the route map of road topology. Traffic stream model takes vehicle mobility as a kind of hydrodynamic phenomena from a macroscopic view, and takes traffic flow as approximate continuous flow, which describes the vehicle flow according to the macroscopic parameters of the traffic, such as speed, density and flow of vehicles. Car following model means that the driver of each vehicle works out the latest location of the vehicle according to the current vehicle location, speed, etc. The major drawback of the synthetic model is that it is lack of real simulation on human behavior, as human behavior is different from the machine behavior, and cannot be realized by certain program. Another drawback is that only a small number of complex models can be close to the real mobility of the vehicle.

Another model named as traces-based model in which the vehicles truly record the traces in the simulation process. This model aims to track, measure and record the trace by means of vehicular device and the auxiliary devices at certain intervals, and save these data as trace files. Thus in the network simulation, these files can be read to reappear the mobility process of the vehicles, and synchronize the simulation nodes location and the corresponding mobility traces of the vehicle. Traces-based model can reflect the actual mobility of the vehicle to the utmost degree in network simulation, but it inherently cannot amend all parameters during simulation. Besides, available free data are rare at present. Traffic simulators-based model, refers to input the sample file of vehicle mobility produced by means of traffic simulator, while generally, traffic simulator can produce sample file of vehicle mobility by means of Synthetic model and traces-based model.

2.1.2. Development of the Mobility Models in VANET Simulation: In term of the mobility of the node in wireless network simulation, several simple random mobility models are generally used, such as random walk model, random direction model, random waypoint model, etc. The random waypoint model is used in many simulation studies of Ad Hoc networking protocol, as it can realistically describe the random node mobility in Ad Hoc network. However, in the VANET simulation, simple random mobility models, such as random waypoint model cannot realistically reflect the mobility situation, as vehicles move in fixed roads and do not make any curvilinear motion in VANET. Besides, vehicles' velocity of mobility is restricted by regulated speed, traffic condition and traffic control system. Literature [9] pointed out that the results obtained by random waypoint model in VANET are insignificant. In the early stage of VANET, the city section mobility model proposed by Davies restricted the node mobility within the road network map of mesh topological structure, in which each line is regarded as two-way and single-way section. The node moves on a certain location of the road network map, and then randomly select an intersection on the road network map as the destination, and move with constant speed. After arriving at the destination, the moving node stops for a certain period of time, and then randomly select another destination to repeat the above process. In this model, all vehicles move with the same speed, and vehicles are allowed to overlap at the intersection, and vehicles do not stop

at the intersection during moving. This model neglected the influences between vehicles. The IMPORTANT frame [11] proposed by Bai and others adopted freeway mobility model and Manhattan mobility model and added two mechanisms in freeway mobility model: one is randomly update vehicle speed, and another is defined the minimum safe distance between vehicles. Manhattan mobility model is similar to the city section mobility model in mesh-based road network map, but it is added with simple intersection steering mechanism, i.e. select the next section at every intersection by means of probability. Rice University Model (RUM) proposed by Saha [12] is based on real road topological graph. The information of road network map came from TIGER geographic information database of U.S. Census Bureau. Randomly select a vehicle node as the destination, and select route by means of shortest path algorithm, weight used to decide every section is included in the information of TIGER database, such as maximum speed of each section and existing vehicles on the section. Two kinds of vehicle mobility models for urban road were proposed by Mahajan and others [13]: The Stop Sign Model (SSM) and The Traffic Sign Model (TSM)

SSM introduces traffic control mechanism for the first time, which set stop signal at each intersection to force each vehicle to stop for a certain period of time, and the following vehicles queue up successively. TSM introduces multilane and acceleration/deceleration mechanisms, which further replaced the stop signal with traffic lights. The vehicle mobility file is available to network simulator NS2. STRAW (Street RandomWaypoint) [14] is an extension of vehicle mobility model based on network simulator SWANS. It supports to draw the urban road network map from the TIGER database. STRAW supports microscopic model and adopts car following model and traffic lights control mechanism, which is capable of simulating the management of the intersection controlled by traffic lights.

VanetMobiSim [15] and SOMO (Simulation of Urban Mobility) [7] of open source are powerful microscopic traffic simulators, which support car following model, lane changing model, routing selection, traffic light control, intersection steering, etc. and are capable of realistically simulating the vehicle moving on urban road. For example, on single-way or overtaking forbidden multi-way, following vehicles of t5 are restricted by car following behavior, and only can follow the front vehicles closely. In the lane changing model and in multi-lanes road network, vehicles can change lanes when car following behavior is influenced by vehicles on neighbor lane. The intersection steering model aims to confirm the steering situation (turn left, drive straight or turn right) in the intersection according to the relationship between the current driving direction of the vehicle and the driving direction of the next section. Output files produced by these two traffic simulators are applicable to various network simulators, such as NS2, QualNet.

3. Classification of VANET Simulators

There are many simulators used in VANET simulation and can be roughly divided in to the following four types.

First type: conduct one-way link on the traffic simulator and network simulator, as shown in Figure 1. Traffic simulator builds the mobile mode of the vehicles and store as mobile sample file. During simulation, input by network simulator, and node moves according to the mobile mode recorded in the sample file. This type is lack of interaction, and the mobile traces of vehicle are input to the network simulator in advance and then simulate. The mobile traces of the node cannot be changed during simulation, such as MOVE [16], CORSIM/QualNet [17], MITSIMLAB/NS2 [18].

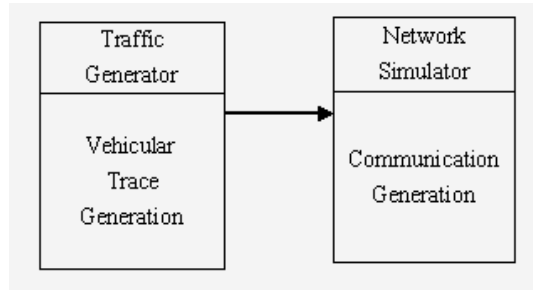


Figure 1. Non-interactive VANET Simulator

Second type: conduct two-way link on the traffic simulator and network simulator, and interact by means of the middleware, as shown in figure 2. CARISMA/NS2 [19], TraNS and Vein are all used the middleware of TraCI [20]. Traffic simulator is responsible for simulating the flow of road network and vehicles, and the network simulator is responsible for simulating the networking protocol. Real-time interaction can be realized by two-way link between them through TCP linkage. Road network topological information, etc. is exclusively possessed by the traffic simulator, while wireless link status, etc. is exclusively possessed by network simulator. Other information, such as the location and speed of the vehicles are shared by the two simulators. Different from the first type, the mobile traces of vehicles are not predefined and fixed, instead, they are real-time and changeable. During simulation, the latest location of every vehicle is send to network simulator from traffic simulator, and the information automatically update at certain internals or update according to the request send by the network simulator. In network simulator, if the vehicle received the information about other vehicles in VANET and this information will change its driving behavior (such as change the current route to avoid traffic jam or danger, or stop to avoid collision), the network simulator will immediately send a request to the traffic simulator to require the traffic simulator to make corresponding changes in vehicle location and route. The advantage of this type lies in that it realized interaction between network simulator and traffic simulator. Besides, it is able to integrate any network simulator and traffic simulator. The disadvantage of this type lies in that the two independent simulators are different in design, realization and definition (for example, the coordinated system they adopted and description on continuous vehicle mobility are different), thus transferring by means of middleware may weaken the execution performance. In addition, due to the loose coupling of these two simulators, and the possibility of operating on different computers and different operating system platforms, thus the simulating performance may be weakened due to excessive messaging (such as the messages send between the two simulators at the same simulating time).

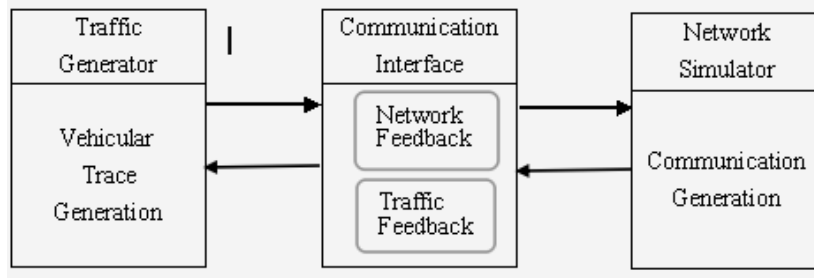


Figure 2. Interactive VANET Simulator

Third type: integrating into one simulator, which includes three methods, as shown in Figure 3. The first method is to integrate the network simulation with the existing traffic simulator. However, it is very complex to integrate the simulating function of communication mode and networking protocol with the existing traffic simulator, as there are a large number of different communication modes and networking protocols, such as standard WiMAX of IEEE 802.16 and standard WiFi of IEEE 802.11. Therefore, this method is time-consuming. We found that there is no such a simulator realized by this method so far. The second method is to add the mobility simulation function of the vehicle on the existing network simulator. It is feasible to add the functions of road network simulation and vehicle mobility model simulation on the existing network simulator, as the existing network simulator has been capable of simulating the mobility of the mobile node (such as the common random waypoint model). On this basis, it is feasible only by adding the supports of road network simulation and node mobility model better in line with the vehicle mobility. It costs less time and easier to be realized as compared with realizing various complex communication modes and networking protocols, such as NCTUns [20] and STRAW/SWANS [14]. The third method is to develop a new simulator and add all functions to it. This method will cause much time and energy, such as MOVES [20] and Gorgorin [20]. Integrating two simulators into one is capable of realizing the programming of the subsystems of network simulation and traffic simulation in one procedure, and the realization of tight coupling of the two subsystems is more conducive to timely interaction and feedback.

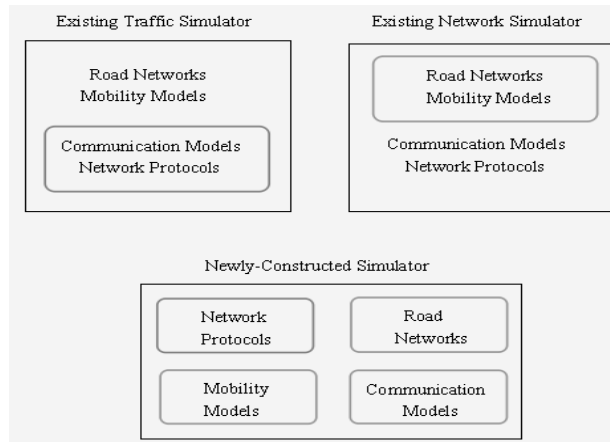


Figure 3. The Three Methods of VANET Simulator Integration

Fourth type: integrate various different simulators into one comprehensive simulation environment, and enable to provide VANET upper layer application with testing environment. It is of great significance for the application and research of Intelligent Transportation System (ITS), such as CARLINK-CMU, MSIE (MultipleSimulator Interlinking Environment), AutoMesh [20]. Some are capable of providing a hybrid testing environment mixed with real vehicle and software simulation, such as GrooveNet, VSimRIT [20]. The advantage of the hybrid simulator lies in that it is capable of providing customers with more visualized feeling and building a prototype quickly to evaluate and test the specific application by real wireless channel, link layer and characters of the network layer. In addition, hybrid simulation also provides the developers with accurate feedback and necessary details required by designing the simulation model.

4. Introduction to Typical VANET Simulators

4.1. MOVE

MOVE [16] (Mobility model generator for Vehicular networks) was developed by the University of New South Wales, Australia, which integrated traffic simulating tool SUMO with network simulating tool NS2 or Qualnet, and transform into script file that available to NS2 or Qualnet network simulators by means of mobility patterns produced by SUMO, so as to provide network simulating tool with VANET simulation environment. MOVE includes three kinds of modules: Map module, Move module and Traffic module. Map module is responsible for building and maintaining the road network map, for example, the users can set the parameters (such as the number of lanes, length of the road, and speed of the vehicle) of the road, and introduce real map database, such as TIGER to strengthen the authenticity of the simulation. In move module, the mobility parameters (such as traffic flow, turning of the vehicle) of the vehicle can be set on the existing road network map, or be randomly generated. MOVE input the above parameters into SUMO to generate the actual vehicle mobility trace, and then input into NS2 or Qualnet of the network simulator after treated by traffic module for evaluating the network efficiency. MOVE also provides a series of graphical user interfaces, by which the users can generate vivid simulation scene rapidly without understanding the specific details of the internal simulator.

4.2. TraNS

TraNS [20] (Traffic and Network Simulation Environment) was developed by Swiss Federal Institute of Technology in Lausanne for VANET simulating environment, which opened source firstly and provided a complete application-centralized VANET evaluation framework. TraNS formed a feedback loop through the interface of TraCI (Traffic Control Interface), realizing two-way link and real-time interaction between traffic simulating tool SOMO and network simulating tool NS2. TraNS provided a graphic user interface to simply and rapidly set the parameters required by simulation. TraCI [20] is the key part for TraNS in realizing interaction between traffic simulating tool and network simulating tool. TraCI adopts customer/server mode, and network simulating tool acts as the server of TraCI, and traffic simulating tool acts as the client of TraCI, thus the traffic simulator and network simulator intercommunicate through TCP/IP. Data exchanges between traffic simulator and network simulator are controlled by network simulator, during which the network simulator send a command to the traffic simulator and then the traffic simulator execute a series actions once it received the command, thus the traffic simulator is able to rapidly adjust the movements of all vehicles according to the information send by the network simulator. In order to ensure synchronization between the two simulators, the network simulator will send a command to the traffic simulator every simulation step, and this command includes the starting time of this simulation interval and one simulation step time (generally, the simulation step is set as 1 second or 0.1 second according to different applications). Traffic simulator will feed back the location of the vehicle to the network simulator before the starting of the next simulation time interval, and network simulator will transform these scattered location information into linear motion, by which the real-time mobility trace of the vehicle will be provided in the network simulator. Veins [20] (Vehicles in Network Simulation) is a VANET simulating environment developed by the University of Erlangen, which realized dynamic interaction between traffic simulating tool and network simulating tool. Veins is similar to TraNS but differs in network simulator OMNet++.

4.3. NCTUns

NCTUns [20] is a kind of simulator used for studying VANET which was developed by National Chiao Tung University. The initial NCTUns1.0 version only possesses the function of network simulation, and gradually possesses the function of traffic simulator since the NCTUns4.0 version, and the present 5.0 version has realized complete a wireless VANET defined by IEEE 802.11p . NCTUns is composed of GUI (graphical user interface), Simulation Engine, Car Agent and Signal Agent. NCTUns adopted Tunnel Network Interface, TNI and directly used the real TCP/IP protocol stack, and ensured Hi-Fi simulation result. It is able to closely integrate the traffic simulation with the existing network simulation and provide a kind of rapid feedback loop.

4.4. MoVES

MOVES [20] (Mobile Wireless Vehicular Environment Simulation) is a simulation frame with parallel and dispersed mobile wireless vehicular environment simulation, which was developed by University of Bologna. This frame is modular design-based, layered modeling and supports expandability. Vehicle model layer includes vehicle mobile model, drivers' behavior, GPS-based street map, traffic lights, intersection management strategy, etc. Wireless communication layer currently includes signal transmission model, network protocol stack, etc.

4.5. GrooveNet

GrooveNet [20] is a kind of hybrid VANET simulator developed by Carnegie Mellon University after GrooveSim. It aims to provide a hybrid testing environment mixed with real vehicle and simulated vehicle, which not only supports communication between simulated vehicles but also supports hybrid communication between real vehicle and simulated vehicle. The real vehicle is equipped with GPS, vehicular computer and wireless network interface, and uses the same protocol and data package with the simulated vehicles within its communication range to communicate. GrooveNet is composed of vehicle simulator, network simulator, network & device interface and vehicle operation controller. It adopts modular construction, has good model interface and convenient for adding new modules.

5. Comparison of Typical VANET Simulators

Every VANET simulator possesses distinctive features and has different performance in different application environments. This section compared and analyzed several VANET simulators from several key characters influencing the VANET simulation results, as shown in Table 1. Road topological graph is the key to obtaining real simulation results, as the length of the road, the number of the intersections, the number of lanes, etc. are the influencing factors of mobility characters of the vehicle. VANET simulators generally generate the road topological graph by the following means: user defined, randomly defined, and introduce the real map of the geographic information database. Table 1 presented real maps that basically can be supported by all VANET simulators. Most VANET simulators support multiple lanes. Simulation of vehicle behaviors is the key influencing factor of simulation result, which mainly include vehicle following behavior and lane changing. The car following model is the most important dynamic model in VANET simulation, which is supported by all VANET simulators. Lane changing behavior is an influencing factor of the authenticity of the simulation result as well. For example, in application simulation, if the vehicle is unable to change lane in the case of failure or obstacles, the following vehicles have

to stop. However, in the real world, drivers can change lane to avoid vehicle collisions. Besides, a lack of lane changing ability means overtaking in simulation is unallowable as well, thus VANET topological structure generated in simulation will not change during the whole simulation process, and the simulation result produced in such a simple and unreal situation is insignificant. Table 1 only presented lane changing behavior of partial VANET simulators.

Table 1. Comparison of Typical VANET Simulators

Simulator	Taxonomy	Real maps	Multi lane	Lane Changing	Radio obstacles	Visualization tool
Move ^[16]	1	Yes	Yes	No	No	Yes
CORSIM/QueNet ^[17]	1	Yes	Yes	Yes	No	No
MITSIMAB/NS2 ^[18]	1	Yes	No	No	No	Yes
TrANs ^[19]	2	Yes	No	No	No	Yes
Vein ^[20]	2	Yes	Yes	No	No	Yes
NCTUns ^[21]	2	Yes	Yes	No	No	Yes
MOVes ^[22]	3	Yes	Yes	Yes	Yes	Yes
STRAWSWANS ^[23]	3	Yes	No	No	No	Yes
Gorgon ^[24]	3	Yes	Yes	Yes	No	No
AutoMesh ^[25]	3	Yes	Yes	Yes	No	Yes
GrooveNet ^[26]	4	Yes	No	No	Yes	Yes
VSimRIT ^[27]	4	Yes	No	No	No	Yes
VSimRIT ^[28]	4	Yes	Yes	Yes	Yes	Yes

VANET is a special mobile Ad hoc network, with time-dependent nature and complex pavement environment. There are many factors influencing the wireless link quality of the VANET, such as relative movement between sending and receiving nodes, movements of surrounding nodes, surrounding obstacles of building, road signs, trees, all of which are able to block the transmission of wireless signal or reduce the power of wireless signal, and influence the stability of the data transmission. Therefore, the ability of supporting obstacle simulation is important for VASNET simulators as well. Table 1 presented that only NCTUns, CARISMA/ns2 and AutoMesh possess this ability.

The last compared character of the VANET simulator is the ability of supporting visual tools. Visual tools are some GUI programs, which is able to present the conditions of road network and vehicle mobility during simulation or after simulation. Some are able to dynamically adjust the network or dynamically present the parameters of vehicle mobility. Visual tools enable to effectively observe and control the VANET. Table 1 presented that all except STRAW/SWANS are provided with visual interfaces.

5. Conclusion

As one of the key technologies in solving intelligent traffic and transportation system, VANET has attracted attentions from many automobile manufacturers, government sectors, and academic research institutions. It is difficult to test and evaluate the protocol and application of VANET in real environment; therefore, researching by using of VANET simulating tools became an effective technological means.

With the deepening of the VANET simulation research, applying the research achievements to road traffic information searching, safety warning and assisting driving is able to relieve the traffic jam in urban area, improve the road safety and transport efficiency, and avoid traffic accident and reduce corresponding losses to the greatest extent.

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