PRECISE EVALUATION OF VEHICLE EMISSION IN URBAN TRAFFIC USING MULTI-AGENT-BASED TRAFFIC SIMULATOR MATES

*Hideki Fujii, School of Engineering, University of Tokyo,
fujii@sys.t.u-tokyo.ac.jp*

*Shinobu Yoshimura, School of Engineering, University of Tokyo,
yoshi@sys.t.u-tokyo.ac.jp*

ABSTRACT

Recently the global warming issues have been discussed all over the world. 20% of the total amount of CO_2 emitted in Japan is occupied by a transportation sector. In the sector, its 90% is occupied by road traffic. It must be reduced drastically so as to realize a low-carbon society. Various measures have been discussed, and at the same time it is strongly desired to estimate their effects quantitatively.

The amount of vehicle emission has been simply calculated through multiplying travel distance or gasoline consumption by an emission coefficient in conventional methods. But such approaches neglect the effects of the interactions among numerous cars.

We attempt to estimate precisely the amount of vehicle emission using an advanced traffic simulator. Here, the interactions among various types of cars must be considered, and car behaviors must be modeled precisely. A microscopic traffic simulator is very useful to achieve this purpose. We have been developing an advanced traffic simulator based on an intelligent multi-agent approach. We model any individual element appearing in traffic systems as an intelligent agent, and then model the whole traffic phenomena through the interaction among numerous agents on a virtual road environment. This paper describes a development of the system to evaluate vehicle emission by integrating a detailed database of exhaust gases of various types of cars into MATES. The database employed indicates the correspondence between car driving data and the amount of exhaust gases. By matching the output information of MATES to this database, the amount of momentary emission from each car can be estimated. The total amount of emission in a particular region or the emission history of a particular car is calculated from the momentary emission.

We also perform some simulations, and demonstrate the quantitative difference between our estimation system and the conventional methods.

Keywords: Traffic Simulation, Multi-agent Model, Vehicle Emission

INTRODUCTION

Road traffic is a key part of infrastructure to support mobility and transportation of human beings and goods. But at the same time, it causes various types of urban and environmental issues such as traffic jam, accident, energy consumption and CO_2 emission. To solve such traffic-related issues, various countermeasures have been taken, including improvement of car performance in gas mileage, traffic signal control, construction of new roads, development and installation of ITS (Intelligent Transport Systems) technology. It is very difficult to recover road environments as they were, once they have been changed. Therefore it is strongly desired to estimate the effects of above-mentioned countermeasures quantitatively for improving traffic environments. Simulations have been playing important roles in the field of traffic engineering, and various types of traffic simulators have been developed and utilized [JSTE 2000].

We are developing an advanced traffic simulator based on a multi-agent approach, which is named MATES (Multi-Agent based Traffic and Environment Simulator) [Yoshimura 2004, Yoshimura 2006, Fujii 2006, Yoshimura 2009, Kohashi 2010]. This paper describes the quantitative estimation of vehicle exhaust gases coming from an urban traffic using MATES.

MODELING OF TRAFFIC FLOW IN MATES

Traffic simulators are roughly classified into the following three categories. Macroscopic models based on continuum fluid dynamics, microscopic models in which each vehicle is dealt as a kind of particles, and mesoscopic models in which a group of cars is dealt as a unit. However, many of them have dealt cars as inorganic matter. Due to such inorganic modeling, they cannot express behaviors of human drivers who have different knowledge, attitude, and logic for driving. This becomes strong constraint when dealing with diversity of drivers' behaviors.

In our research, we essentially regard traffic phenomena as complex systems produced by numerous human beings who have intelligence as well as individuality. Based on such a natural concept, we construct a traffic simulator MATES. Here, we model any individual element appearing in traffic systems as an intelligent agent [Russel 1995], and then model the whole traffic phenomena through the interaction among numerous intelligent agents on a virtual road environment.

Multi-Intelligent Agent Model

While driving cars, drivers acquire various kinds of information on traffic environment such as road situation, traffic signs and signals, cars in the vicinity of them through their own senses of sight and hearing. The drivers make their own decision for driving attitudes, for example acceleration, deceleration, stop, turning right or left, passing, changing lanes and so on. In addition they utilize global information through road maps and car navigation systems. Today, various types of local as well as global information are expected to be available for drivers through the installation of ITS, and drivers will make their decision based on such integrated information. Considering real world's situation, it is essential that a car (driver) model in traffic simulators can make its own decision autonomously. It is also indispensable for advanced traffic simulators to precisely model such situation that drivers utilize various types of local as well as global traffic information for their own decision. In addition, depending on their individuality, drivers select their necessary information out of various types of traffic information they acquire and sometimes they process the information. It is strongly needed to take into account such individual character of each driver in traffic simulators.

Multi-agent approach is a well-known method to simulate complex systems. In the complex systems, a number of agents are working in an environment. Each agent acquires information from the environment, judges it autonomously referring to agent's own knowledge and preference, and acts for the environment. Such processes interact among others, and as a result, global complex and non-linear phenomena are emerged. Figure 1 illustrates a conceptual image of the intelligent agent. And Figure 2 shows an image of interaction between a car agent and an environment in MATES.

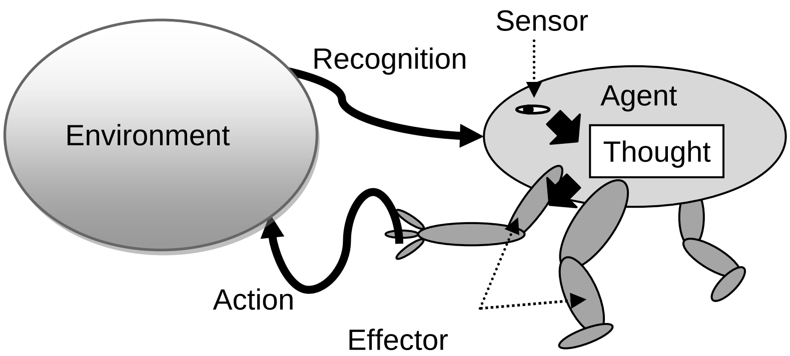

Figure 1 - Conceptual image of intelligent agent

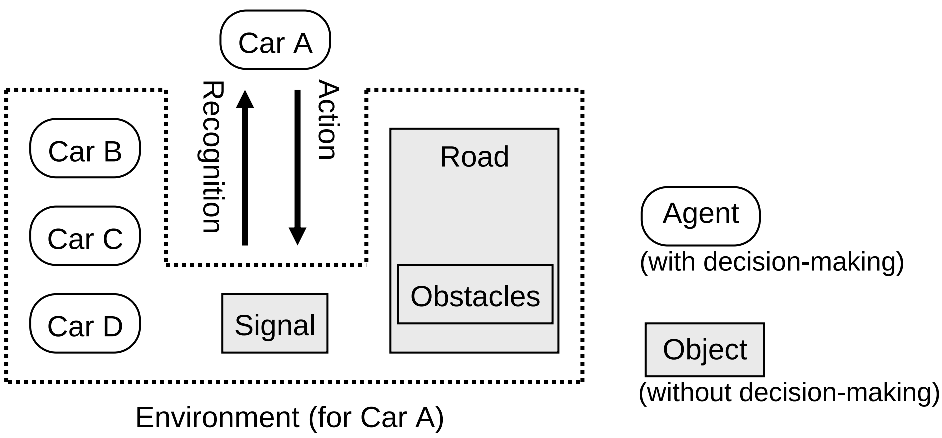

Figure 2 - Intelligent agent and environment in MATES

In the traffic simulator developed in this research, human beings are directly modeled as intelligent agents, and they interact among others. The intelligent agents are more suitable to imitate drivers highly accurately.

Intelligent Agent

In MATES, each driver is modeled as an intelligent agent. The agent can behave himself autonomously. Autonomy that the car agent needs is listed below:

Autonomy regarding global movement in road network:

- Planning (Confirmation of origin and destination)
- Global search of route in road network
- Route selection based on preference

Capability of autonomous driving on road:

- Knowledge on traffic rules and capability of driving following the rules
- Decision on driving speed
- Changing lane, merging, division
- Turning right and left at intersections, considering behaviors of confronting cars
- Deciding lane on the road

Route search and selection algorithms

Route search algorithm that should be invoked after a planning phase of driving route is implemented. It should be noted here that the present version of MATES doesn't include a planning process in which origin and destination points should be decided. Users input the origin and destination (OD) traffic volume data a priori. As the first step of the research, the route search based on A* algorithm is implemented. The utility function is defined as a weighted sum of the following multiple factors:

- Distance between starting (origin) and destination points
- Trip period from the starting point to destination one
- The number of times of going straight at intersections

- The number of times of turning right at intersections
- The number of times of turning left at intersections
- Width of road

The route that maximizes the utility function is then selected. Each car is capable of having a different utility function for route selection.

Autonomy of microscopic traffic behaviors

After determining the global route on a road network, each car drives from the starting point to the goal, following the selected route. During the driving, the car agent needs the following autonomy:

- Autonomy to follow traffic rules

The most fundamental traffic rule on a virtual road environment is that each car must drive on virtual lanes. Other traffic rules such as prohibit of passing and speed limit are attached on a road environment. We define communication protocol such that each car asks any information to the road environment.

- Autonomy to determine driving speed

MATES employs the generalized force model [Helbing 1998] to determine speed. This model is shown below:

$$\frac{dv_i(t)}{dt} = f_i^{\,0}(t) + \sum_{j \neq i} f_{ij}(t) + \xi_i(t) \ , \qquad \text{(Eq.1)}$$

where $v_i(t)$ is velocity of car agent i at time t. The first term of the right hand represents acceleration toward driver's desired velocity. The second term represents the repulsive force from interactions with other car agents. The third term is a fraction term.

The generalized force model is the model that a driver determines his/her driving speeds reflecting only the distance and velocity difference from the preceding car. But in urban traffic, speed determinants are not only the preceding car but also traffic signals, the situation of the forward intersection, and so on. Therefore we expand the model and put the virtual preceding cars reflecting the forward road conditions and apply Eq.1.

And to estimate the amount of emission correctly, we added the slope term to Eq.1, since the effect of slopes causes significant differences. The new equation to determine driving speed of car agent is below:

$$\frac{dv_i(t)}{dt} = f_i^0(t) + \sum_{j \neq i} f_{ij}(t) - \beta g(\sin\theta - \sin\theta_u) + \xi_i'(t) \quad , \qquad \text{(Eq.2)}$$

where β is the sensitivity for slope effect ($0 \leq \beta \leq 1$) and described later, θ is the road gradient that the car is on, θ_u is the road gradient that the driver has already recognized, and $\xi'_i(t)$ is the new fraction term.

And then we defined the time-dependent change of parameter β. If β is always 0, the car is not affected the slope. It means that the driver can always keep the desired speed. If β is always more than 0, the driver cannot achieve his/her desired speed. It is natural to assume that β is 1 at first and becomes 0 later. It is not until the driver recognizes the road gradient that he/she tries to recover the speed. Therefore we modeled the change of β by two processes: the recognition process and the adjustment process (see Figure 3).

In the recognition process, β is always 1. And the difference between the actual speed and the desired speed is evaluated. Here, the desired speed is calculated by excluding the slope effect. When the difference becomes more than the threshold v_d, it moves the adjustment process.

In the adjustment process, β declines to 0 linearly. The rate of change is proportional to v_d.

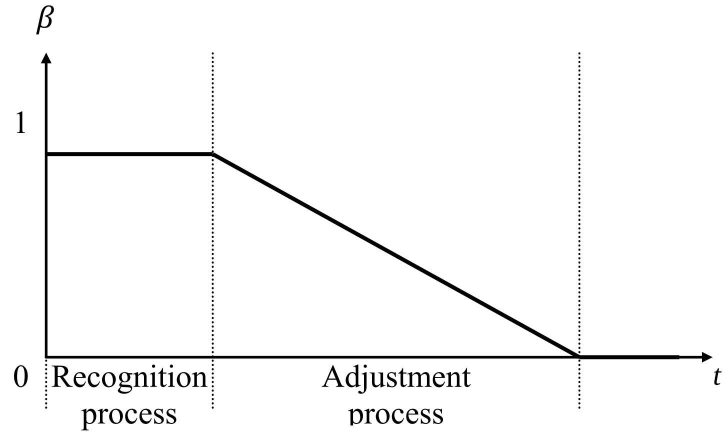

Figure - 3 Time-dependent change of parameter β

- Autonomy of deciding lane to drive

In MATES, each car agent can decide autonomously which lane it should drive on. A simple linear search algorithm is implemented for this purpose.

- Autonomy of lane change

When changing lane, the car must consider both cars in the previous lane and the next lane simultaneously. To do so, the dummy of the car agent that is going to change lane is virtually created in the next lane, and appropriate speeds are evaluated in both lanes, respectively, and finally the speed is compounded from both speeds.

Road environment

In MATES, the environment means the generalized physical as well as conceptual field surrounding agents, which includes road network and accompanied information. In the research, the three-layered road network model is invented and employed. Here virtual lane is the smallest unit to model an actual road. This is a kind of directive graph. In the modeling, we restrict the maneuver of car agent only that along the lane. Each lane has various kinds of information on length, connection with other lanes, and accompanied attributes. The environment provides such information into the agent if requested.

In order to model an actual road network, lane bundle objects are implemented. Lane bundle object consists of the following two kinds of objects: single road section and intersection. Each of them consists of virtual lanes and their connectors as shown in Figure 4. A number of lane bundle objects are organized as a global road network. Each connector is placed on either the initial point or the end point, and has two kinds of direction either inflow or outflow. Figure 5 shows hierarchical structure of the road.

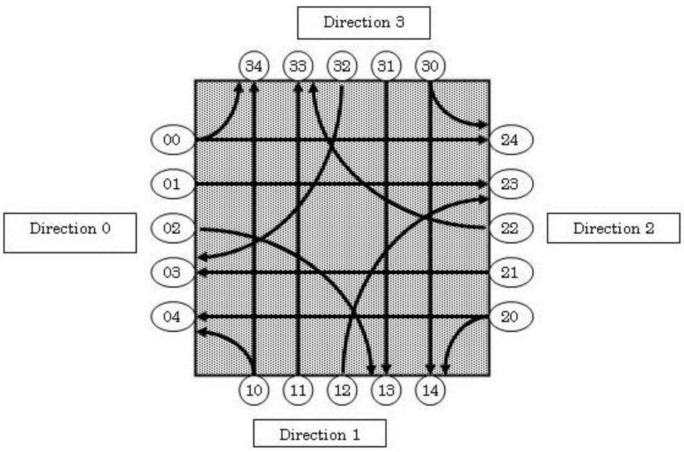

Figure 4 - Lane bundle object

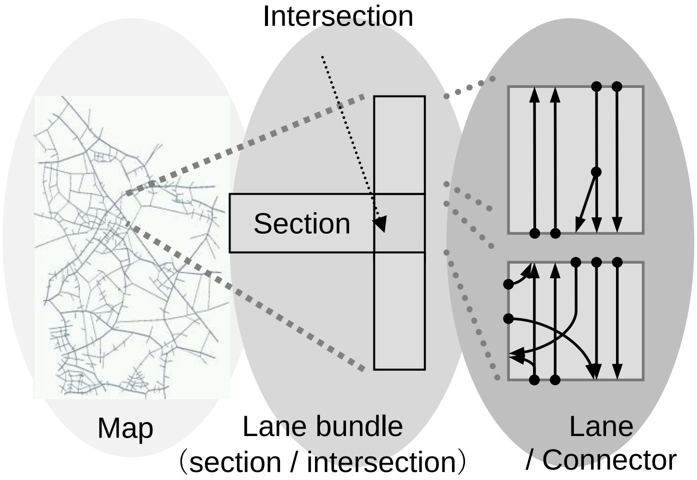

Figure 5 - Hierarchical road network

COOPERATION BETWEEN MATES AND DATABASE OF VEHICLE EMISSION

We use emission map files of JCAP2 (Japan Clean Air Project 2) in JPEC (Japan Petroleum Energy Center) as vehicle emission data. This is the database that indicates the correspondence between car driving data (speed, acceleration, vehicle family, engine type and road gradient) and the amount of exhaust gases (CO, CO_2, HC, NOx and SPM) [JPEC].

By matching of the output of MATES (speed and acceleration data of each car agent and road gradient) to above-mentioned database, the amount of momentary emission by each car can be estimated. In addition, the total amount of emission in particular region can be calculated from the momentary emission. The overview of the system is shown in Figure 6.

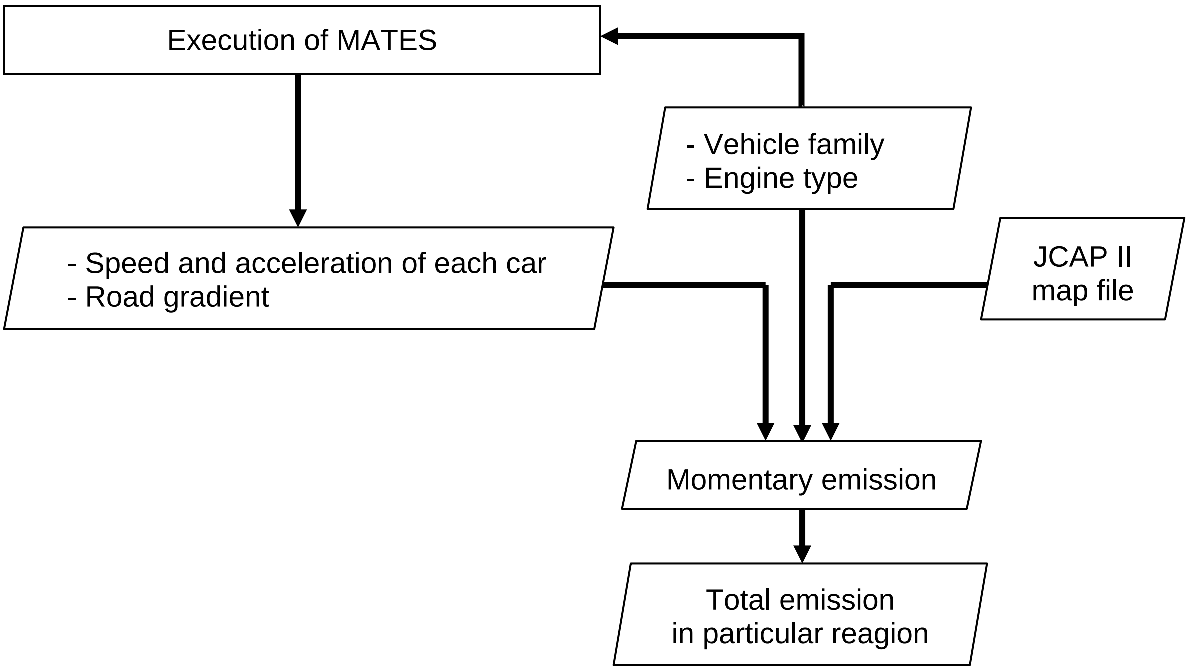

Figure 6 - Overview of estimation system

SIMULATION RESULTS

Emission at slope section

We simulated a car driving in a simple road section with slope and confirmed the changes of the amount of momentary CO_2 emission to demonstrate the adequacy of our model.

The road was 2km long, where the first half was flat, and the last half had particular gradient (0%, 1%, 2%, 4%, 8%) (see Figure 7). The speed limit was 60km/h and the threshold v_d was set to 15km/h. The result is shown in Figure 8.

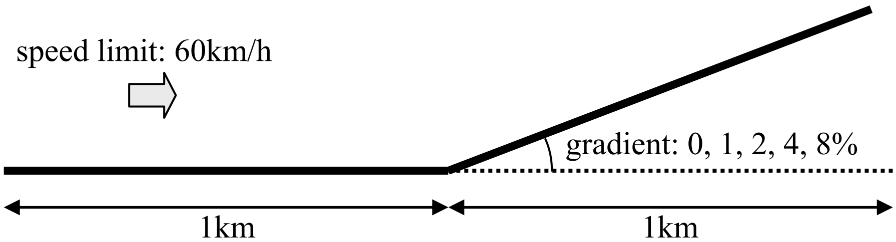

Figure 7 - Simulation condition

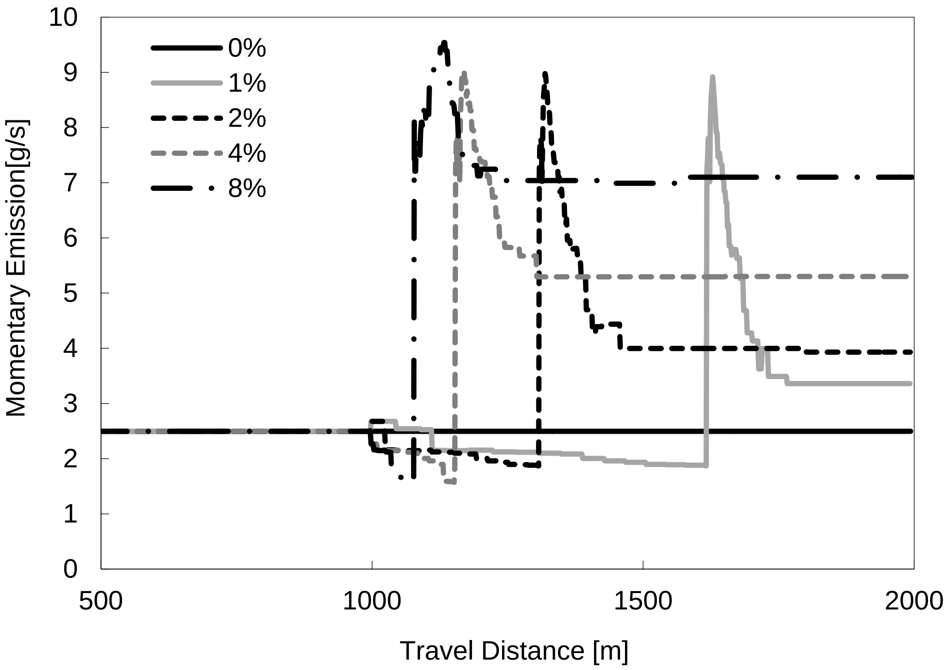

Figure 8 - Estimation of CO2 emission at slope section

Emission in traffic jams

Next we performed the simulation in a simple road section with a bottleneck and estimated the total amount of CO_2 emission in the whole section.

The road was 2km long, where speed limit of the first half was 60km/h and the last half was 30km/h (see Figure 9). The number of car agent was set to 500, 600, …, 1500 per hour. Inputting enough traffic volume to this road, traffic is jammed from around the midpoint of the section to upstream.

The result is shown in Figure 10. The line in the graph shows the estimation according to the assumption that the total amount is only proportional to the number of cars. In Japan, the coefficient value is 267.06 [g-CO_2/km/car]. It is the conventional estimation method, but sometimes it makes underestimations. In the worst case, the disparity between two methods is about 30%. It is important to consider the effect of traffic jams for the correct estimation.

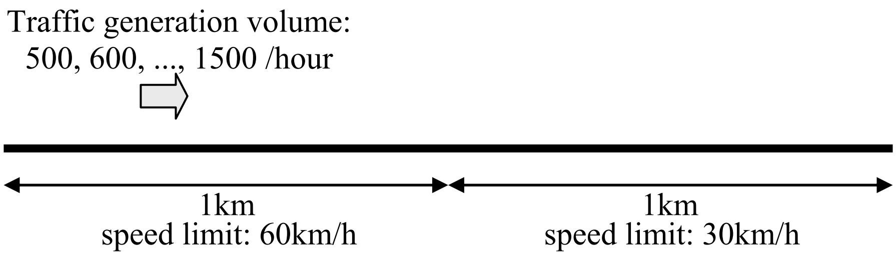

Figure 9 - Simulation Condition

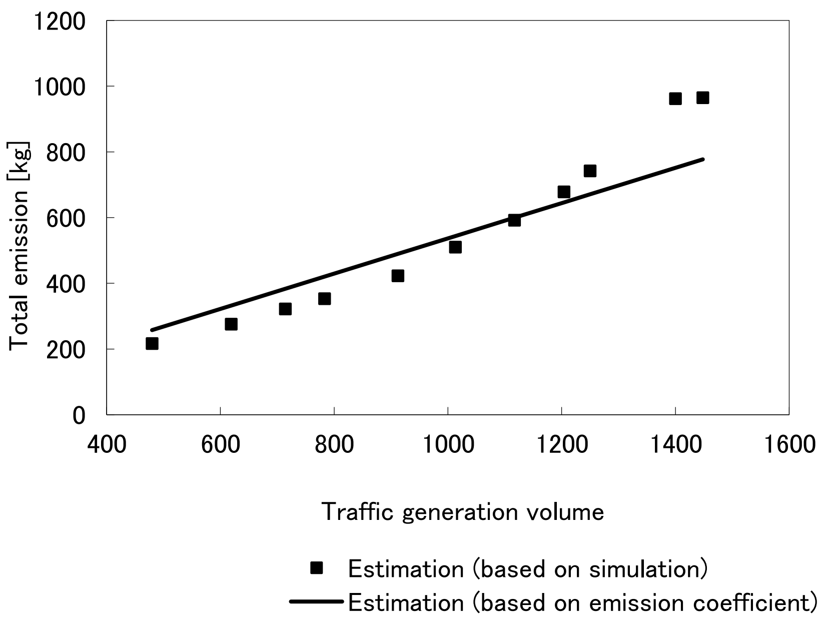

Figure 10 - Estimation of CO2 emission in a traffic jam

Emission in urban road network

We also estimated the CO_2 emission in urban road network. The road map is shown in Figure 11. It is the northwest area in Kashiwa City, Chiba Japan. It is 9.2km from east to west in width, and 7.3km from north to south in length. There are 172 nodes and 229 links in this area. 10,715 cars generated in 1-hour simulation.

The amount of CO_2 emission of each car is shown in Figure 12. In the graph, each spot represents each car. And the line in the graph is the estimation by the conventional method. In the complex network which has many intersections and signals, the amount of emission is not always proportional to the driving distance. And total amount of emission in this area is 17005.93 kg-CO_2 by our method, while 14453.59 kg-CO_2 by the conventional one. There is about 20% disparity between them.

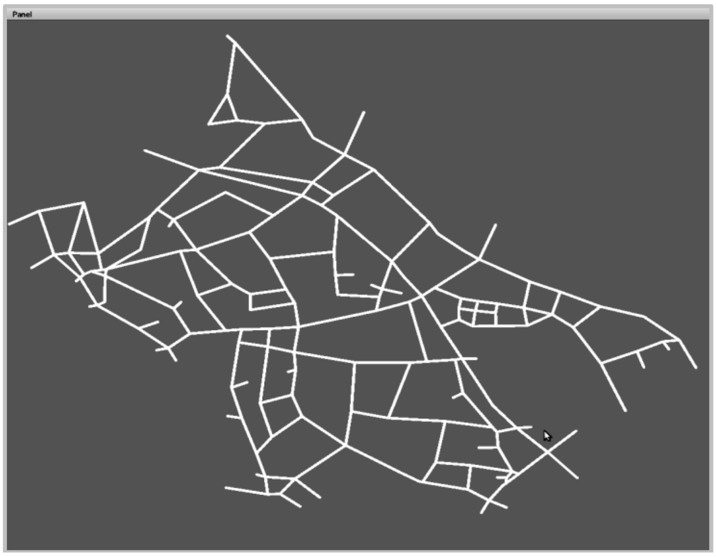

Figure 11 - Road map of the northwest area in Kashiwa City

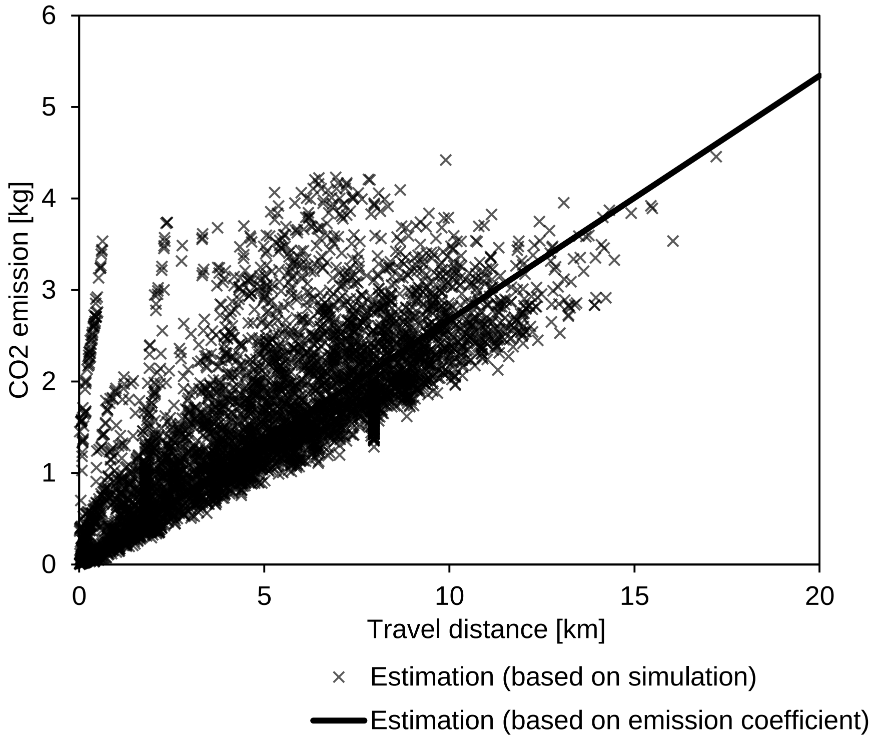

Figure 12 - Estimation of CO_2 emission in Kashiwa City

CONCLUSION

To estimate the amount of vehicle emission precisely, we construct a new estimation system which is the combination of multi-agent-based traffic simulator MATES and the detailed database of vehicle emission. In the simulator, we consider the effect of the attribute of road and interactions among numerous cars such as traffic jams.

We performed some simulations to clarify the difference of our method based on the simulation and the conventional method based on the emission coefficient. The disparity in estimation results is 20~30% in the worst case.

The Kyoto Protocol requires industrialized nations to reduce greenhouse gas emissions by 6 to 8% from 1990 levels by 2012, and we are discussing how we achieve the goal. Under these circumstances, the uncertainty of 30% is not acceptable. If we can solve the problem of difficulty of collecting realistic input data, the simulation-aided method is very useful to estimate the amount of emission gases under the actual traffic condition precisely.

ACKNOWLEDGEMENTS

We wish to thank Mr. Yoshioka, Mr. Hikita, Mr. Takahashi (TOYOTA InfoTechnology Center Co., Ltd.) and Mr. Miyoshi (Insight, Inc.).

REFERENCES

Fujii, H., Nakama, Y. and Yoshimura, S. (2006). Development of Multi-Agent Based Traffic and Environmental Simulator MATES : Second Report: Implementation of Pedestrian Agent and Comparison of Pedestrian-Car Interaction with Theoretical and Monitored Values. Simulation, Vol.25, No.4, pp.274-280. (in Japanese).

Helbing, D. and Tilch, B. (1998). Generalized Force Model of Traffic Dynamics. Physical Review E, No.58, No.2, pp.133-138.

Japan Petroleum Energy Center (JPEC). JCAP&JTOP. http://www.pecj.or.jp/english/jcap/index_e.asp

Japan Society of Traffic Engineering (JSTE) (2000). Traffic Simulations. Maruzen. (in Japanese).

Kohashi, T., Bunya, S., Fujii, H. and Yoshimura, S. (2010). Parallelization of Intelligent Multi-Agent based Traffic and Environment Simulator MATES. Transactions of JSCES, Vol. 2010, 20100003. (in Japanese).

Russel, S. J. and Norvig, P. (1995). Artificial Intelligence: A modern approach. Prentice-Hall Inc.

Yoshimura, S., Nishikawa., H. and Moriyasu, S. (2004). Development of Multi-Agent Traffic and Environmental Simulator MATES. Simulation, Vol.23, No.2, pp.228-237. (in Japanese).

Yoshimura, S. (2006). MATES : Multi-Agent based Traffic and Environment Simulator -Theory, Implementation and Practical Application-, Computer Modeling in Engineering and Sciences, Vol.11, No.1, pp.17-26.

Yoshimura, S., Seki, K. and Fujii, H. (2009). Multi-agent Based Traffic Simulation of Merging Section. Traffic Engineering, Vol.44, No.1, pp.81-90. (in Japanese).