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Multi-agent Based Traffic Simulation at Merging Section Using Coordinative Behavior Model

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Abstract: Traffic system is a typical complex system emerged through interactions among a large number of traffic actors such as car drivers, pedestrians and others. We model each actor as an intelligent agent that can judge and act by itself autonomously, and develop a traffic simulator named MATES, which is based on an intelligent multi-agent model. In this simulator, microscopic behaviors of the traffic actors cause macroscopic traffic phenomena through their interaction. In this research, we newly develop a coordinative behavior model among multiple cars, and implement it to MATES to enhance the reproducibility of traffic behaviors at merging sections. In order to verify the developed simulation model, we apply MATES to the simulation of a merging section near Kandabashi Entrance of Tokyo Metropolitan Expressway. Through the detailed comparison between the results of the simulation and the observation, we confirm practical effectiveness of the developed model.

Keywords: Traffic simulation, intelligent multi-agent model, coordinative behavior, merging section

1 Introduction

For the traffic system where a large number of traffic actors complexly interact among others, a computer simulation as alternative to an experiment plays a very important role. Traffic social experiments are very difficult from the viewpoints of constraints of cost, time and safety, while computer simulations relatively easily overcome such constraints. Recently, various types of ITS (Intelligent Transport Systems) technology have been implemented gradually, and to quantitatively evaluate the effectiveness of the technology, traffic simulators have been increasingly important.

Many traffic simulators have been developed in the past [JSTE (2000); Brackstone, and McDonald (1999); Hollander, and Liu (2008)]. We have been developing an

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innovative traffic simulator named MATES (Multi- Agent-based Traffic and Environment Simulator) since 1999 [Yoshimura, Nishikawa, and Moriyasu (2004); Yoshimura (2006); Fujii, Nakama, and Yoshimura (2006)]. Since various kinds of complex traffic phenomena can be reproduced by using MATES, it has been applied for not only traffic jam analyses but also traffic accident analyses, estimation of vehicle emission, and assessment of ITS technology.

In this research, we newly develop the model of a coordinative behavior of multiple cars, which plays a key role in real traffic, and implement the model to MATES. To verify the effectiveness of the simulator with the model, traffic behaviors at a merging section near Kandabashi Entrance of Tokyo Metropolitan Expressway on November 2nd, 2000 are precisely simulated.

2 Previous Researches on Drivers' Behaviors at Merging Section

Since a merging section is a typical bottleneck and many traffic accidents occur there, various researchers have been studies so far.

Ran analyzed the merging behaviors of cars from a viewpoint of the development of a safety support system [Ran, Leight, and Chang (1999)]. Nishikawa compared observational results with simulated ones using the algorithm to determine desired headway of each car reflecting its driving speed [Nishikawa, Sarvi, Kuwahara, and Morita (2000)]. They employed the models in which the behaviors of merging and mainline cars were instantly predicted.

Shimizu built the model in which merging and mainline cars always predicted the position of another car [Shimizu, Yai, and Mimuro (2004)]. Kita modeled the merging behavior of a car and another car in the mainline using Game theory [Kita (1999)]. The models that determine the merging behaviors in near future at the merging start are far different from actual situations such that merging behaviors with mutual concession change dynamically. In an actual situation, three or more cars are related to merging behaviors and cars may be added during the merging process.

In the present research, we employ the concept of coordination graphs to model such realistic merging behaviors of cars.

3 Overview of MATES

3.1 Intelligent Multi-Agent Model

Traffic phenomena are typical phenomena of social complex systems. A multi-agent approach is a well-known method to simulate complex systems. Cellar automata are often employed to simulate such complex systems. Several researches have been performed on cellar-automata-based traffic simulations [Knospe, Santen, Schadschneider, and Schreckenberg (2004); Jablonskyte (2010)].

On the other hand, in the traffic simulator developed by the present authors, human beings are directly modeled as intelligent agents, and they interact among others. In the complex systems, a number of agents are working in an environment. Each agent gets 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 nonlinear phenomena are emerged.

3.2 Intelligent Agent

Fig.1 shows the concept of an intelligent agent. An agent has sensors that recognize information and effectors that execute action. It decides its behavior based on the information obtained through the sensors, its own knowledge and criterion, and act for the environment through the effectors.

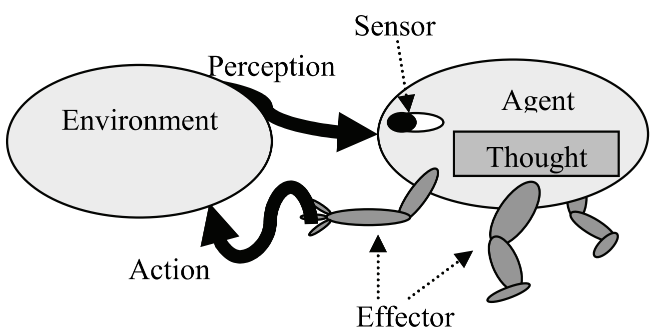

Figure 1: Intelligent agent

Fig.2 shows the interactions among an agent and its environment. The environment of car agent A consists of other cars, walkers, LRTs (Light Rail Transit), traffic lights, roads and obstacles. On the other hand, from the viewpoint of car B, car A is a part of the environment of B. Car B acts according to its environment. Complex traffic phenomena emerge as a result of interactions among traffic actors.

The car agent can behave autonomously. Autonomy is listed below:

- Route selection based on preference
- Decision on driving speed

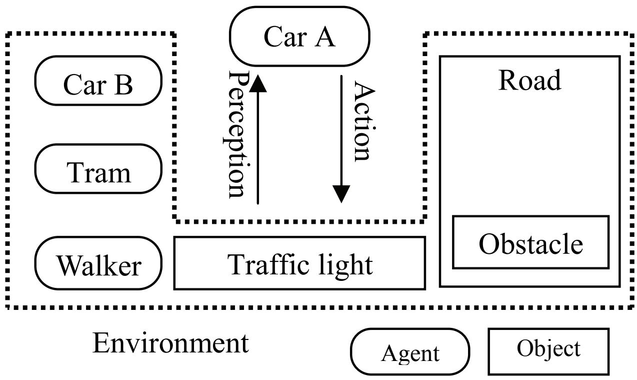

Figure 2: Agent and environment in MATES

- Changing lane, merging, division
- Turning at intersections, considering behaviors of confronting cars

We also employed the optimal velocity (OV) model [Bando, Hasebe, Nakayama, and Shibata (1995)] as a rule of decision on driving speed. In the OV model, the acceleration of a car is calculated below.

$$\frac{d^2x_n(t)}{dt^2} = \alpha \left\{ V_{opt}(\Delta x_n(t)) - \frac{dx_n(t)}{dt} \right\} \tag{1}$$

where $x_n(t)$ is the position of nth car, Δx is the distance between n th an n-1 th car, α is the sensitivity factor depending on the difference between the OV and an actual velocity. The OV function $V_{opt}(\Delta x)$ is introduced as the control information of driving behavior. In this research, we employ Eq.2 which is derived due to experiments at highway [Tadaki (2002)].

$$V_{opt}(\Delta x) = \frac{V_{\max}}{2} \left\{ \tanh \left(2 \frac{\Delta x - d}{w} \right) + c \right\} \tag{2}$$

where $V_{\max}$ is the maximum velocity, d=25.0[m], w=23.3[m], and c=0.913.

3.3 Virtual 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 was 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 each agent if requested.

In order to model an actual road network, lane bundle objects are implemented. The lane bundle object consists of the following two kinds of objects: single road section and intersection. A number of lane bundle objects are organized as a global road network.

4 Coordinative Behavior Model

4.1 Coordinative behavior

Coordination is defined as such that "mutual cooperating, especially cooperation by people having different interests or being in different positions" [Honinden, Iijima, and Ohsuga (1999); Ohuchi, Yamamoto, and Kawamura (2002)]. Being different from other living things such as animals and organs, human beings can take cooperative behaviors under artificial rules such as social rules and customs, and further can suppress their selfish behaviors for the cooperative objectives. Under a multi-agent environment, there are the two following major definitions on cooperative behaviors:

Definition 1: For common objective, multiple agents work cooperatively and result in more than the simple summation of their performances.

Definition 2: Suppressing a profit pursuing behavior of each agent, they enable to keep the common profit of their group.

The former definition indicates work distribution and conflict cancelation, while the latter one does self-interest sacrifice and accident evasion.

Under the multi-agent environment, there are some conflicts or cooperation of interests when individual agents try to achieve their own objectives. It is a significant characteristic of the complex system that microscopic behaviors of individual agents affect macroscopic behaviors of a whole system. Therefore, considering coordinative behavior in a traffic simulation is very important.

4.2 Implementation of Coordinative Behavior

A few but representative examples of coordinative behaviors among cars are listed below:

- To merge at a merging section
- To yield the course of a straight car to a turning car

- To yield the course to a lane changing car

In the above examples, common characteristics are the situation such that there are one or some cars which yield their courses and temporally suppress their desires. That means the coordinative behaviors appeared in traffic phenomena correspond to the Definition 2 mentioned above.

In order to deal with the coordinative behaviors of Definition 2 in the multi-agent-based simulation, we need to consider the following two points. First, we must make the connection between the interests of individual agents and that of the agents' group. Second, since the number of agents is huge in the traffic simulation, we should avoid taking into account the interests of all agents because of calculation load.

In this research, considering the above two points, we construct a new coordinative behavior model for traffic simulation, referring to the modified coordination graph, which is used in the simulation of RoboCup soccer [Guestrin, Venkataraman, and Koller (2002); Kok, Spaan, and Vlassis (2005)].

4.2.1 Coordination Graph

When multiple agents coordinate among others, each often interacts with a small group in its neighborhood. In the coordination graph, out of multiple agents of a small group, some agents having mutual dependence are indicated by a locally linked graph as shown in Fig.3. Then the coordinative behaviors of the linked agents are considered, and their interests are to be maximized.

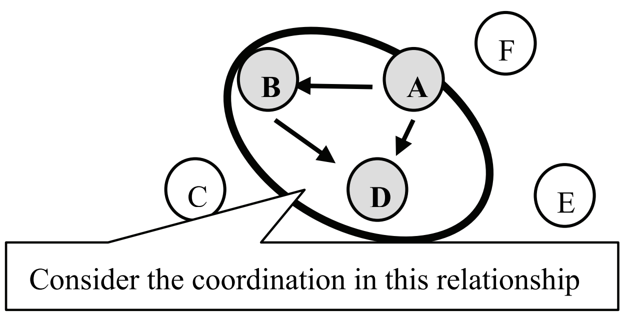

Figure 3: Concept of coordination graph

4.2.2 Implementation

The concrete implementation of the coordination graph to MATES is described in this section. In this research, we focus on the coordinative behavior at a merging section.

Step 1: Occurrence of situation such that coordinative behavior is needed

When a car agent turns blinker on for lane-change or enters a merging section, coordination is started.

Step 2: Setting up of coordination area and roles of coordinated agents

Multiple agents which should take coordinative behaviors are picked up and their relative positions are judged and distinguished. In the case of merging situation, there are the merging car and its neighbor cars. The neighbor cars include the car driving behind the merging car, the cars driving ahead and behind in the next lane. Those cars have different roles in the coordinative behaviors.

Step 3: Defining situations of agents

The position and velocity of the merging car are obtained and relative distances and velocities of its neighbor cars are also obtained. Such information is possessed by the merging car.

Step 4: Selection of area of coordinate graph and classification of the situation

Since coordinative behaviors may change depending on the positional relationship among agents, classified situations of coordinative behaviors are defined, and the coordination graph is created. Coordination situation is identified as in Table 1. The car number and distance d_n are defined as in Fig.4. Here any cars which are more than 15m away are removed from the coordination graph.

Table 1: Definition of coordination situation

No.	Car 1	Car 2	Car 3
1	$d_1 \geq 15$	$d_2 \geq 15$	–
2	$d_1 \geq 15$	$d_2 < 15$	$d_3 \geq 15$
3	$d_1 \geq 15$	$d_2 < 15$	$d_3 < 15$
4	$d_1 < 15$	$d_2 \geq 15$	–
5	$d_1 < 15$	$d_2 < 15$	$d_3 \geq 15$
6	$d_1 < 15$	$d_2 < 15$	$d_3 < 15$
unit: [m]			

Step 5: Determination of agents' behaviors

The candidate behaviors of each agent are either acceleration, deceleration, lane-changing, or normal car-following. Depending on relative distance and velocity, the behavior of each car is determined.

Step 6: Definition of utility function of each coordinative behavior

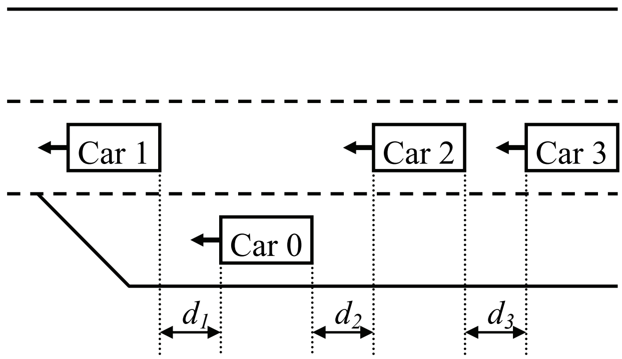

Figure 4: Definition of car number and variables

For each coordinative behavior which is determined depending on the situation of each agent such as relative distances and velocities, a utility function is defined.

As examples, the utility function in Situation No.3 in Table1 is shown in Table 2. In the table, *Car 0*, *Car 2*, *Car 3* are the same as in Fig.4, and $\Delta x_{i,j}$£¬$\Delta v_{i,j}$ represent relative distance [m] and relative velocity [km/h] between car i and car j, respectively. X and V are weights of distance and velocity. In this paper, they are set to 1[/m], 1[/(km/h)]. According to Table 2, *Car 0* starts merging when the distance between *Car 0* and *Car 2* is sufficiently large. Otherwise, *Car 0* accelerates in order to enlarge the distance between *Car 0* and *Car 2*, if the velocity of *Car 0* is relatively larger than that of *Car 2*. If the distance is not sufficient and the velocity of *Car 2* is relatively larger, *Car 0* decelerates and tries to merge in between *Car 2* and *Car 3*.

Step 7: Selection of the coordinative behavior with maximum utility function

At Step 6, the utility functions of coordinative behaviors of agents' group are compared among others, and the coordinative behavior pattern with the maximum utility function value is selected, and then each agent behaves following the selected pattern. When two cars try to merge simultaneously, it is allowed that one car can belong to multiple coordinative graphs. In such a case, all the utility functions belonging to the multiple coordinative graphs can be considered.

Steps from 2 to 6 are executed in order in every simulation step. Owing to this process, one can change coordination area dynamically.

4.2.3 Merits of Coordination Graph

The Merits of using the coordination graph for multi-agent simulation can be summarized as follows:

Table 2: Examples of utility function (in Situation 3)

Car 0	Car 2	Car 3	Utility function
Merge	Decelerate	Follow	$X\Delta x_{0,2}$
Decelerate	KeepSpeed	Decelerate	-5+$V\Delta v_{0,2} - X\Delta x_{0,2} + X\Delta x_{2,3}$
	Accelerate	Accelerate	15+$V\Delta v_{0,2} - X\Delta x_{0,2} - X\Delta x_{2,3}$
Accelerate	Decelerate	Follow	$-V\Delta v_{0,2}$

Merit 1: Saving calculating time by focusing on local coordination

By limiting the area of coordination, only a limited number of agents take coordinative behaviors. This results in limiting calculation time. In addition, depending on the condition of the agent of origin of the coordinative graph, one can create various types of coordinative graphs.

Merit 2: Easy to add new behaviors or new utility functions

In the coordinative graph model, one can determine kinds of behaviors and utility functions in a local area where coordinative behaviors occur. Therefore the addition or deletion of those rules within a certain graph does not affect other normal agents outside the graph. This results in flexibility of implementation.

Merit 3: Optimization of coordinative behaviors in local area

There is another method to realize coordinative behaviors, i.e. assigning different utility for each agent which takes coordinative behavior. This method causes the order of agent's behavior, and the behavior of the first executed agent takes the first priority. For example, when the merging car takes an action of "merging", the cars in the neighbor lane drive following the behavior of the merging car. On the contrary, in the coordinative graph approach, all the agents that take coordinative behavior behave themselves simultaneously so as to maximize the utility function of the coordinative behavior pattern. In other words, the coordinative graph approach gives equal opportunity for behavior selection.

Merit 4: Dynamically changing coordination area and judgment depending on environment change

In some models, the behaviors of cars in merging situation are determined by an instant judgment. On the other hand, in the coordinative graph model, the iterative process allows modification of behaviors for situation change. For example, when the number of agents taking coordinative behaviors increases, the area of coordination is enlarged to cover all the agents.

Because of the above-mentioned merits, the method using the coordination graph is effective to the multi-agent simulation, especially the traffic simulation in which numerous agents exist and it is difficult to make the connection between the interests of individual agents and that of a whole group. In the RoboCup simulation, the number of choices of behaviors is so large that the behavior patterns need to be limited whenever coordinative behavior is required. In the traffic simulation, however we determine utility functions of all possible behavior patterns because the number of behavior patterns is small.

5 Model Verification

5.1 Target Area and Input Data

Through the simulation of a merging section of highway, we validate our simulation method. The target area for simulation is the merging section near Kandabashi Entrance of Tokyo Metropolitan Expressway. We compare the simulation result with the observational result on November 2nd, 2000 [JSTE (2006)]. Dimensions of the road structure are given in Table 3, and the road map for the simulation is shown in Fig.5.

From the report of Japan Society for Traffic Engineering [JSTE (2006)], we can obtain the data of traffic volume of each lane in every 5 minutes and that of mean velocity of each lane in every 5 minutes. Those data were actually monitored with vehicle detectors set at both upstream and downstream points near the merging section. The present simulation by MATES requires mean velocities at the upstream, i.e. those before merging. The mean velocities monitored at some point of the upstream of the observation section are employed.

Then we compare the simulation results of traffic volume and velocity at the downstream of the merging section with the observational values. The overview of the present verification process is shown in Fig.6.

Table 3: Road parameters of target area

Number of lanes	Main lane	2
	Merging lane	1
Merging type		Side ramp
Length of merging section		80m
Speed limit on main lane		50km/h

The traffic condition of the target area is as follows. Traffic jam starting from the merging point always occurs at about 16:00, and lasts to the midnight. Sometimes traffic jam occurs at about 8:00. The traffic jam starting from Takebashi junction ahead the target area or that staring from Daikan-cho entrance ahead the target area

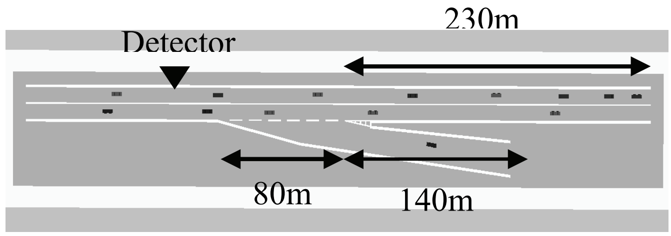

Figure 5: Road map of simulation area

sometimes extends and connects to the traffic jam of the target area.

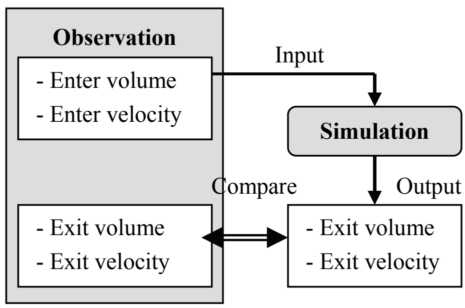

Figure 6: Overview of validation process

For the simulation, we construct car generation data of cruising lane and passing lane of main road and that of merging lane every 5 minutes based on the observational values. The detail of this process is described in more detail next. A simulation step is set to be 100msec.

5.1.1 Velocity Data

We provide mean velocity obtained from the observational data to all cars entering onto the lanes of the main road. On the other hand, we set the velocity of 0km/h to the cars entering onto the merging lane, because the entering point of the merging lane is a tall gate.

5.1.2 Traffic Volume Data

Keeping the volume of the entering cars the same as the observational data in every 5 minutes, entering cars are generated at random according to a uniform distribution. However, if this car generation process is fully random, cars are sometimes generated in consequent time steps and they happen to causes local jam. In such a case, it becomes meaningless to input the velocity data determined based on the observational value. We avoid such a situation using the following method. We assume the optimal velocity V_{opt} of the OV model as the initial velocity V_0 of the entering car velocity, and evaluate a corresponding headway Δx from Eq.3 and then define Δx as a safe distance x_{safe}. x_{safe} is then employed as the lower limit of car generation.

$$x_{safe} = \frac{w}{2}\text{arctanh}\left(2\frac{V_0}{V_{\max}} - c\right) + d \tag{3}$$

The parameters of the equation are the same as those of Eq.2. Since there are some possibility of the discrepancy of generating traffic volume between simulation and observation, we checked the number of generating cars before actual simulation. As the results, we found that the error of generating traffic volume of each lane in every 5 minutes was less than 10%, and the accumulated error from 0:00 to 15:00 was about 17%.

5.2 Verification of Reproducibility

Next, we compare the simulated results of exit traffic volume and mean exit velocity with those of observational values, respectively. In the simulation, these values are determined only through the interactions among cars driving in the target area. In other words, traffic jams occurred at the downstream area cannot be considered. Therefore we simulate the traffic situation of the period from 0:00 to 15:00, when traffic jam at the downstream area does not occur. In addition, we compare the simulation results with / without considering the coordinative behavior model described in section 4. The conventional algorithm of MATES includes the module to determine driving speed by presuming the car starting a merging process as a preceding car, so that the merging car and a car driving the main lane do not collide with each other. This might be regarded as a kind of coordinative behavior to some extent. However, this conventional model does not take into account situation judgment through getting information on cars before starting a merging process. Moreover, a yielding behavior of a merging car cannot be simulated by the conventional MATES, since the utility functions are the same as the velocities themselves.

5.2.1 Verification by Macroscopic Behavior

The exit traffic volumes of the cruising lane and the passing lane of the main road are shown in Fig.7 and Fig.8, respectively. The mean value of the exit velocity is shown in Fig.9.

5.2.2 Discussions

As for traffic volume, observational results are reproduced well by the simulations, irrespective of the employment of the coordinative behavior model. The simulation result with the coordinate model reproduces it slightly better than that without the model.

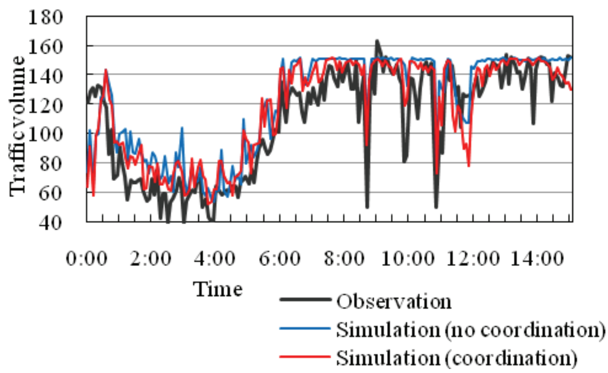

Figure 7: Exit traffic volume of cruising lane

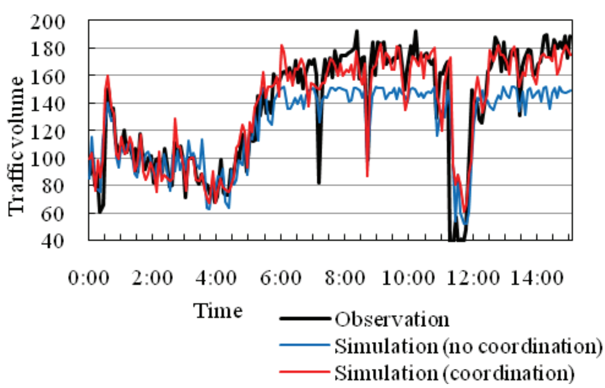

Figure 8: Exit traffic volume of passing lane

On the other hand, as for mean exit velocity, the simulation with the coordinative behavior model gives good results, while the simulation without the model gives larger velocity values than the observational results. The average relative error of mean exit velocity simulated without the coordinative behavior model is 55%, while it is improved to 24% by the simulation with the model.

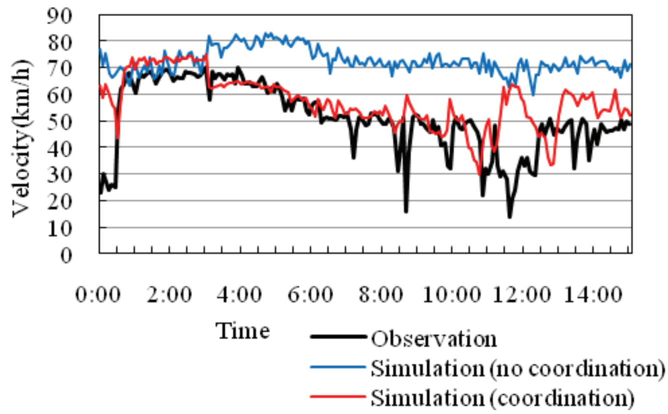

Figure 9: Mean exit velocity

Large differences between the simulation and the observational results can be observed between 0:00 and 1:00 and between 11:00 and 12:00. These are because car troubles occurred in these periods [JSTE (2006)]. Excluding the above two periods, the mean relative error between the simulation and observation results reduces to 11%.

5.2.3 Verification of Reproducibility of Microscopic Behaviors

Next, to confirm the effect of the coordinative behavior model to the microscopic behaviors of cars, we examined the temporal changes of the position of merging cars from the merging lane to the main road.

The simulated trajectories of the merging cars are shown in Figs.10 and 11. Fig.10 is the result simulated with the coordinative behavior model, while Fig.11 is that without the model. The simulated period is between 10:00 to 10:05, when many cars try to merge and coordinative behaviors frequently occur.

The comparison between Fig.10 and Fig.11 clearly shows that the coordinative behavior model significantly influences microscopic behaviors of the merging cars. In the case employing the model, many merging cars start shifting lanes in the former part of the merging section, and the traces of the merging cars seem smooth and reverse of S curve. It is then estimated that those cars keep their speed and properly perform deceleration and acceleration. On the other hand, in the case without the coordinative behavior model, many cars change lane suddenly in the latter part of the merging section. This is because those hardly find chances to change lane and almost stop before changing lane. Thus, the coordinative behavior model makes traffic flow smooth. We can check the above-mentioned behaviors more clearly through their animation. Fig.12 is a screen shot of the animation. The two encircled cars make coordinative behaviors in this time step.

Thus we can confirm that the coordinative behavior plays an important role in microscopic behaviors of merging cars, and makes merging traffic flow natural and smooth.

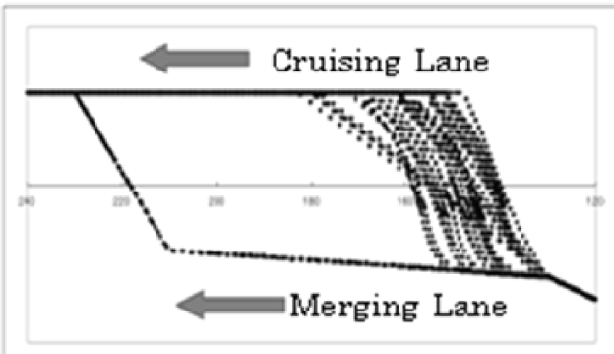

Figure 10: Trajectory of merging car (coordination)

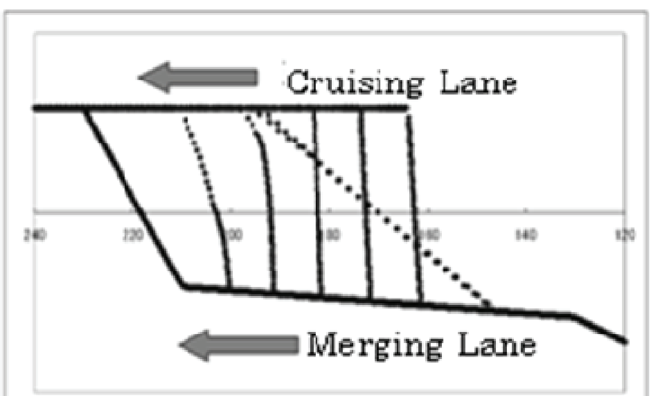

Figure 11: Trajectory of merging car (no coordination)

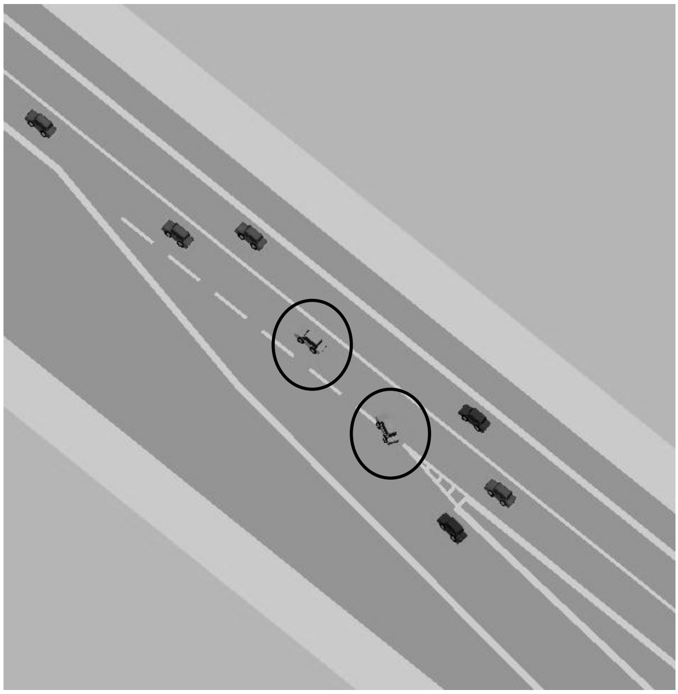

Figure 12: Screen shot of animation

6 Conclusions

In this research, we newly construct a coordinative behavior model for multi-agent traffic simulation based on the concept of the coordination graph, and implement it to our developing traffic simulator MATES.

To verify the reproducibility of the new model, we executed the simulation of cars at the merging section near Kandabashi Entrance of Tokyo Metropolitan Expressway, and compared the simulation results with the observational ones. As the result of comparison, the employment or non-employment of the coordinative behavior model brings significant differences in macro-indicators as well as micro-behaviors of traffic flow. We can confirm that the simulation with the coordinative behavior model shows good results.

In this research, we cannot consider the effect of jams that occurred in the downstream of target area. The large area simulations to include these jams are future tasks.

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