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EVALUATION OF METROPOLITAN TRAFFIC FLOW WITH AGENT-BASED TRAFFIC SIMULATOR AND APPROXIMATED VEHICLE BEHAVIOR MODEL NEAR INTERSECTIONS

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ABSTRACT

In this paper, we introduce a metropolitan traffic simulation with microscopic vehicle agents with approximated behavior near intersections. We simulate a metropolitan traffic flow for Tokyo and surrounding four prefectures with fine-grained traffic demand obtained from Tokyo Person Trip survey. Though this simulator has an ability to manage signal control, it is difficult to obtain the real signal data of the city. Without signal data, the behavior of vehicles in a city becomes too smooth because they do not stop at intersections. This causes differences in traffic volume distribution. In this paper, we introduce a virtual vehicle that appears virtually in the front of the lead vehicle on each road to achieve natural deceleration with a car following speed model. We evaluate the aggregated effect of the virtual vehicle by comparing simulated traffic volume and trip length with real traffic data including road traffic census and person trip survey data.

1 INTRODUCTION

Today, more than half of the world population lives in urban areas and the level of urbanization is predicted to rise to 66% in 2050 (United Nations 2015). One of the key issues of local governments is heavy traffic congestion from both viewpoints of environment and economics. By utilizing the information technologies which support city planners, we consider it is possible to decrease the CO2 emissions and time loss caused by traffic jams. Though real operations and social experiments in a city require an immense amount of efforts and costs, computational simulations can perform enormous number of trial using various scenarios to support decision-makings of city planners with significantly lower costs. The comprehensive simulations can estimate both optimal cases and worst cases in the same way that Monte Carlo simulations by financial institutes support traders' decision.

There are various types of traffic simulations. Some of macro or mesoscopic traffic simulators consider the particle model or queuing dynamics in cellular models (Helbing 2001, Yoshii and Kuwahara 1995). On the other hand, some of microscopic simulators reproduce the motion of vehicles in detail and visualize them with 3D movies often applied in a small area for better design of airport facilities or parking lots (Gomes, May, and Horowitz 2004). The agent-based modeling is used to consider individual drivers' behavior model with heterogeneous preferences (Yoshimura 2006; Kato et al. 2008). Along with the rapid growth of computer hardware and programming environment, it becomes possible to evaluate detailed behavior models with huge number of agents such as traffic flows in a metropolitan area (Mizuta, Yamagata, and Seya 2012).

In this paper, we introduce a metropolitan traffic simulation and an approximated vehicle behavior near intersections with an agent-based traffic simulation. We utilize a large-scale agent-based simulation environment to support the decision-making of city planners via what-if simulations. Though many traffic simulators have an ability to control the traffic with signals, it is often difficult to obtain the real signal data (e.g. cycle time and offset for each traffic signal) from the associated department due to the government's vertical administrative structure. But without the signal control, the behavior of vehicles in a city becomes too smooth because they do not decrease their speed at intersections and the route selection of vehicles is also affected due to different congestion status. Hence, we introduce a virtual vehicle (ghost car) that appears virtually in the front of the lead vehicle on each road to achieve natural deceleration with Gipps' car following model (Gipps 1981). This procedure can provide not only an approximate behavior at intersections, but also a possible deceleration behavior in wider situation such as parking, pit stop, and critical events.

Various types of the car following model including Gipps' model are developed and used in traffic simulations. Panway and Dia (2005) evaluated several traffic simulators with different car following models and reported the good replication of the real data by AIMSUN which implemented Gipps based model. As another approach, Chong, Abbas, and Medina (2011) compared a general form of the car following model with an agent-based model using a reactive-structure artificial neural network (ANN) that can learn a realistic behavior after trials. There are also literatures of agent-based simulation that also investigate the driver's behavior near intersections. Cunto and Saccomanno (2007) consider the crash potential at intersections with different types of control method of speed and signals. Pulter, Schepperle, and Böhm (2011) optimize the traffic flow to reduce fuel consumptions and emissions. These literatures aim at replicating the precise microscopic behavior with car following models and also use the traffic control for an improved traffic from the viewpoint of safety and energy efficiency. On the other hand, we introduce the approximated behavior near intersection to reproduce the inefficient traffic flow and the city-wide traffic pattern in a whole.

Though we consider large-scale traffic flow in a metropolitan area, we can also observe an individual microscopic traffic behavior by utilizing a distributed agent-based simulation environment. We will show simulated traffic flows both in a simple road network for verification of the microscopic vehicle behavior and a metropolitan area for the actual usage.

The rest of the paper is organized as follows: in Section 2 we briefly introduce our agent-based traffic simulator used in the experiments. Section 3 describes proposed procedure of vehicle behavior near intersections. Section 4 summarizes the simple simulation results and the microscopic behavior of each vehicle. Then Section 5 shows the comparison with real data in a metropolitan area. Finally, Section 6 concludes with future works.

2 AGENT-BASED CITY TRAFFIC SIMULATOR

The agent-based simulation is a powerful tool to understand the complicated dynamic system such as a whole city including many human beings. However, agent-based simulation systems in the early stage tended to examine complex systems with rather a smaller number of agents. Since autonomous agents are intuitively implemented using objects and multi-threads, the Java programming language has been widely utilized as an easy-to-use environment even for researchers not in the department of Computer Science (e.g., Economics or Social Science). Until recently, these systems can treat only hundreds or thousands of agents mainly because of the limitation of early programming model of Java threads and memory, which is a trade-off with the intuitive design.

The X10 programming language has a Java-like syntax with PGAS-based distributed computing environments and Suzumura et al. (2012) developed an X10-based large-scale distributed agent-based simulation environment. On this environment, we developed a traffic simulator with more realistic drivers' behavior models by analyzing the real probe car data that are obtained from GPS equipped on taxies in Tokyo (Osogami et al. 2012; Osogami et al. 2013). The Agent-based traffic simulator considers each microscopic vehicle as agent, which travels through a given road network with Crosspoints (node) and Roads (links). Each agent is assigned an origin, a destination, and a departure time as a trip according to a origin-destination (OD) table obtained from population and traffic census survey data. The simulator creates the agent at the origin at the departure time. The agent chooses a route from the origin to the destination, according to a model of the route choice, and travels along that route. In this simulator, heterogeneous agents (drivers) select a route with their probabilistic preference distribution estimated from probe car data and change their car speed and lane based on the car following model (Gipps 1981) and Integrated Lane-Changing Model (Toledo, Ben-Akiva, and Koutsopoulos 2003) that represent the dynamic interaction with surrounding cars. At each time step (typically, 1 sec), the microscopic car behavior in roads are controlled by connected Crosspoints each of which is assigned an individual thread from a thread pool to effectively simulate the fine-grained car movement in and across roads even in a distributed HPC environment.

The simulator tracks the location of each agent and records information of vehicles (position and speed), roads (average speed, number of vehicles, CO2 emissions on the road) and trips (travel time and total CO2 emissions of each vehicle) into log files which are used for analysis and visualization.

The route choice model of this simulator determines the route of an agent from his origin to his destination, taking into account three quantities: travel time, travel distance, and the number of turns. Specifically, the route that minimizes the weighted sum of the three quantities is selected, where the weight depends on individual agents. This weight used for an agent is denoted as the agent's personality and can be estimated from the probe car data.

Once the personality of an agent is determined, Dijkstra's algorithm can be used to find the route, from his origin to his destination, that minimizes the linear combination of the three cost using his personality as the weight. To take into account the number of turns, Dijkstra's algorithm is run on a network whose vertexes represent a segment of roads and whose edges represent a connection from a segment of roads, which we refer to as the first road-segment, to a neighboring segment of roads, which we refer to as the second road-segment. The edge cost then represents the convex combination of the travel time along the second road-segment, the travel distance along the second road-segment, and the indicator (zero or one) of whether there is a turn from the first road-segment to the second. The travel time used for the route selection is updated every 10 simulated minutes according to the simulated travel time to avoid congested roads.

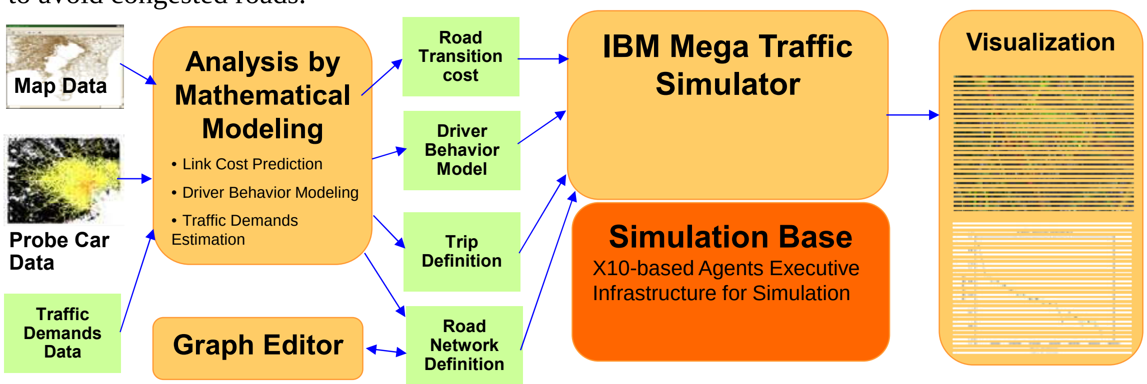

Figure 1: Inputs and output of the traffic simulator.

3 SIMULATION PROCESS OF VEHICLE BEHAVIOR NEAR INTERSECTIONS

In this section, we describe the process to simulate the vehicle behavior near intersections. We denote intersections as Crosspoint objects which are connected to Road objects in our definition of the road network.

During the simulation execution, each vehicle calculates the speed at the next timestep using the Gipps' car following model (Gipps 1981) as described below. In the simulator, this calculation is performed by each Crosspoint in parallel if enough threads are assigned to CPU cores from the thread pool in each computation node.

The Crosspoint has a list of incoming roads and the road has a list of vehicles running on it. The calculation of speed changes are performed sequentially for each vehicle on each road using the relative position and speeds of the front vehicle and the current vehicle. If the gap length to the front car is long enough, the current vehicle will accelerate to the desired speed (typically determined to the limit speed of the road). If the front vehicle is slower than the current vehicle and the gap length is not sufficient, then the current vehicle will decelerate to the speed which keeps safety margin to stop before the crash even when the front vehicle decelerate suddenly. For the first vehicle in a list, the gap length and the speed of the front vehicle are set to the maximum value of the system (for example, Float.MAX_VALUE).

Now, we describe the proposed process for the vehicle near the intersection. To control the speed of the lead vehicle on the road, we introduce the virtual vehicle information (ghost car) in the front of this vehicle in the top of the vehicle list.

This ghost car appears when the lead vehicle has entered the zone near the end of the road with given gap and speed (see Figure 2). To restrict this behavior only on the main road, we can apply this procedure only when the vehicle is located in trunk or primary roads.

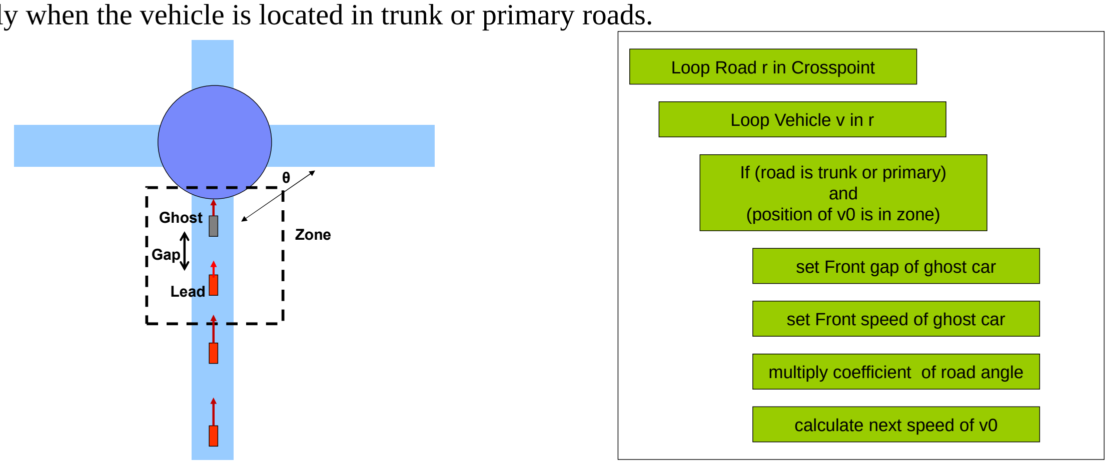

Figure 2: Information and parameters of the virtual vehicle and the procedure of speed calculations.

If this gap and speed are large, the ghost car gives only a little effect to the lead vehicle. If these values are small, then the lead car is forced to decrease its speed rapidly. In addition, the length of the zone changes the duration of the effect. By calibrating these parameters, we can obtain the desired traffic situation.

In addition, we consider the road angle θ between the target road next to the Crosspoint by modifying the speed of ghost car as $V\_ghost \mathrel{*}= (1 + \cos(\theta))/2$. The speed of the ghost car does not change when the vehicle goes straight ahead. But the speed decreases greatly as the vehicle turns drastically.

Such a variation of parameters for the virtual vehicle may sound too arbitrary, but the effective range of parameters where the ghost car affects the lead vehicle substantially and not block the entire traffic is restricted. If the gap is too long (50m or 100m) or the speed of the ghost car is near the limit speed (60 Km/h), the lead vehicle need not to decrease its speed. If the gap is too small (e.g. 1m) or the speed is too slow, following vehicle cannot drive on the road. We choose sensible range of parameters, the variation of the correlation coefficients of road traffic volume in a whole is small. For experiments of the city traffic in Tokyo, we perform experiments using the virtual speed at 5m/s and 1m/s with almost same results. In this meaning, this approximation has a certain robustness.

4 SIMPLE SIMULATION SETTINGS FOR CONFIRMATION OF THE BEHAVIOR MODEL

In this section, we show the simple simulation results by changing parameters of the ghost car to confirm the microscopic behavior.

As a simple example, we use a simple road network (Figure 3). The circles are Crosspoints and lines are Roads. The limit speed is 60 Km/h and each road has one lane. Our evaluation scenario included four vehicles, which start from Crosspoint 1 every 10 seconds toward Crosspoint 5.

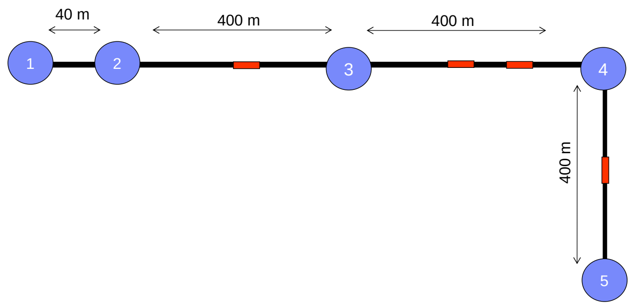

Figure 3: Simple road network definition with 5 Crosspoints and 4 Roads.

Positions measured by the distance along a road from the origin and speeds of the four concrete vehicles with IDs (0, 1, 2, 3) at each timestep are shown in Figure 4. Though our simulator outputs both the position and speed as log data, the right hand plot can be obtained as the derivative of the left hand plot. The gap length and zone length of the ghost car are set to 10m and 100m, respectively. The speed of the ghost car is 1 m/s for straight roads. We can see that vehicles decrease their speed to a very low value suddenly and stay near the speed of the ghost car till they exit the road. In addition, the distances between these vehicles become shorter near intersections as observed at a real congested road.

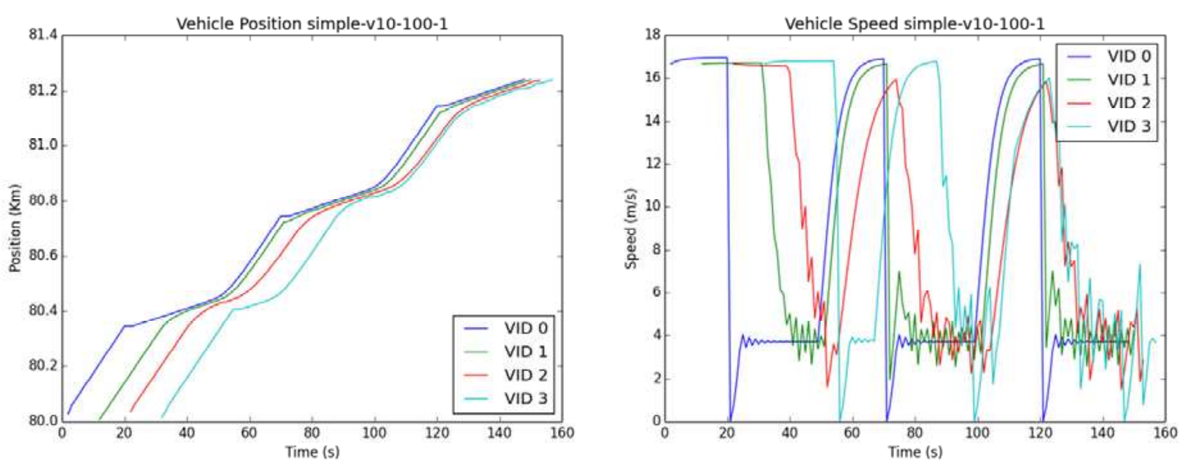

Figure 4: Vehicle Positions and Speeds at each timestep with virtual vehicle.

For a comparison, we also perform a simulation which does not use the ghost car but set a cap speed in a zone near intersections. The zone length and cap speed are set to 50m and 5m/s, respectively. Positions and speeds of four vehicle are shown in Figure 5. We can see uniform deceleration near intersections and smooth moving keeping stable gap lengths.

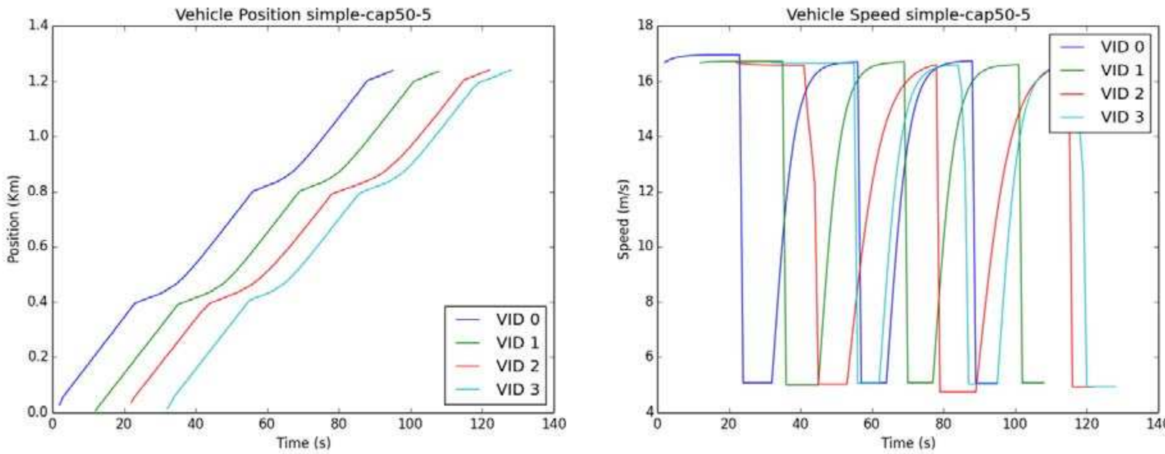

Figure 5: Vehicle Positions and Speeds at each timestep with zone cap.

5 EVALUATION IN TOKYO METROPOLITAN TRAFFIC

To evaluate our traffic simulation in a real large city, we utilized fine grained hourly OD data given with small-level zones (which divide Tokyo into 417 areas for example) obtained from Tokyo Person Trip Survey data in 2008 and Traffic road census data in 2010. The simulation area includes Tokyo and surrounding four prefectures. For comparison with observed data, we use census points only in Tokyo. However, we perform the simulation including surrounding prefectures, because there is significant traffic demand to/from these areas passing roads in Tokyo as in Table 1.

Table 1: Traffic demand between Tokyo and surrounding prefectures and number of small-level zones in each prefecture.

Prefecture	Traffic demand to/from Tokyo	Number of small zones
Tokyo	3,848,290	417
Kanagawa	469,924	507
Saitama	452,830	317
Chiba	224,573	311
South Ibaraki	20,597	103

Traffic road census is given as traffic volumes of 12 hours from 7:00 to 19:00. We execute the traffic simulation for 13 hours from 6:00 to 19:00 to reduce the effect of initial rise and aggregate the 12 hours traffic volumes for each road from the simulation log data.

The road network for the simulation of Tokyo metropolitan is extracted from OpenStreetMap in the area shown in Figure 6. In this area, we have 891,335 nodes (Crosspoints) and 2,465,767 links (Roads).

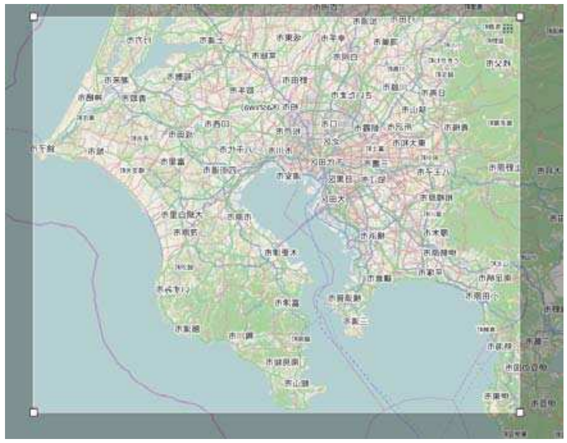

Figure 6: Simulation area for Tokyo metropolitan. Range of latitude is from 34.8927N to 36.1445N and longitude from 139.0018E to 140.8887E.

The Person trip (PT) OD matrix is given between small zones that are defined with a list of addresses. To obtain trips between Crosspoints, we utilized 2,105,428 GIS reference points dataset with the address and location (longitude and latitude) in 2008. By matching address, we can associate a zone code with each GIS point. Then, we find the nearest GIS reference point for each Crosspoint and assign the zone code of the GIS reference point to Crosspoints. Finally, we can define trips by choosing random Crosspoints from the origin and destination zones repeatedly with a number of traffic demand for each hour. Figure 7 shows examples of selected trip route between small zones. These GIS reference point dataset, Person Trip survey data and Traffic road census data (General Traffic Volume Survey 2012) are provided by Ministry of Land, Information, Transport and Tourism (MLIT) of Japan. The map image in Figure 6 and the colored streets in Figure 7 and 8 are based upon OpenStreetMap data (©OpenStreetMap contributors) and licensed under CC-BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0/) or ODbL (http://opendatacommons.org/licenses/odbl/).

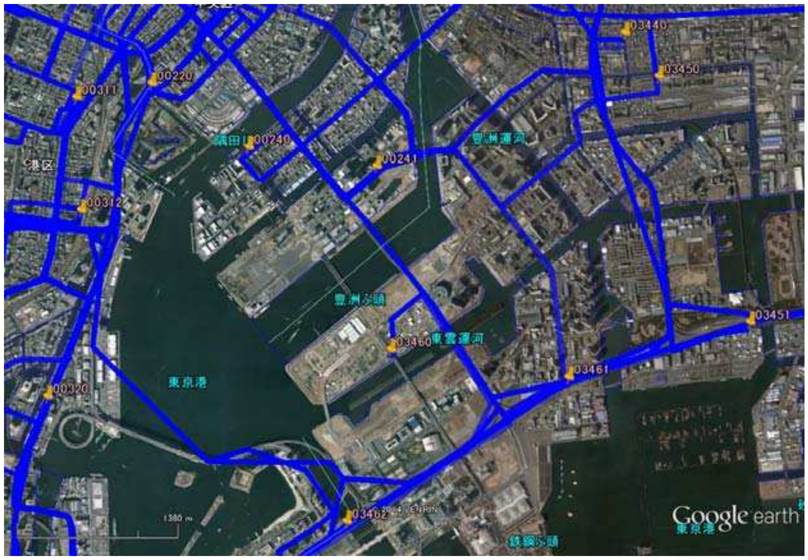

Figure 7: Examples of route (blue lines) between randomly selected Crosspoints in small zones (pins with zone label).

By performing a simulation for 13 hours, we obtain log data of roads and trips. The road log data contains the number of vehicles and average speed on each road for each hour and the trip log data contains trip duration for each trip. Figure 8 shows an example of visualization for the traffic volume by means of a heat map.

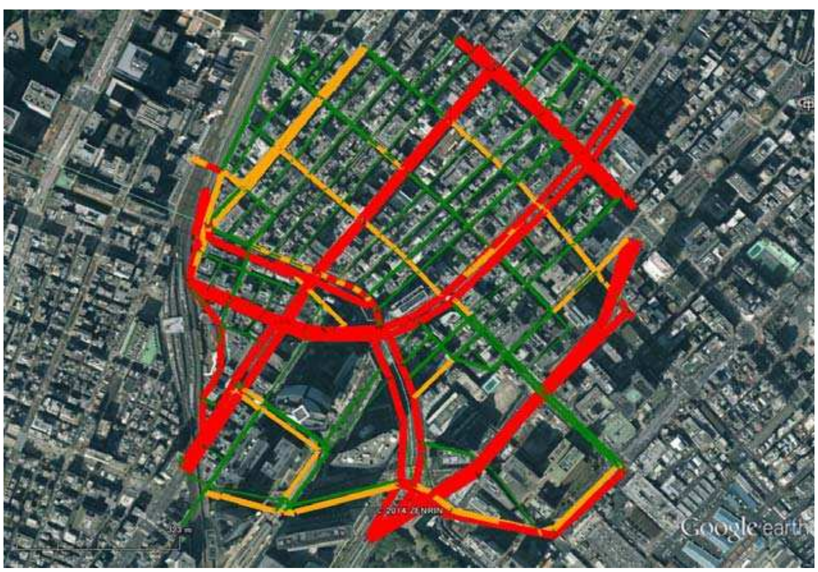

Figure 8: Simulation Visualization Example (Heat map of road traffic volume represented with KML and Google Earth).

To evaluate the simulation results with the observed traffic volumes, we use scatter plots (Figure 9) and correlation coefficients of the simulated logarithmic traffic volumes on 50 census roads with 12 hours census data. Since the distribution of traffic volume decays exponentially, we evaluate the log value of traffic volumes. As the first result, we obtained a low correlation coefficient 0.5979 without the virtual vehicle method introduced in previous sections.

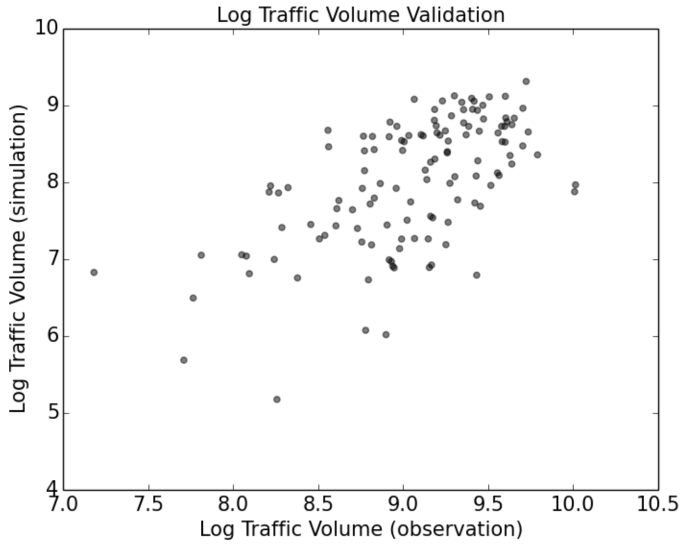

Figure 9: Comparison of logarithmic traffic volume at census points.

The number of vehicles (agents) on the whole area at the simulation time step 3600 (after one hour) is 58,254. At each second, about 90 vehicles depart from their origin. We can estimate that the average vehicle remains on the road network for 10 minutes. This duration is shorter than the average trip length which is around 20 minutes obtained from the survey data. This can be considered as one reason that the simulated traffic volumes tend to smaller than the observed traffic volume. Though environment (rain or road condition) or traffic regulations can change the trip length, one of main reason for this short trip length of the simulation is caused by the too smooth traffic flow without decreasing speed at intersections or stopping by red signals. Hence, we introduce virtual vehicle model into the simulation. The parameters of the virtual vehicle we used here are gap length = 10, zone length = 100, and virtual speed = 1.

We performed 13 hours of simulation again and compared the 12 hour traffic volume of selected roads (census points) between simulation results and observed data. The correlation coefficients using both traffic volume and logarithmic traffic volume and scatter plots with logarithmic values are shown in Table 2 and Figure 10. We can see correlation increases by using the virtual vehicle behavior model up to 0.7028 for logarithmic values. We also compare the result with another approximation method using zone cap which restrict speed limit in predefined zone (50m for example) near intersections to a small value (5 m/s for example). Though zone cap method increase the trip length, the correlation coefficients decreases.

Table 2: Correlation Coefficients with and without virtual vehicle.

Correlation Coefficient	Baseline (Without approx. method)	With Virtual Vehicle	With Zone Cap
Traffic volume	0.5206	0.6760	0.5084
Logarithmic traffic volume	0.5979	0.7028	0.5155

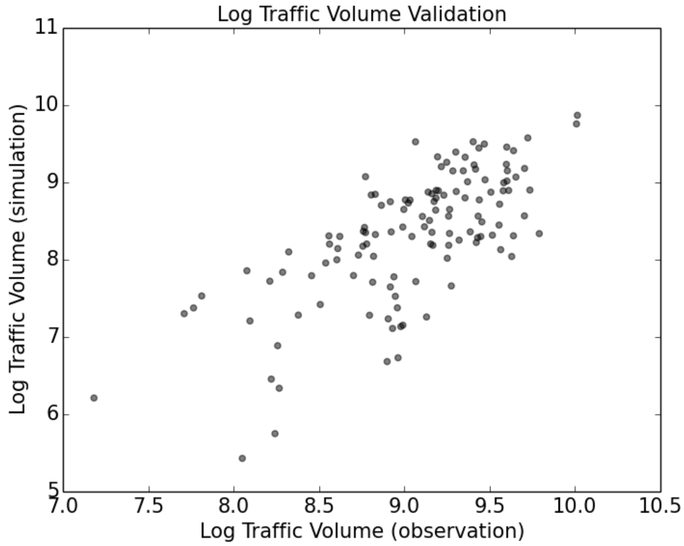

Figure 10: Comparison of logarithmic traffic volume at census points (with virtual vehicle).

In addition, we evaluate simple statistics of trip length distribution for simulation results and Person Trip survey data though the trip length data from sample-based PT survey may have errors. Indeed, the change of trip length caused by the virtual vehicle is small. The summary statistics for three simulations and PT survey data is shown in Table 3. In the experiment with virtual vehicle, leading vehicles only decreases its speed but does not stop at intersections for significant seconds as with red signals. The trip length only becomes 1.2 times longer and not 3 times longer as survey data. This means the total number of vehicle at a moment or aggregated traffic volume for 12 hours at a census point is not become sufficiently large enough to compete with the real observation data. But the absolute value itself is not important for the traffic pattern in a city that relates the correlation coefficient because normalization does not change the coefficient. However, the road congestion near the intersection is changed by the virtual car and this may cause the substantial change on the traffic flow pattern via the route selection which uses a shortest travel time and link cost that is changed by non-uniform congestion caused by the ghost car.

Table 3: Summary statistics of trip length of PT survey and three simulations.

Trip length (sec)	Person Trip Survey	Without Virtual Car	With Virtual Car	With Zone Cap
average	2006	609	733	933
median	1386	344	378	516
75 percentile	2400	710	834	1140

6 CONCLUDING REMARKS

In this paper, we proposed a procedure to decelerate vehicles near intersections as observed in the real traffic situation. Though this setting lacks signal controls, we reproduced the non-uniform congestion or traffic jam caused by the slow speed approaching intersections and traffic volume pattern that has a higher correlation coefficient with the observed traffic data in a whole.

Without the control by signals, simulated vehicle flow tends to become too fast and smooth. By utilizing proposed vehicle behavior, we can adjust the traffic flow with a few parameters though this is an approximation methodology.

We observed that both the macroscopic simulation and microscopic vehicle behavior (speed and congestion) are easily changed by small number of parameters used for the ghost car (virtual vehicle information in the front of a road). We also evaluated the traffic flow in the Tokyo metropolitan area compared with the traffic road census data and found that the introduction of the virtual vehicle can improve the correlation coefficients. Though the change in the distribution of the trip length is small, we consider status of whole traffic flow in metropolitan approaches to the real traffic flow with this approximated vehicle behavior.

Our method using the virtual vehicle causes an instantaneous brakeage that is psychologically similar response near intersections or dangerous areas and causes shrinkage of inter-vehicular distances. This brings approximated jam due to retention near intersections that are not observed with the uniform deceleration by other methods, and then generate global change in the distribution pattern of road travel costs in the whole city. We can consider that resulting changes of the route selection cause the improvement of the correlation coefficients that indicates the global similarly of the traffic volume pattern.

Currently, it is difficult to obtain the full data of signal locations and their cycles. But in some cases, we can estimate the partial data of signal if we can obtain car navigation data or monitoring camera images. To obtain a more realistic traffic flow with such a partial information together with our approximation and further analytical method remains for future works. In addition, this procedure can be used for other critical events such as traffic accidents or disasters. In such a case, the importance of the real time simulation increases to evaluate plans of the evacuation management as what-if analysis.

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