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LARGE-SCALE TRAFFIC SIMUALTION FOR LOW-CARBON CITY

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ABSTRACT

This paper considers environmental city design using land use scenarios and large-scale traffic simulation. Low Carbon City (LCC) can be achieved by combining appropriate land use and transportation. We simulate the possible low carbon city by combining spatially explicit land use equilibrium (LUE) model and agent-based traffic model. First, land use scenarios of a city with different urban forms (compact and dispersed etc.) are created using the LUE model. Then the corresponding transportation is projected under each urban form with a large-scale traffic simulator for a case study city (Yokohama) in Japan. We also simulate the current traffic using the detailed person-trip data. Finally, we analyze the relationship between the urban form and the resulting CO_2 emission both from land use and transportation are estimated. The proposed method can be a useful tool for urban planners to test some land use and transportation policies for designing sustainable cities.

1 INTRODUCTION

In order to achieve the long-term goal of reducing 50% global Green House Gases (GHG) by 2050, as it was discussed at G8 Summit and COP15 etc., it is urgent for developed and some developing countries to start designing future low carbon society. Especially, developed countries with the higher GDP have larger responsibility and requested to set more ambitious GHG reduction target as high as 80%. In addition, rapidly growing developing countries are also expected to take part in the efforts with substantive technology transfer and financial support from the developed countries to achieve the so called sustainable low carbon development pathways.

Low carbon city as an integration of all possible emission reduction technologies in the areas such as renewable energies, sustainable buildings and electric transportation systems is one of the most promising approach for achieving the goal. In this paper, we propose a concept of simulation technology for designing Low carbon city (LCC).

LCC can be achieved by combining appropriate land use (compact city with energy efficient buildings) and transportation (trains and electric cars). We simulate the possible low carbon city by combining our newly developed spatially explicit land use equilibrium (LUE) model and microscopic transportation simulation model. First, several land use scenarios of a city with different urban forms (compact and dispersed etc.) is created using the LUE model. Then the corresponding transportation is projected under each urban form with a traffic simulator for a case study city (Yokohama) in Japan. We also analyze the relationship between the urban form and the resulting CO_2 emission both from land use and transportation are estimated. The proposed method can be a useful tool for urban

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planners to test some land use and transportation policies at a city or even at a town level for designing sustainable low carbon city.

This research is novel with respect to attempting to combine land equilibrium model and micro simulator. There are some works on combining CGE model with micro simulator (e.g., Davies 2009), however, as far as we know, there are no attempts related to this combination. By using the transportation simulator, we can easily consider the heterogeneity of car types, which enables us to make realistic policy.

2 STUDY AREA

The study area of our simulation experiments is the Yokohama city, which is one of the largest cities in Japan. First, the LUE model is constructed based on the entire spatial units (zones) in the Tokyo metropolitan area including Yokohama city (Figure 1). The existing literatures on constructing LUE model in the Tokyo metropolitan area all uses municipality (city) level zones, whereas this study uses the micro-town level zone (around 1 km^2) called cho-cho-moku in Japanese, as the zones. The number of the municipalities in 2005 was 333, whereas the number of the micro-districts was 22,368. Thus, use of the cho-cho-moku as the zone enabled us to build a model with a spatially finer resolution, which leads to the realistic traffic simulation. Second, two extreme urban form scenarios——compact city and dispersed city is derived with the constructed LUE model. Then, the population in each cho-cho-moku and the corresponding OD traffic volume among the zones in Yokohama city is derived.

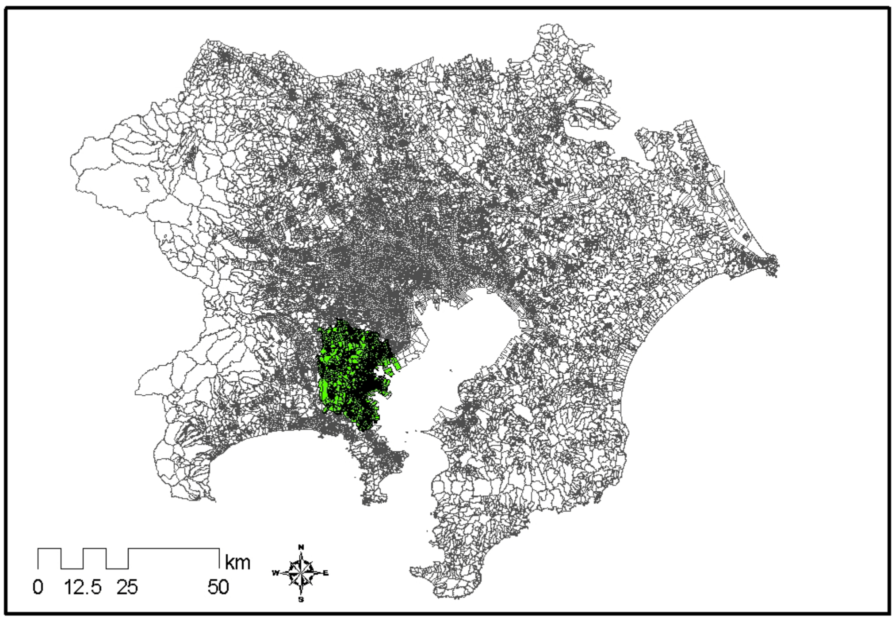

Figure 1: The Tokyo metropolitan area and Yokohama city

3 LUE MODEL

LUE models have been developed for use in infrastructure planning and regional science studies, and since the 1980s, many such models have been applied to actual urban policy planning and the creation of land use change scenarios. For more details, see for example Hunt, Kriger, and Miller (2005). For the LUE model, we employed the simplified version of computable urban economic model developed in Japan (Tomita and Terashima 2005). The main assumptions of our LUE model are as follows: [a] there exists a spatial economy whose coverage is divided into zones. [b] There is one land market in each zone. These markets reach equilibrium simultaneously. [c] The society is composed of two types of agents: households and absentee landowners. [d] The behavior of each agent is formulated on the basis of micro-economic principles, that is, utility maximization by households, and land rent maximization by landowners. [e] The total number of households is given exogenously. With respect to the mathematical equations of our LUE model, see Yamagata, Seya, and Bagan (2010). As the existing literatures, we assume the 30% of the households actually move, and the other 70% households remain.

According to Ueda et al. (2009), an equilibrium state of an urban economy is defined by two conditions. One is that no household has any incentive to relocate or to change its location. In other words, the household cannot enjoy a higher level of maximized utility in zones other than the zone in which it is presently located. The other condition is that demand–supply balancing or clearing of the land markets in any zone is attained simultaneously. The structure of our LUE model is shown in Figure 2.

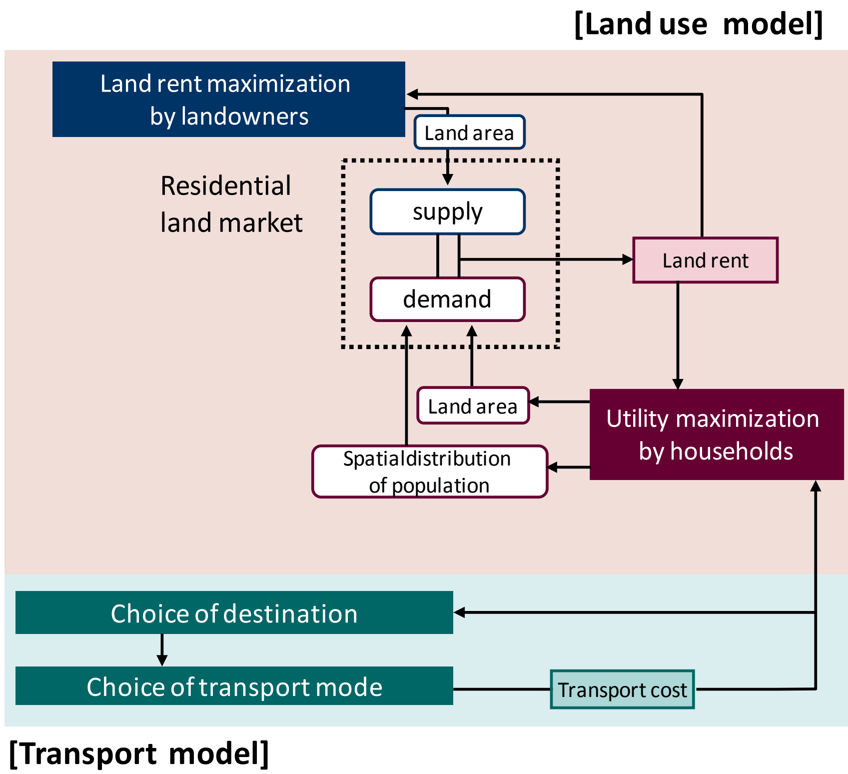

Figure 2: Structure of the LUE model

4 SIMULATING URBAN FORM WITH LUE MODEL

Here, we tested two extreme urban form scenarios——compact city and dispersed city. With respect to the compact city scenario, we assumed that fewer people can use a car (setting the gasoline very high). This assumption raises the transport cost, resulting in an increased preference to live near a train station. This is an extreme case of compact city concept (Neuman 2005). With respect to the dispersed city scenario, we assume that households work at their own homes, and do not need to commute to their offices. This assumption will raise real income as commuting cost can be saved, and resulting in the increase of household's preference to live in suburb areas where large residential land area is available. The other spatial land use scenarios distribution in the future can be assumed to lie between these two extreme scenarios.

Figure 3 shows the spatial distribution of population in Yokohama city in 2005 (present), and Figure 4 and 5 show the ratio of the population of the compact city to the present one (compact city / present in Figure 4), and dispersed city to the present one (dispersed city / present in Figure5), respectively. Figure 4 suggests that population in Yokohama city under compact city scenario will increase around the train stations very locally, whereas decreases in most of the other areas. Such a "compact" urban form can contribute to the reduction of the total amount of CO_2

emission. Figure 5 shows the results of dispersed city case. In dispersed city scenario, population will increase in the suburb regions, and decrease urban area like Yokohama city.

Using the simulated population, the generation/attraction traffic volume in each zone of Yokohama city is calculated by simply multiplying the trip generation unit of each ward in Yokohama city obtained from the results of the "4th Nationwide Person Trip Survey", in Japan. Then the Origin Destination (OD) distribution of traffic volume is calculated via traditional Frator method, and inputted into the traffic simulator introduced in the next section.

Then it must be noted that the estimated OD traffic volume distribution is very tentative because it does not consider the modal shift, for example, from vehicle to train or walk. Constructing more realistic model which considers modal shift (including to the electric vehicles) is discussed in the last section.

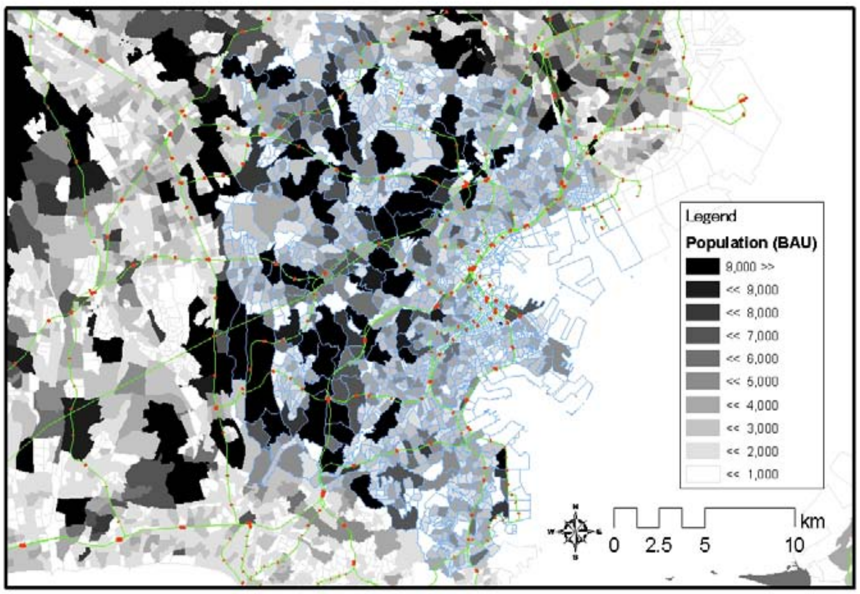

Figure 3: Population of Yokohama city in 2005 (present)

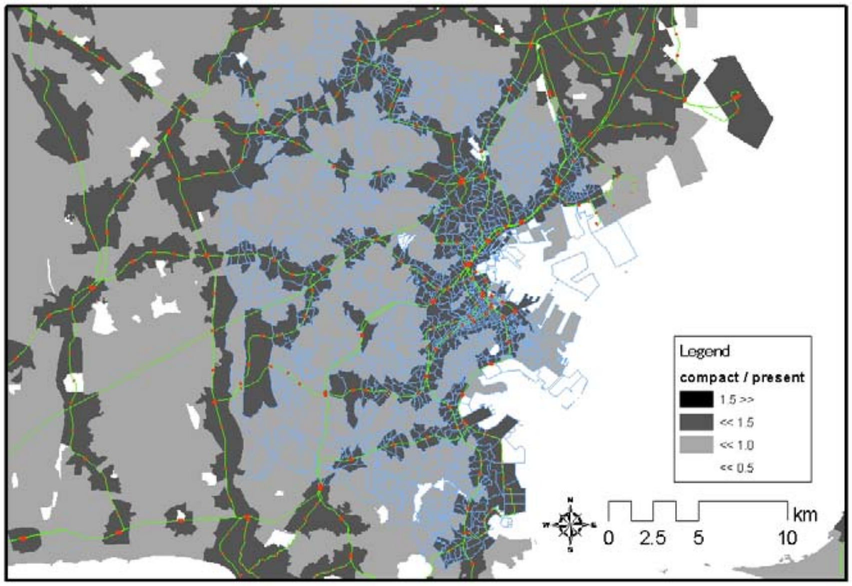

Figure 4: Ratio of the population of the compact city scenario to the present one (compact city / present; the blank zone shows that the present population is zero)

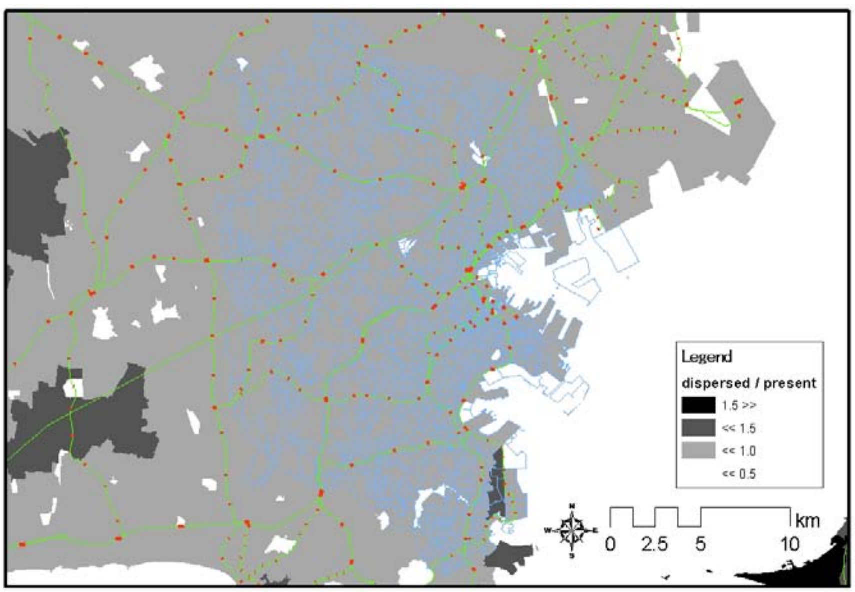

Figure 5: Ratio of the population of the dispersed city scenario to the present one (dispersed city / present; the blank zone shows that the present population is zero)

5 LARGE-SCALE TRAFFIC SIMULATOR

For microscopic traffic simulations with two LUE scenarios, we utilize the agent-based approach and IBM's large-scale simulation environment.

The agent-based approach is an inter-disciplinary approach between computer science and social science to investigate complex social systems. In real social situations, the dynamic behavior and interactions between people are very complicated and may often seem irrational. It is very difficult to analyze dynamically changing situations involving heterogeneous subjects with traditional economic models or physical models. From the last decade, many researchers, including physicists and computer scientists, have been starting to apply new approaches to investigate such complex dynamics in their studies of social systems (Terano et al. 2001). One of these approaches is the agent-based simulation approach.

The agent-based simulation has become easily available recently, with the advent of fast, cheap, and readily available computers. This opens the door to the study of the interaction of large numbers of heterogeneous, interacting agents. The agent-based simulation is a powerful tool to understand the complicated dynamic system such as a whole city including many human beings and support the total optimization of integrated activities for smarter cities.

However, agent-based simulation systems in the early stage tended to examine complex systems with rather smaller number of agents. Since autonomous agents are intuitively implemented using objects and multi-threads, 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). Till fairly recently, these systems can treat only hundreds or thousands of agents mainly because of the limitation of Java thread number and memory, which is a trade-off with the intuitive design.

Utilizing the methodology of enterprise systems, Yamamoto, Tai, and Mizuta (2006) developed a large scale agent-based simulation environment, ZASE (Zonal Agent-based Simulation Environment) with massive threads management and distributed messaging mechanism, which consists of simulation space and agent space for efficient object and execution control. Using this environment, researchers can develop various simulators such as traffic, energy, or financial market with millions of agents.

On this framework, Kato et al. (2008) developed a whole city traffic simulator and examined the traffic flow with the road network in the Kyoto city with 32,654 links and 22,782 nodes. Recently, we have developed X10-based large-scale distributed agent-based simulation environment XAXIS (Suzumura and Takeuchi 2012) and improved traffic simulator with more realistic drivers' behavior models (Figure 6). This traffic simulator considers each microscopic vehicle as agent, which travels through a given road network with cross points (node) and roads (links). 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 dynamic interaction with surrounding cars. At each time step (typically, 1 sec), microscopic car behavior in roads are controlled by connected cross points each of which is assigned individual thread from a thread pool to effectively simulate the fine-grained car movement in and across roads even in a distributed HPC environment.

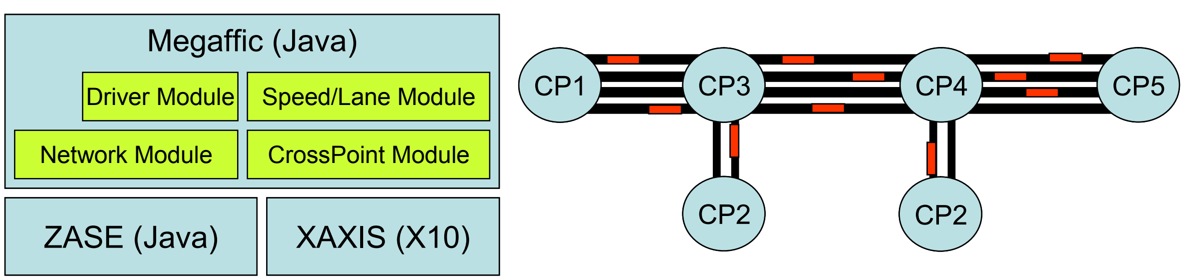

Figure 6: Mega traffic simulator on simulation environment ZASE and XAXIS

6 TRAFFIC SIMULATION ON LUE SCENARIOS

We perform trial simulation on the traffic simulator using two LUE scenarios. Though LUE assumes the real city (Yokohama), we use a simplified road network for simulations without traffic signals.

We generated a network definition file based on the real map data of Yokohama which has 38,464 cross points (nodes) and 115,124 roads (links). This huge road network and enormous number of microscopic vehicles are required to simulate the LUE scenarios which consider fine grained resolution of the city (cho-cho-moku as the zone) to consider environmental effects, which can only be simulated with our new large-scale traffic simulator. In addition to the network information, the traffic simulator requires OD (Origin-Destination) Trip information.

In two LUE scenarios (the dispersed city scenario and the compact city scenario), we use the same network information and different trip information. We generate trip data from OD traffic volume among zones estimated in the previous section for each scenario. Traffic simulator performs 1 hour of microscopic vehicles' behavior on the simplified road network with given trip demands and output log files including road and vehicle information.

We also simulated 24 hours of present traffic situation as well as estimated two scenarios for comparison. For this purpose, we generated trip definition data which were associated with origin and destination cross points calculated from original GIS positions and travel start time (sec) in 24 hours using the person trip survey data of the Tokyo Metropolitan area (Figure 7). The snapshot of simulation viewer where vehicles are drawn as dots with random colors is shown in Figure 8.

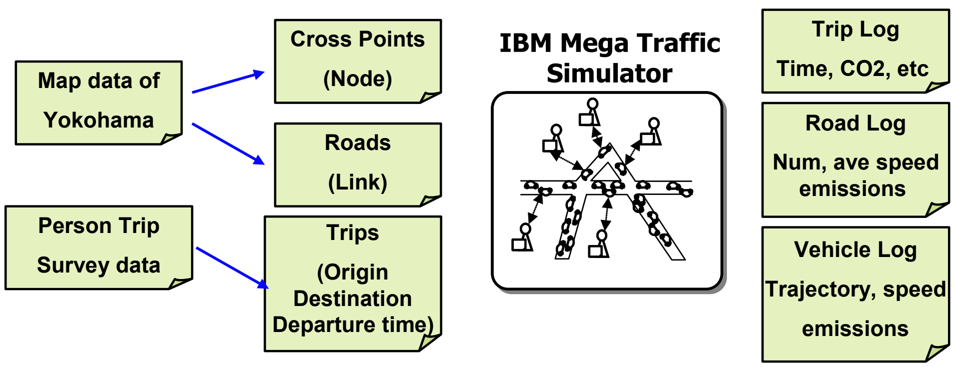

Figure 7: Input and Output of Traffic Simulator

The trip data of "The Tokyo Metropolitan Area person trip survey", which is obtained via "People Flow Project (PFP)" (http://pflow.csis.u-tokyo.ac.jp/download_e.php) was used in this study. This survey is implemented every ten years since 1968, and we use the data of the 4th survey implemented on the weekday in the autumn of 1998. The data includes the Origin Destination (OD) distribution of the trips and its generation time of each agent. Hence we can consider the within-day dynamics of transport with this data.

However, this survey is performed to the 2% samples of the whole population (except for the child whose age is less than five years old), and therefore it was magnified according to the rate of magnification provided by the PFP in order to simulate the whole traffic in the Yokohama city.

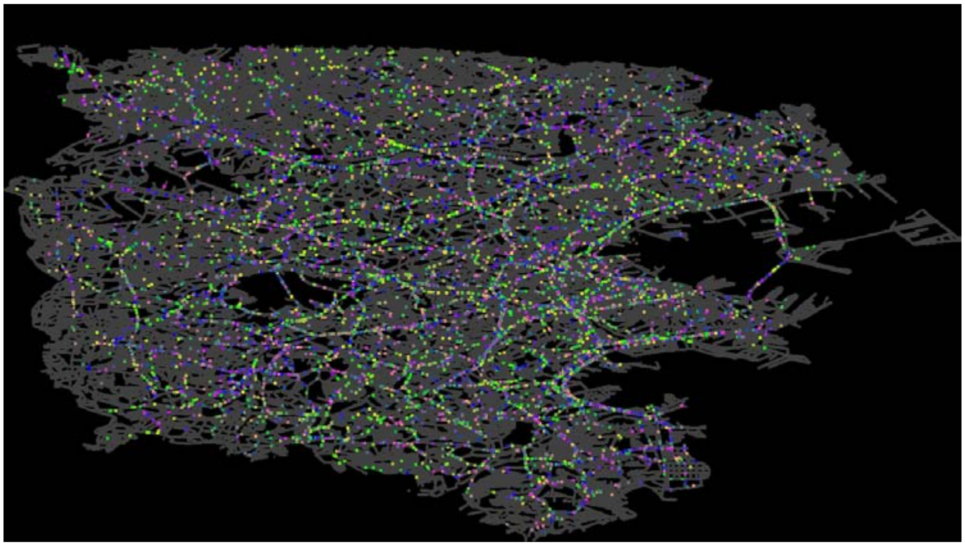

Figure 8: Traffic Simulation Snapshot

Figure 9 shows the accumulated simulation results of traffic volume and CO2 emissions for 24 hours. These graphs indicate that there are lag and magnification in CO2 emissions at peak hours which may be caused by traffic jams.

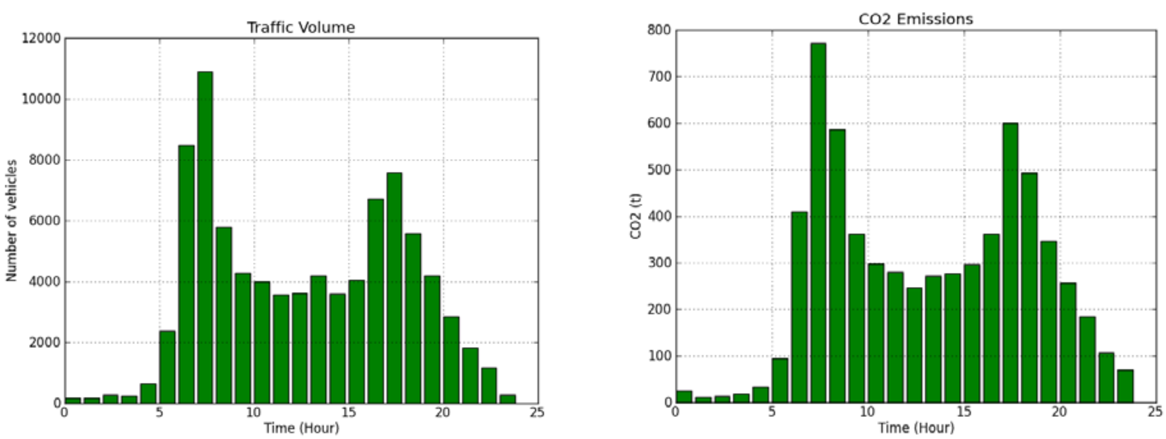

Figure 9: Traffic volume and CO2 emissions for 24 hour simulation based on Person-Trip data

We can also evaluate the simulated traffic volume (Figure 10), CO2 emissions (Figure 11) and average vehicle speed (Figure12) on each road as histogram for each scenario. These indicate the aggregated frequency in log scale over the simulation length (1 hour) of all roads, on/through which the specific number n (n > 0) of vehicles have moved. At now, we change the several economic parameters such as transportation fee to generate compact and dispersed cities and calculate origin-destination traffic demand from the estimated population. But, we can see little difference between current compact and dispersed cities scenarios with these simulation results. As we can see from the histogram of the traffic volume (Figure 10) and vehicle speed (Figure 12), there is excessive concentration into major streets and traffic jams in the result. We consider that these traffic jams obscure the difference between scenarios.

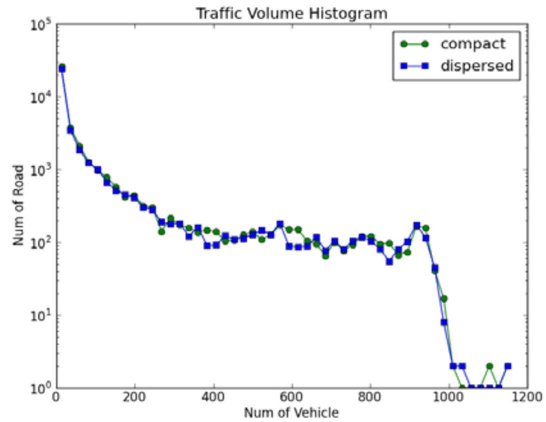

Figure 10: Histogram of traffic volume in two scenarios

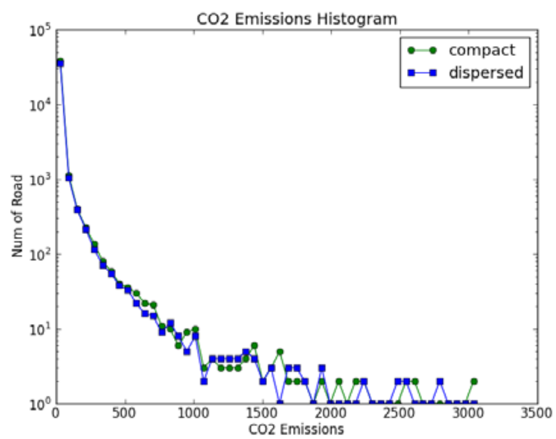

Figure 11: Histogram of CO2 emissions in two scenarios

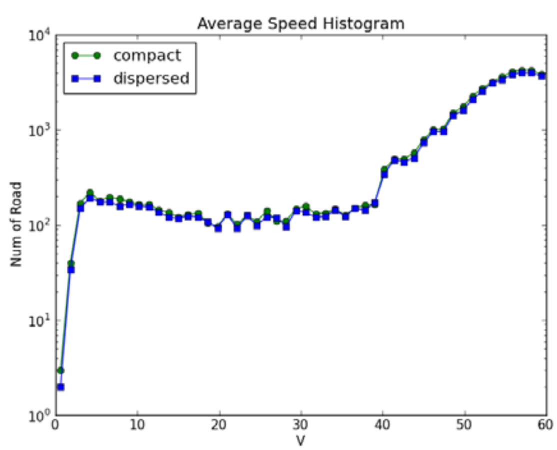

Figure 12: Histogram of average vehicle speed in two scenarios

For this analysis, we evaluate the CO_2 emissions from individual vehicle speed at every simulation time steps (1 sec). By Oguchi and Katakura (2000), fuel consumption per unit time, f *(cc/sec)*, can be estimated from a vehicle speed, *v (Km/sec)* as *f = 0.338 + 0.00895 v* and CO_2 emissions *E (kg-CO2)* from total fuel consumption, *F (cc)* as *E = 0.0231 F*. From the simulation results, we obtained emissions per hour as *601 tCO2* in dispersed city scenario and *657 tCO2* in compact city scenario.

For these simulations, we only used simple road information without signals and limit speed variation. In future works, we should utilize more road information and modal traffic split both in LUE model and simulation for high accuracy and validate detailed analysis results with real city data with collaboration .

As shown in these analyses, we developed a system with fine grained land model and large-scale traffic simulation which can support decision making for city planners by indicating road traffic volumes, including traffic jams and CO_2 emissions with estimated future scenarios in detail.

7 THE EFFECT OF GASOLINE PRICE CHANGE ON TRAFFIC VOLUME AND CO_2 EMISSION

Figure 13 shows the effect of gasoline price change on traffic volume and CO_2 emission. The current gasoline price is approximately 150 yen/l, and we raise the price up to 2000 yen/l in order to look at the effect of maximum gasoline price fluctuation (including carbon tax). When we set the price to 500 yen/l, then the traffic volume will increase because the effect of population increase exceeds the effect of modal shift from vehicle/bus to train/walk. In the 1000 yen/l case, it is shown that the latter effect will exceed the former effect. On the other hand, the CO_2 emission may decrease in the 500 yen/l case despite traffic volume may increase (CO_2 emission is calculated using the emission coefficient 319.42 g-CO_2/km for an average automobile, Ministry of the Environment 2001). This result is caused by the decrease of the long-distance trip, which is shifted to train.

By demonstrating such a simulation with LUE model output, we can estimate the CO_2 emission from the transport sector at the city level, and can discuss the introduction of carbon tax with considering urban form. Such a novel analysis can be very useful for designing LCC. However, the current LUE model is *static*, and can consider only (daily) mean velocity of vehicles. Hence we are required to input the modal-share-adjusted OD traffic volume distribution into the traffic simulator, and simulate the CO_2 emission in detail. This analysis is posted to the next research.

(We cannot simulate the CO_2 emission in the current dispersion city scenario, because we have assumed that households will not commute, then estimated CO_2 emission of commuting purpose may equal to zero).

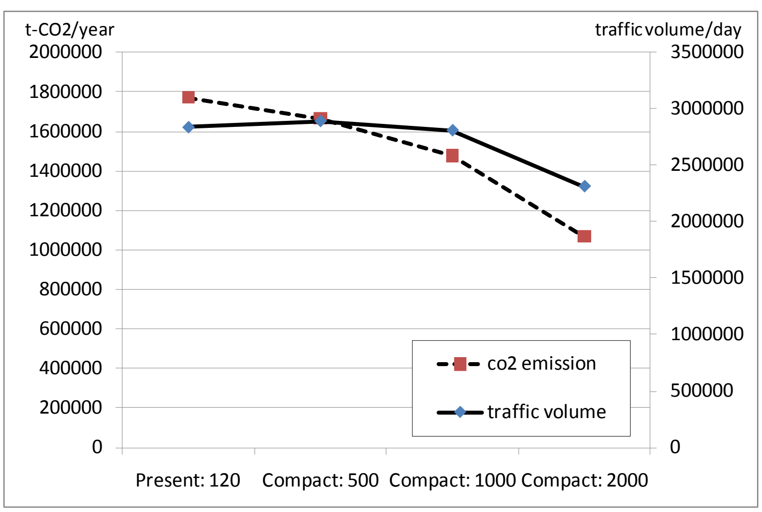

Figure 13: The Effect of Gasoline Price Change on Traffic Volume and CO_2 Emission

8 CONCLUSIONS

In this paper, we tried to discuss a new concept to simulate Low carbon city by integrating the sectors of land use (residential, commercial), transportation where CO_2 emissions are mostly produced. Especially, in order to achieve effective carbon management strategy in the coming LCC, we need to design land use and transportation system at the municipality level using such simulation tools, as it is discussed recently as the smart city concept that also include the smart grid systems using all possible renewable energies.

At this point, we have focused on the traffic of gasoline vehicle in the simulation because CO_2 emissions from this sector occupy a large portion in a city and should be reduced swiftly for LCC. But, the modal traffic split is also a quite important issue that can radically change the road traffic volume and CO_2 emissions. The public transportation including railway are treated in our land use model as economic factor to control the distribution of population. However, we can also modify the traffic demand for traffic simulation not only with the estimated population but also the current survey data on the modal traffic split. Furthermore, LUE model itself can be refined iteratively with the results of traffic simulations. Such a stepwise development of integrated LCC simulation is left for future work.

Based on the developed simulations tools and their tests at a city, we can argue that a new approach of LCC simulation could be applicable to make possible scenarios for achieving the ambitious emission reduction target (such as 80% by 2050) that might need to be considered in the near future.

In the future, the detailed geographical city energy consumption demands can be modeled from the point of local land use planning including the assessment of associated renewable energy based electric transportation system. Then, this kind of simulations tools would play an important role for designing and also managing LCC. The simulation would be also important for the planning process, because urban planners need to discuss with the local stakeholders by showing the possible scenarios using such simulations.

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