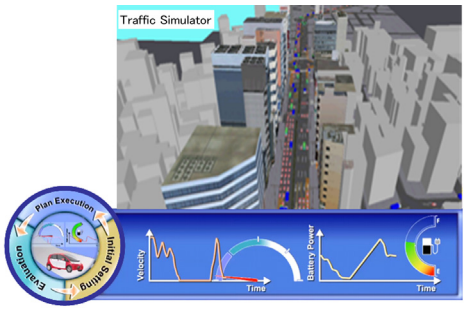
Environment-Conscious Urban Design Simulator "Clean Mobility Simulator" – Traffic Simulator that Includes Electric Vehicles –



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For discussion and proliferation of smart community projects around the world that strive for a low-carbon society through the effective use of energy and electric power-demand management, there is a growing demand of technology for the quantitative evaluation of urban comfort and energy management. Mitsubishi Heavy Industries, Ltd. (MHI) has focused its attention on traffic, which is difficult to evaluate quantitatively. MHI has developed a traffic evaluation simulator that can examine the introduction of infrastructure related to charging equipment and transportation measures for the spread of electric vehicles. This paper presents an overview of the simulator and several examples of its use

1. Introduction

Smart community projects that intend to establish a social system based on electricity and realize low-carbon society are discussed and executed around the world in response to attention-drawing large scale environmental issues such as global warming. In these projects, as well as renewable energy and more-efficient fossil fuel applications, the efficient use of electricity through electric power-demand management has a significant role in achieving a low-carbon society. These projects often include the adoption of electric vehicles (EVs) for transportation. Thus there is a growing need to study the required charging infrastructure and traffic measures for electric power-demand management in the context of the accompanying increase in the demand for electric power. However, quantitative evaluation of the electric power demand of transportation is difficult because the demand is significantly influenced by social behavior of each person. This requires an evaluation approach that can consider such factors.

We have developed a Clean Mobility Simulator, a traffic evaluation model that can simulate city traffic flows including the charging of EVs. The simulator can also quantitatively evaluate traffic-related urban comfort and energy management. This paper presents an overview of the simulator.

2. Clean Mobility Simulator Overview

This simulator models city traffic conditions through simulation of EVs and gasoline-powered vehicles traveling from their start points to destinations on a platform on which information about road networks and traffic signals is set.

Figure 1 shows the main structure of the simulator. This simulator has a main traffic flow simulation function, an input function that sets data of road networks, vehicles, infrastructure (e.g., charging stations and traffic signals), a charging route control function and an EV characteristic calculation function that simulate EV travel, a charging simulation function that simulates charging, and area electric power calculation and monitoring functions that check and evaluate the status in real time. The following five sections describe the main functions of the simulator.

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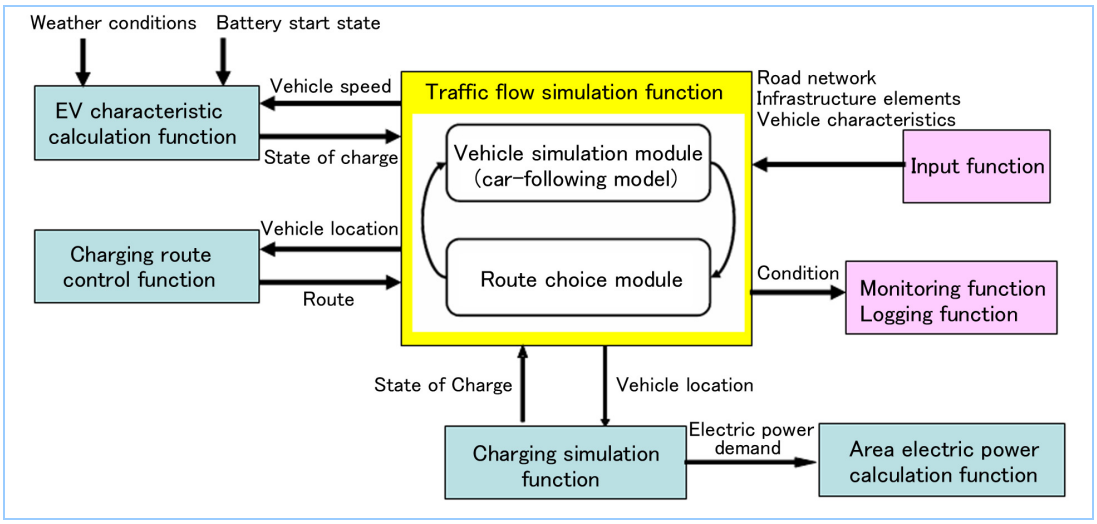


Figure 1 Simulation structure

2.1 Traffic flow simulation function

The traffic flow simulation function, a main function of this simulator, is based on the SOUND large-scale road network simulation model developed by the University of Tokyo's Institute of Industrial Science and sold commercially by the i-Transport Lab. Co. Ltd.[1] Like other typical traffic flow simulators, SOUND consists of a module for a simulated road network based on road data from maps, and modules for simulated vehicles traveling on the road network. SOUND has the following main characteristics:

- A traffic flow module calculates vehicle travel based on the traffic-flow–traffic-density relation (Q-K curve) assigned to each road. Although this requires only simple logic, it can reproduce dynamic traffic conditions such as the increase in traffic congestion durations.
- Vehicles can be handled discretely. The behavior of each vehicle is calculated based on the vehicle's properties, which can be set individually.
- A route choice module uses link costs, which are travel-related evaluation values (e.g., tolls and required time). Because link costs are updated sequentially, simulation of route choice in response to traffic conditions is possible. In addition, route choice characteristics can be specified in the aforementioned vehicle properties, based on which route choice simulation according to individual driver characteristics is made possible.

2.2 EV characteristic calculation function

This function calculates the change of charge state of each EV as it travels. **Figure 2** shows an overview of the calculation logic. This function calculates the change of charge state based on vehicle speed, driving conditions such as use of air conditioning equipment or headlights, and the number of occupants. Consideration of environmental conditions such as air temperature, road grade, and battery temperature are included to produce a more accurate module.

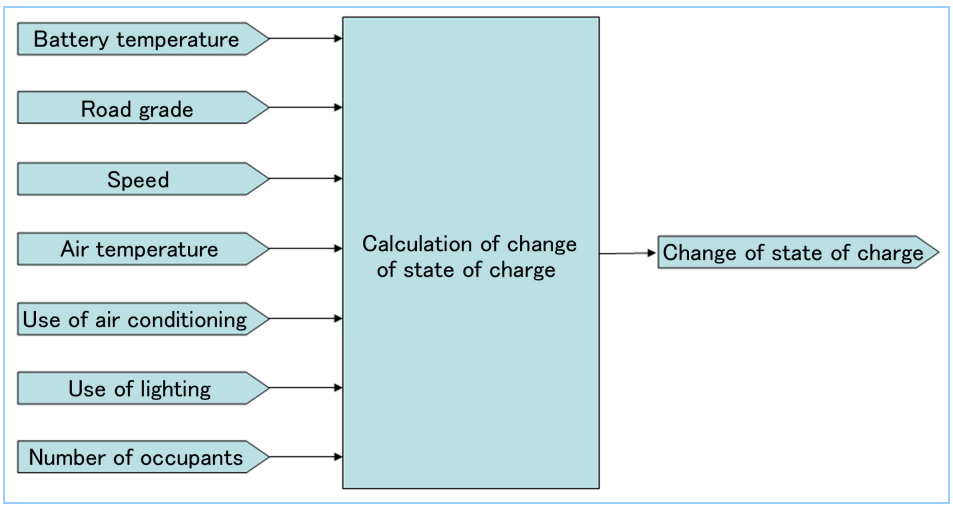


Figure 2 Calculation of change of charge state

Inputs to this function, e.g., use of the air conditioning or headlights, are determined according to each vehicle's criterion based on the preset time and temperature. Road grade information has been incorporated into to the road network information.

2.3 Charging route control function

Gasoline-powered vehicles and EVs with a sufficient state of charge select their routes using a route choice module included in the traffic flow simulation function described in Section 2.1. The charging route control function is used to select a route that includes a charging station for an EV whose battery is running low.

For an EV requiring charging, this function sets the priority of charging stations according to the route choice characteristic of each EV, taking into account the required travel time from the current location to each charging station, the geographical relationship between the destination and each charging station location, the charging fee, and the degree of congestion at each charging station. Each EV makes the top priority charging station its temporary destination and heads toward it.

2.4 Charging simulation function

This function simulates charging stations and EV charging. Each charging station has certain properties, including the number of vehicles that it can charge simultaneously and the electric power capacity that the charging station can accept. If the number of vehicles that require charging is greater than the number of vehicles that a charging station can charge simultaneously, an EV joins a queue when it arrives at the charging station. When the EV reaches the head of the queue, charging starts and continues until the vehicle reaches the specified state of charge, at which point it resumes travel to its original destination.

2.5 Area electric power calculation function

This function calculates the average speed, electric power demand, and CO2 emission across the simulated area[2] and evaluates the decrease in urban comfort caused by congestion and the effect of energy management measures. This module can also calculate the electric power demand of all charging stations in an arbitrary area of the simulation to evaluate the electrical load of each area.

3. Simulation Results of EVs Operating in Urban Area

The required number of charging stations compared to the rate of EV adoption in the target evaluation area as well as the effects on congestion of the charging stations' locations, capacities, and charging fees can be evaluated by modeling traffic flow including EVs using this simulator. The example below shows an evaluation of the EV adoption rate on traffic density.

3.1 Parameter setting

The road network is based on map data. The road grade and air temperature are then set; these both affect EV electric power consumption. Next, infrastructure effects such as traffic signals and charging stations are specified. The properties of each charging station are then set; these include its location, the number of vehicles that it can charge simultaneously, and the electric capacity that it can accept. Three charging stations were set in this example. The settings for the vehicle module are determined from traffic census and include each vehicle's start point, destination, start time, and route choice properties. The battery capacity and initial state of charge are also set for EVs.

3.2 Simulation operation

Figure 3 shows the simulator screen. When the simulation runs, vehicles appear on the road network according to their individual start times and start points. They then travel to their individual destinations while selecting routes that depend on the road conditions and their individual route choice properties. The vehicles interact with each other and change the road conditions. Traffic flow across the city is thus simulated from a macro perspective.

The EVs travel to their destinations and undergo charging as required by calculation of electric power consumption during their journeys. **Figure 4** shows an EV monitoring screen indicating the state of charge, travel distance, and average travel speed. When charging is required, a list of the charging station options appears, as shown in **Figure 5**. This permits monitoring which charging station is selected and why (i.e., distance to the station, congestion, etc.).

Figure 6 shows a charging station monitoring screen indicating charging conditions of the charging station. This also permits monitoring electric power demand for a certain area or the whole simulation.

These monitoring functions allow simulation operators to determine traffic conditions intuitively and accurately even if they have no expert knowledge.

Figure 3 Simulator screen

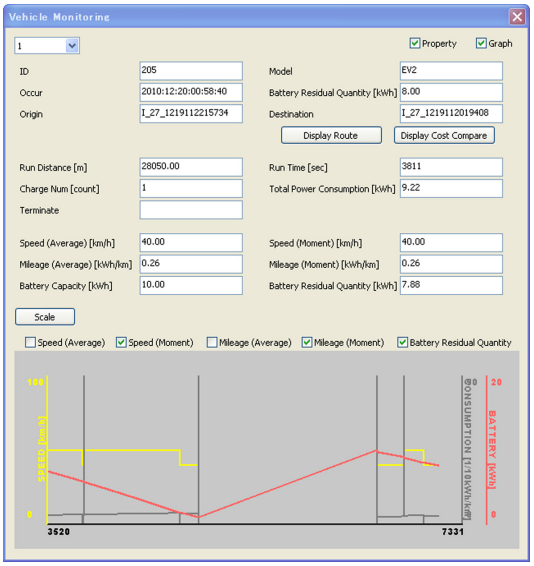


Figure 4 EV monitoring

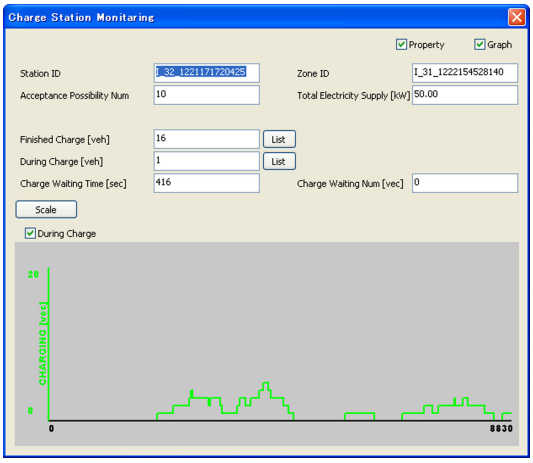
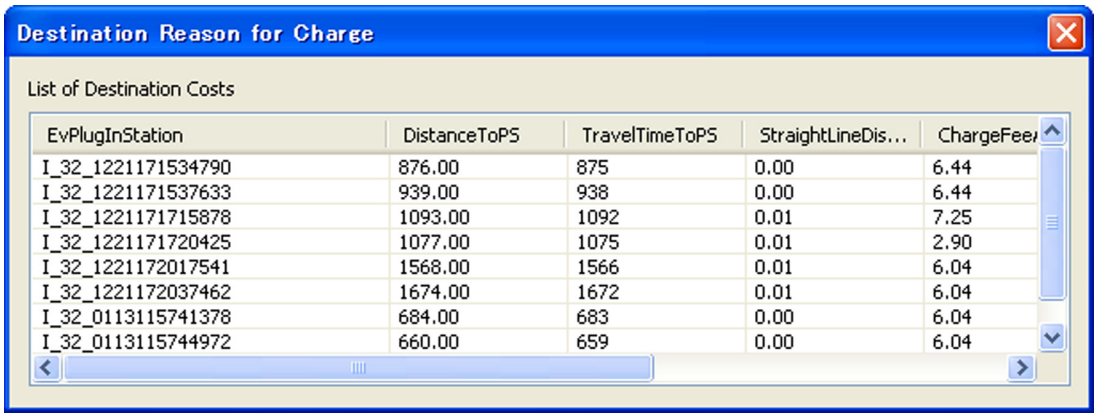


Figure 6 Charging station monitoring



Destination Reason for Charge

List of Destination Costs

EvPlugInStation	DistanceToPS	TravelTimeToPS	StraightLineDis...	ChargeFee/
I_32_1221171534790	876.00	875	0.00	6.44
I_32_1221171537633	939.00	938	0.00	6.44
I_32_1221171715878	1093.00	1092	0.01	7.25
I_32_1221171720425	1077.00	1075	0.01	2.90
I_32_1221172017541	1568.00	1566	0.01	6.04
I_32_1221172037462	1674.00	1672	0.01	6.04
I_32_0113115741378	684.00	683	0.00	6.04
I_32_0113115744972	660.00	659	0.00	6.04

Figure 5 List of charging station options

3.3 Evaluation

The log function facilitates understanding of trends over the whole simulation area as well as the specific details of each vehicle's behavior. For example, a comparison of the trends in three separate areas of the whole simulation area was performed. **Figures 7** and **8** show the average speed and electric power demand as functions of time in each area.

Figure 7 shows that area A is relatively clear in the first half of the simulation but is congested in the second half, whereas area B experiences limited-time congestion such as commuter rush hours in both halves of the simulation. Area C experiences no heavy congestion at any time.

Figure 8 shows the peak electric power demand in each area; the required electric energy can be calculated. Figures 7 and 8 together show that in all areas, the electric power demand is lower when the average speed is higher (i.e., lighter congestion) and the electric power demand is higher when the average speed is lower (i.e., heavier congestion). The cause of congestion for heavier-congestion periods and heavier-congestion areas can be analyzed based on these results. If the cause is due to waiting time for charging at a charging station, for example, countermeasures such as increasing the number of vehicles that charging stations can charge simultaneously are possible to reduce both congestion and electric power demand. Furthermore, the efficiency of such countermeasures can be improved by checking their effect using the simulation.

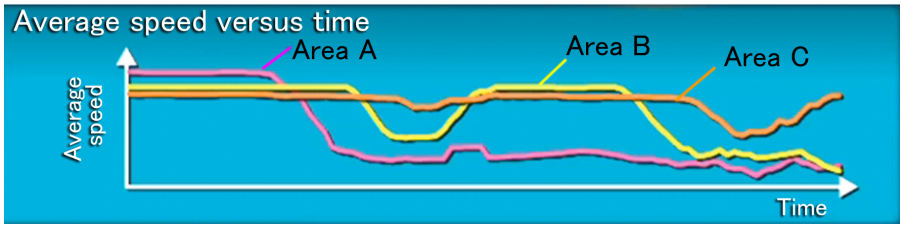


Figure 7 Average speed as a function of time

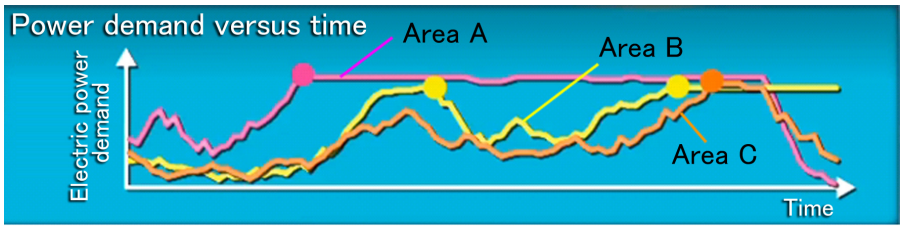


Figure 8 Electric power demand as a function of time

3.4 Application to transportation measures and infrastructure evaluation

The effect of introducing infrastructure and transportation measures can be evaluated by running this simulation under various conditions. For example, **Table 1** shows the effects of various EV adoption rates on average travel time, total travel time, and CO_2 emissions using this simulation while holding the number and locations of charging stations fixed.

Table 1 Effect of EV adoption rate

EV adoption rate	5%	20%	50%
CO_2 reduction rate	3.9%	15.4%	38.5%
Total travel time	44min	47min	49min
Average travel speed	42.0km/h	41.6km/h	41.4km/h

In this way, the effect of the EV adoption rate on CO_2 reduction, total travel time, and average travel speed for a certain configuration of charging infrastructure, i.e., charging stations, can be calculated. This simulator can be used to discuss effectiveness of an infrastructure plan such as addition of charging stations and determination of their locations by evaluating the results as a function of EV adoption rate.

This simulator was well received at the World Future Energy Summit held in the United Arab Emirates in January 2011 (**Figure 9**).

Figure 9 World Future Energy Summit 2011

4. Future Plans

In Section 3, we introduced evaluations based on the EV adoption rate. This simulator can also be used to evaluate the introduction of public transportation facilities and operational measures using transportation modules such as EV bus modules.

Extending the road traffic module of this simulator to handle rail transportation will permit the evaluation of more types of public transportation facilities. This simulator could be used for evaluating modal shift, which is attractive in terms of its effect on maintenance of urban comfort and the efficient use of energy.

Adding human factors, i.e., characteristics specific to individuals, to model behaviors such as route selection and start time will permit simulating behavior that depends on local customs and cultures. This will permit even more effective measures to be examined.

5. Conclusion

We introduced a Clean Mobility Simulator to the market where energy management is increasingly important in transportation systems. This traffic evaluation simulator includes simulating the travel and charging of EVs. It can evaluate the electric power demand of EVs and the degree of congestion in an urban area, and permits studying the introduction, operation, and adjustments of charging infrastructure.

In the future, we will consider extending this simulator to rail transportation and include individual selection behavior to increase its flexibility. We would like to contribute to smart community projects using this simulator as an effective evaluation tool for urban design.

References

1. i-Transport Lab. Co. Ltd., Large Scale Road Network Simulation Model, SOUND http://www.i-transportlab.jp/products/sound/index.html
2. Oshiro et al., Fuel Consumption and Emission Factors of Carbon Dioxide for Motor Vehicles, Civil Engineering Journal Vol. 43 No. 11 (2001)