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A Japanese model plan for a quick-charging network based on traffic simulation for promoting EVs

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Abstract

The Central Research Institute of Electric Power Industry and Kozo Keikaku Engineering, Inc. have been developing the Optimizer for Layout of Electric Infrastructure Network by Traffic Simulator for Electrified Vehicles (EV-OLYENTOR) to contribute to optimizing the geographic layout of charging infrastructure in in the world. With the aim of popularizing electric vehicles (EVs) and plug-in hybrid vehicles (PHVs) in Japan, EV-OLYENTOR performs road traffic simulations for EVs and PHVs based on an origin–destination traffic database. The Japanese Ministry of Economy, Trade and Industry has unveiled a model plan for quick-charging infrastructure on roads and in cities by reference to EV-OLYENTOR simulations. In March 2016, the Japanese government proposed a strategic “EV-PHV roadmap” to increase the number of EVs and PHVs by more than 1 million, and to prepare charging infrastructure through 2020. The model plan proposed by EV-OLYENTOR is contributing to the strategic "EV-PHV roadmap."

Keywords: BEV, PHEV, Charging, Fast charging, Infrastructure

1 Background

Reducing energy demand and CO_2 (carbon dioxide) emissions from power supply systems is an important strategy against global warming. Japan is installing renewable electric energy sources, including photovoltaics and wind turbines. A combination of low-carbon electric power generation and high-efficiency electrical technologies should help to decrease CO_2 emissions. The Japanese government has an ambitious target of reducing CO_2 emissions by more than 25% by 2030. In the transportation and energy conversion sectors, the goal is to reduce emissions by 28%. We believe that the popularization of next-generation vehicles will be accelerated by improving energy efficiency to reduce CO_2 emissions.

To realize a low-carbon society, it is important to combine low-carbon electricity and energy-saving technologies to reduce CO_2 emissions. We also need to supply low-carbon electricity from highly efficient thermal generation and renewable energy sources. We need to use high-efficiency technologies on the demand side, too. Examples include next-generation vehicles, electric vehicles (EVs) and plug-in hybrid vehicles (PHVs), and heat pumps. By addressing both demand and supply, we can considerably reduce CO_2 emissions.

Combining high-efficiency technologies and low-carbon power is very effective for reducing CO_2 emissions. In particular, we know that charging high-efficiency EVs with low-carbon electricity is very effective. Overall EV CO_2 emissions depend on the CO_2 emission factor from bulk electric power generation [(1)]. The solid line in Fig. 1 shows CO_2 emissions from EVs. The emissions of the Toyota Prius hybrid vehicle have been reduced from 123 to 90 g-CO_2/km, and then to only 60 g-CO_2/km in the most recent model. Even though the CO_2 emission factor was only about 0.4 kg-CO_2/kWh before the Great East Japan Earthquake, this has increased now to about 0.55 kg-CO_2/kWh, increasing CO_2 emissions from driving EVs. We need to decrease the CO_2 emission factor by introducing renewable energy sources, and we should improve EV driving performance to move the solid line toward the dotted line in Fig. 1.

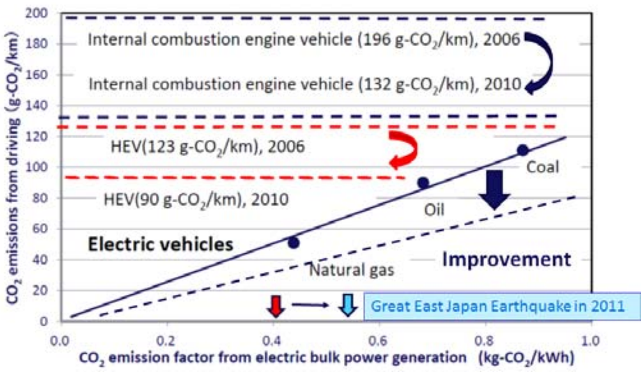

Fig. 1 CO_2 emissions from driving EVs based on the CO_2 emission factor from bulk electric power generation

There are three challenges in achieving this: extending driving distance per charge, reducing cost, and preparing a charging infrastructure to accelerate popularization of EVs and PHVs. Infrastructure preparation of quick-charging stations and optimization of their locations in cities are necessary to prevent EVs from stopping due to insufficient battery capacity [(2, 3)].

Today, there are more than 5,500 quick-charging stations across Japan. The Central Research Institute of Electric Power Industry (CRIEPI) has been researching scenarios and markets for EVs and PHVs, optimizing the locations of EV charging stations and estimating battery power depletion during driving. CRIEPI and Kozo Keikaku Engineering, Inc. (KKE) developed a traffic simulator and suggested a policy of optimizing the locations of quick-charging stations in cities through an EV simulation for discussing the EV–PHV roadmap [(2, 3)]. In this paper, we describe a simulator called the Optimizer for Layout of Electric Infrastructure Network by Traffic Simulator for Electrified Vehicles (EV-OLYENTOR) for discussing obstacles to popularizing EVs and PHVs.

2 Simulations for optimum arrangement of quick-charging stations

2.1 EV-OLYENTOR

CRIEPI and KKE have proposed much simpler estimation methods [2, 3] for optimizing EV charging station locations, based on an origin and destination traffic database for internal combustion engine vehicles not only in Japan also in other areas in the world. EV-OLYENTOR is based on the Artisoc social simulator created by KKE. EV-OLYENTOR has a multilayer structure, with the three layers shown in Fig. 2. The first layer is for the pre-post tool. We input data from a map database, along with traffic and census data. The second layer is the traffic simulator. Each EV drives on the map according to the traffic conditions and census data. The third layer outputs results from the simulator. This allows optimization of locations for quick-charging stations to be used by EVs driving in cities.

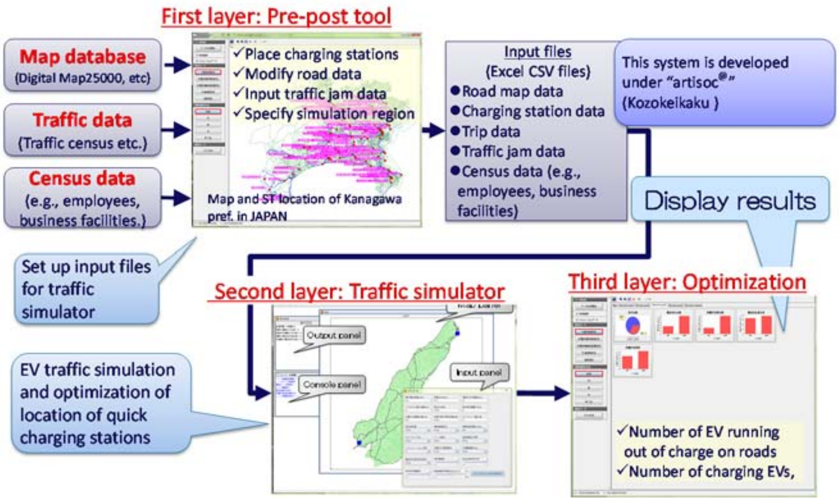

Fig. 2 Structure of the EV-OLYENTOR traffic simulator with multiple layers to analyze locations for quick-charging stations for EVs.

In the simulation, some EVs are stranded on the road (at locations indicated by red crosses) because they ran out of charge. In the second layer, on the left side in Fig. 2 and Fig. 3, the locations of charging stations are optimized by moving them to areas with higher densities of red crosses. The second layer has two sub-layers, as shown in Fig. 3. Sub-layer 1 is the traffic

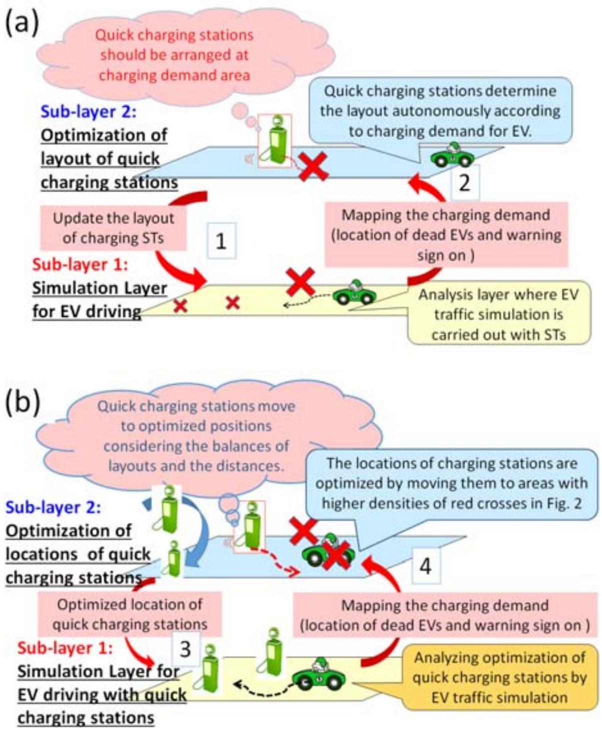

Fig. 3 Optimization of the location of quick-charging stations on roads, in cities, and across regions, proceeding from 1 to 4. (a) EV simulator and arrangement of quick-charging stations; (b) Optimization of the layout.

simulator and sub-layer 2 arranges the quick-charging stations and rearranges against stranding EVs in Fig. 3 (a). We repeated the simulation several times to optimize the arrangement of quick-charging stations so as to decrease the number of stranded EVs while considering the balance of the layout (Fig. 3 (b)). This method can optimize the location of quick-charging stations on roads, in cities, and across regions by considering the layouts and the distances around every charging station in the area. The quick-charging stations are moved based on the optimized layout.

2.2 Optimizing the location of quick-charging stations

We first run the simulator with no quick-charging stations. We then add quick-charging stations, 20 at a time, on a trial basis. We continue to increase the number of charging stations until the percentage of stranded EVs is less than 1%. (We recognize that the percentage of stranded internal combustion engine vehicles is much less than 1%.). We use the simulation to optimize the location of quick-charging stations for more than 10 areas in Japan. We discuss the models of the locations of quick-charging stations for areas such as towns, mountains, peninsulas, and bays.

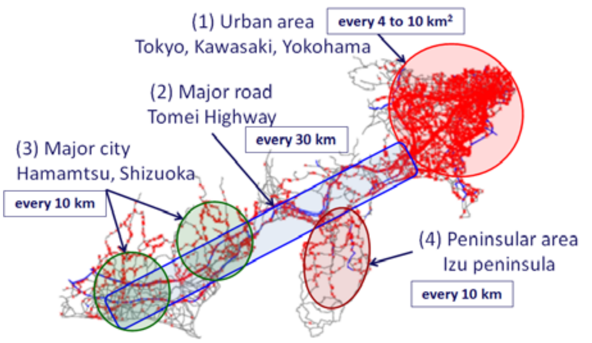

Fig. 4 Model plan for quick-charging station locations in Tokyo, Kanagawa, and Shizuoka prefectures, as analyzed by EV-OLYENTOR

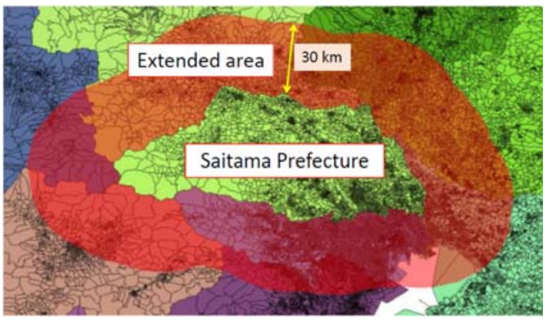

Fig. 5 The A 30-km extended area for the current quick-charging station layout

The simulator suggests that in the three prefectures of Tokyo, Kanagawa, and Shizuoka, EVs could drive for a day without running short of charge if there were 160 quick-charging stations installed in that region (Fig. 4). We have similarly used EV-OLYENTOR to propose model plans for quick-charging station placements for all Japanese prefectures. For example, we estimated the current state of existing quick-charge stations in Kanagawa, and proposed to the Kanagawa government installation of a quick-charging station at the entrance of the Hakone Mountains to prevent EV charge shortages. We have furthermore prepared estimations of the current layout of quick-charging stations for each prefecture with a 30-km extended range (Fig. 5). The method mentioned above has also been applicable in other areas in the world.

3 Modeling layout plans for quick-charging stations in Japan

Based on EV driving simulations in several areas, model layout plans for installing quick-charging stations on roads and in cities can be summarized as follows. Quick-charging stations should be installed every 4 to 10 km^2 in a grid-like pattern in urban areas, every 10 km on major inter-urban roads, every 30 km on roads connecting smaller cities, and every 10 km on roads along peninsulas and in highland areas. Japanese local governments have been accelerating installation of quick-charging stations. As of April 2017, we have more than 5,000 normal and quick-charging stations. The model plan proposed by EV-OLYENTOR contributes to the strategic "EV-PHV roadmap" and the numbers of both normal and quick-charging stations have been increasing gradually.

4 Summary

CRIEPI and KKE have been using EV-OLYENTOR to conduct R&D on technologies for estimating the effects of charging infrastructure to help popularize EVs and PHVs based on the geography and road layouts in the area. METI has unveiled a model plan to install charging infrastructure on roads and in cities for quick-charging stations, and its “EV-PHV roadmap” in reference to the results of these simulations. Japan is trying to get more than 1 million EVs and PHVs on the road by preparing a charging infrastructure.

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