Analysis on Optimum Layout of Charging Station

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Abstract

- Analysis result on optimization of the layout of charging stations (ST) by estimating charging demand of electric vehicle (EV) based on the traffic simulation.
- As the layout method for STs, the following empirical methods are proposed based on the optimum layout analysis, condition for preferential placement to large city, space of ST placement along major roads, allocation of ST for major cities, No. of ST for each prefecture.
- Basic concept for optimizing the ST layout and outline of traffic simulator for analyzing charging infrastructure of next generation vehicles EV-OLYENTOR®.
Content

1. Introduction : study on EV and charging infrastructure in CRIEPI
2. Outline of H24 sponsored research on Optimum Layout of Charging Station
3. Outline of traffic simulator for analyzing charging infrastructure of next generation vehicles 「EV-OLYENTOR®」
4. What is the optimum layout of charging STs?
5. Analysis result on optimum layout of charging ST
6. Layout method for charging STs based on the analysis of optimum layout
7. Summary
Study on EV and charging infrastructure in CRIEPI

- Study on the effect on the electric network by the electric demand, potential of CO$_2$ reduction, diversification of vehicle fuel by introduction of next generation vehicle
- Study on the leveling method of electric demand and the stabilizing method of renewable energy by charging battery of EV (collaboration with Univ. of Tokyo)
- Development of traffic simulator (EV-OLYENTOR®) for analyzing charging demand and charging infrastructure applicable to the study on the effect of EV introduction on the electric network
Outline of the sponsored study

◆ The optimum layout of charging STs are analyzed for the development of charging infrastructure network, and the guideline of locating a ST to minimize the empty energy risk is proposed.

◆ Study items

① Analysis of the effect of the present ST network for the model regions
② Analysis of optimum layout of ST for the model regions
③ Analysis of optimum location for the additional STs for the model regions
④ Proposal of the guideline of locating STs
Traffic simulator for analyzing charging ST of next generation vehicle: 「EV-OLYENTOR®」

**Pre-post tool**

- Map Database (Digital Map25000, etc.)
- Traffic Data (Traffic census etc.)
- Census Data (employee, business facility etc.)

Set up input files for traffic simulator

**Traffic simulator**

- EV traffic simulation and ST optimization

**Input files** (Excel CSV files)
- Road map data
- Charging ST data
- Trip data
- Traffic jam data
- Census data (employee, business facility)

**Display results**

- Map and ST location of Kanagawa pref. in JAPAN
- No. of EV running out of electricity
- No. of charging EV, etc.

This system is developed under “artisoc” (Kozokeikaku Eng. Inc.)
Demo. of traffic simulation

× : dead EV  × : point where warning sign is on of dead EV
▲ : EV with warning sign on  ▲ : commuter use  ▲ : go home use
▲ : random use  ▲ : out-of-service EV  ■ : charging ST
Model of road network

- Digital Road Map (Japan Digital Road Map Association)
- Digital Map 25000 (Geospatial Information Authority of Japan)、Open Street Map (http://www.openstreetmap.org/) are also available.

Analysis target: highway, national rd., major local rd.

Map database

Map model

- Rd. width more than 13m
- Rd. width of 5.5m～13m
Rd. gradient based on elevation data

Fig. Elevation of Tottori and Okayama prefs.

Fig. Rd. gradient of Tottori and Okayama prefs.
Effect of rd. gradient on mileage

Based on the CRUISE® system of AVL company in Austria, a fuel mileage simulation model of i-MiEV (2010 model, type: ZAA-HA3W) is applied to develop the mileage function (shown as the figure).

Fig. Simulation model of i-MiEV on CRUISE.  Fig. Mileage function applied in traffic simulation.
Algorithm of charging behavior and EV conditions

**EV conditions**

<table>
<thead>
<tr>
<th>EV conditions</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery capacity $C_i$ (kWh)</td>
<td>16</td>
</tr>
<tr>
<td>Initial state of charge $SOC_i^{start}$</td>
<td>1.0</td>
</tr>
<tr>
<td>Fuel mileage $L^{fm}_{km/kWh}$</td>
<td>7.5</td>
</tr>
<tr>
<td>Accessory power $p_{ac}$ (kW)</td>
<td>3.0</td>
</tr>
<tr>
<td>Threshold for warning sign $E_{alarm}$ (kWh)</td>
<td>8.0</td>
</tr>
<tr>
<td>velocity normal rd./hwy. (km/h)</td>
<td>45/80</td>
</tr>
<tr>
<td>Traffic jam effect</td>
<td>on</td>
</tr>
</tbody>
</table>

EV starts the charging behavior to nearest ST just after warning sign on
Threshold of battery energy for warning sign

- SOC $\leq 50\%$ starts the charging behavior (Fig2-7, Guideline of installing charging infrastructure to parking area, 2012, Ministry of Land, Infrastructure, Transport and Tourism)

- SOC $= 50\% \sim 60\%$ at the start of charging is maximum. (http://avt.inl.gov/evproject.shtml)

- SOC $\leq 50\%$ is applied as the trigger to the charging behavior.

- However, it is said that learning EV operation enables to make small the trigger of SOC for charging behavior.
EV operation conditions

- Use: owner-driven car
- Origin: proportional to employed population
- Trip length: based on the traffic survey
- Destination: proportional to No. of company
- Route: to minimize the trip period from origin to destination
- Daily trip freq.: based on the traffic survey

Fig. Distribution of trip length

Ref.: Disclosed data from JARI to METI obtained in the standardization project of basic technology for integrated battery system (New Energy Promotion Council)

Ref. The investigation committee for transportation system for Imabari city
Validation of traffic simulation 1

- Simulation results (simulation) is compared with person trip survey (survey) for validation.

Comparison of EV generation distribution (%)

Yokohama Kawasaki 22 23 24 25 26 27 28 29

Simulation Survey Simulation Survey Simulation Survey Simulation Survey Simulation Survey Simulation Survey Simulation Survey

37 34 11 10 6 6 3 3 9 8 4 6 4 5 2 3 10 10 14 15

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Validation of traffic simulation 2

- Simulation results (simulation) is compared with person trip survey (survey) for validation as for origin and destination.

Comparison of origin and destination (%)

- Kawasaki
- Yokohama

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Algorithm for relocation of ST

Layer 2
Charging ST Layer

Charging ST moves to charging demand area

Analysis layer where charging STs determine the layout autonomously according to charging demand

Layer 1
EV Layer

Update the layout of charging STs

Mapping the charging demand (location of dead EVs and warning sign on)

Analysis layer where EV traffic simulation is carried out with STs
Demo. of relocation of ST
Algorithm for optimizing layout of STs

1. Analyze the locate of warning sign on and the total elapsed time of warning sign by traffic simulation.
2. According the ranking of the elapsed time of warning sign for each city, charging ST is tentatively placed.
3. Charging STs relocate autonomously according to the charging demand of warning sign on.

① EV traffic simulation
② ST is tentatively placed according to the ranking
③ STs relocate autonomously according to the charging demand
What is the optimum layout of charging STs?

◆ How many STs are required?
  ➢ The point is two viewpoints from EV user and from infrastructure company (feasibility of ST operation as business)
    ■ EV user: The more charging ST number, the more useful for EV user
    ■ ST company: The more charging ST number, the less the ST availability (excessive competition)

◆ Where should the ST be placed?
  ➢ Placement priority of STs depends on the charging demand
Risk of empty electric energy

◆ Risk of empty fuel for the owner-driven car
  ➢ No. of gas station in Japan: about 40000 (2010)
  ➢ Risk of empty fuel: \( \sim 5.0 \times 10^{-4}\% \)
    - Annual rescue No. for empty fuel: 84420 (JAF
      [http://www.jaf.or.jp/rservice/data/index.htm](http://www.jaf.or.jp/rservice/data/index.htm))
    - No. of the owner-driven car: about 68,000,000
    - Availability of the owner-driven car (2008): 70% (Ministry of Land, Infrastructure, Transport and Tourism)

◆ Risk of empty energy for EV
  ➢ No. of charging ST in Japan: 1677 (April. 2013)
  ➢ Risk more than 10% is expected under the operation condition similar to the present owner-driven car exclusive of several prefectures

◆ In this report, the target risk of empty electric energy for EV is considered as less than 1%, and the required No. of ST is analyzed.
Optimum Layout of STs in this report

- ST No. required to reduce the dead EV rate less than 1% under the present owner-driven usage
  
  Notice: 1% of dead EV ration is just a milestone, and it should be reduced more by improving EV performance and ST placement

- Placement to area of large charge demand based on traffic simulation without the present ST
  
  Notice
  - Several layouts exist corresponding the dead EV rate of 1%
  - Highway, National Rd., major local Rd. is considered
  - Simple route selection for minimum time from origin and destination
  - Prediction of charge demand is not precise enough to specify the location of ST

- Guideline of ST placement (the required No. of ST for each city and prefecture, max. space between ST along the major road) is proposed
Analyzed regions for ST layout

◆ Points to be considered for selection of the region
  ➢ Shape of prefecture (complexity of rd. network)
  ➢ Layout of major cities
  ➢ Geographical characteristics (highland area etc.)
  ➢ Wide simulation area over several pref. (urban and rural area)

◆ Selected regions for analysis (6 region with 10 pref.)
  ➢ Tottori and Okayama pref.
  ➢ Osaka pref.
  ➢ Gifu and Aichi pref.
  ➢ Tokyo, Kanagawa and Shizuoka pref.
  ➢ Tochigi pref.
  ➢ Aomori pref.
Tokyo-Kanagawa-Shizuoka prefs. case

① Metro area
  Tokyo • Kawasaki • Yokohama

② Major road
  Tomei Highway

③ Major city
  Hamamatsu • Shizuoka

④ Peninsula area
  Izu peninsula
Tottori and Okayama prefs. case

① Metro area
Okayama • Kurashiki

② Major road
Hwy. of Okayama • chugoku • Yonago

③ Highland area
Daisen

④ Major city
Yonago • Kurayoshi • Tottori

④ Major road
National Rd. 53 • 482

② Major city
Tuyama • Mimasaka

© CRIEPI
Osaka pref. case

① Metro area
Osaka

② Highland area
Northern Minou area

② Highland area
Kawachinagano
Gifu and Aichi prefs. case

① Metro area
Gifu, Nagoya, Toyohashi

② Major city
Takayama

③ Major road
Tokaihokuriku Hwy.

④ Highland area
Norikura • Okuhida

⑤ Highland area
Eastern Aichi area

④ Peninsula area
Chita, Atsumi
Tochigi pref. case

① Major road
Tohoku Hwy.
Nikko-Utsunomiya Rd.

② Major city
Ashikaga • Oyama

③ Highland area
Kanuma • Nikko • Nasu

④ Major city
Nasukarasuyama • Otawara

② Major city
Utsunomiya
Aomori pref. case

① Major city
Mutsu

② Major road
National Rd. 4 • 279

③ Major road
Michinoku Rd.
National Rd. 279

④ Peninsula area
Tsugaru

① Major city
Hirosaki • Goshogawara

③ Highland area
Hakkoda

④ Highland area
Shirakami

① Major city
Aomori

① Major city
Hachinohe • Towada
Procedure of ST placement

Pattern of ST placement based on the analysis results

① Preferential placement in grid-like fashion to the Metro area

② Placement to the major city

③ Placement to the major road between major cities

④ Placement to peninsula and highland area

⑤ Placement uniformly to the whole area
Preferential ST placement to metro area

- Preferential ST placement if there is a metro area in the target cities for charging ST installation.
- Evaluation index is investigated according to the state of a prefecture (population, company no., area etc.)
- Evaluation index
  \[
  \text{Evaluation index} = (\text{Population density}[\text{person/km}^2]) \times (\text{company density } [/\text{km}^2]) \times (\text{area}[\text{km}^2])
  \]
- If a city has a standard deviation score more than 150, or there are neighbor cities which have its value more than 100, those cities are corresponding to the preferential placement area.
Standard deviation score for all cities

**Preferential placement area**: Tokyo 23 wards

Fig. Standard deviation score of evaluation index for Tokyo-Kanagawa-Shizuoka prefs.
Standard deviation score for all cities

Fig. Standard deviation score of evaluation index for Gifu-Aichi prefs.

Preferential placement area: Nagoya city

Preferential placement area: Okayama & Kurashiki

Not preferential placement area: Utsunomiya

Fig. Standard deviation score of evaluation index for Tottori-Okayama prefs.

Fig. Standard deviation score of evaluation index for Tochigi pref.
Placement of ST along major road

- Analyze separately highway and general road
  - Highway: ST placement to the service area (SA) • parking area (PA)
  - General road: evaluate ST space along the major road required for fuel empty risk less than 1%

- Averaged ST spaces along 24 national roads are evaluated according to the optimum ST layout analysis for fuel empty risk less than 1%

- \((\text{ST space}) \leq -0.00064 \times (24\text{hr. traffic volume}) + 38.8\)
Upper limit of ST space

\[
(\text{ST space [km]}) \leq -0.00064 \times (\text{24hr. traffic volume [car]}) + 38.8
\]

Grid-like placement of 5-10km in a metro area and large cities

Highland area (Okutama, Fuji foot area) and peninsula (Izu) without Hwy.
Placement of ST in the major city

- No. of ST in a city required for fuel empty risk less than 1% is evaluated as for about 400 cities in the analyzed prefectures.
- The more frequently the city is selected as origin and destination, the larger the charging demand.
  - Frequency selected as origin is assumed to be proportional to the population density
  - Frequency selected as destination is assumed to be proportional to the company density
- ST index is defined as a function of area, population, and company number based on the correlation analysis

ST index

\[ \text{ST index} = (\text{area [km}^2]\}^{0.68} \times (\text{population [person]}^{0.2} \times (\text{No. of company})^{0.19} \]
No. of ST for major cities

- **ST index** = \((\text{area \ [km}^2]\)^{0.68} \times (\text{population \ [人数]}^{0.2} \times (\text{No. of company})^{0.19} \times (\text{No. of ST a city}) \geq 0.0006x(\text{ST index}) + 0.822

The city which recently merged with depopulated area has a tendency to be the lower limit.
Summary

- Analysis on optimization of the layout of charging stations (ST) was carried out by estimating the charging demand of EV based on the traffic simulation.

- As the layout method for STs, the following empirical methods are proposed based on the optimum layout analysis, condition for preferential placement to large city, space of ST placement along major roads, allocation of ST for major cities, No. of ST for each prefecture.

- Increase of sample number of the prefecture is required to improve the accuracy and to develop an empirical evaluation method for ST number in each prefecture.

- The result reported here is based on the tentative target of fuel empty risk less than 1%, and the ST No. should and will be more required than evaluated in this report in order to improve the EV convenience similar to the present owner-driven car (fuel empty risk about 10^{-4}%).
Acknowledgement

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Thank you for your attention. If you have any questions or comments, please contact Hiwatari (hiwatari@criepi.denken.or.jp)