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@」

This system is developed under "artisoc@" (Kozokeikaku Eng. Inc.)

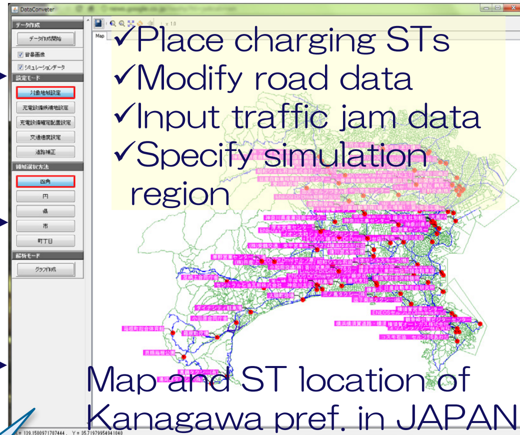
Map Database (Digital Map25000, etc)

Traffic Data (Traffic census etc.)

Census Data (employee, business facility etc.)

Set up input files for traffic simulator

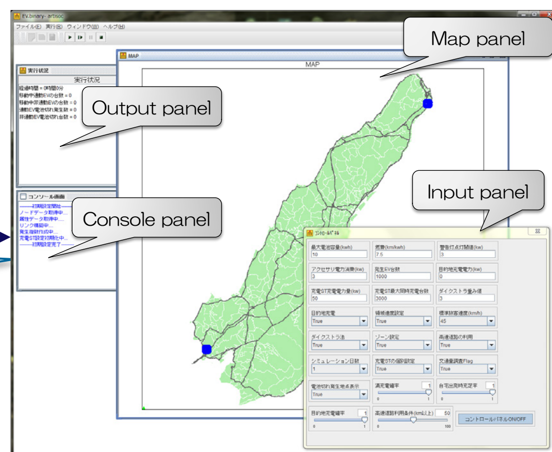
Pre-post tool



Input files
(Excel CSV files)

- Road map data
- Charging ST data
- Trip data
- Traffic jam data
- Census data (employee, business facility)

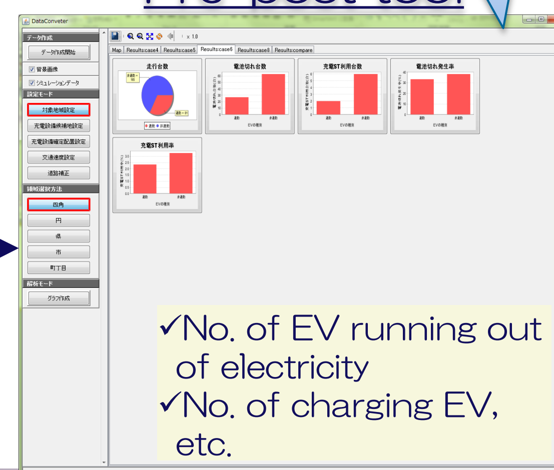
Traffic simulator



EV traffic simulation and ST optimization

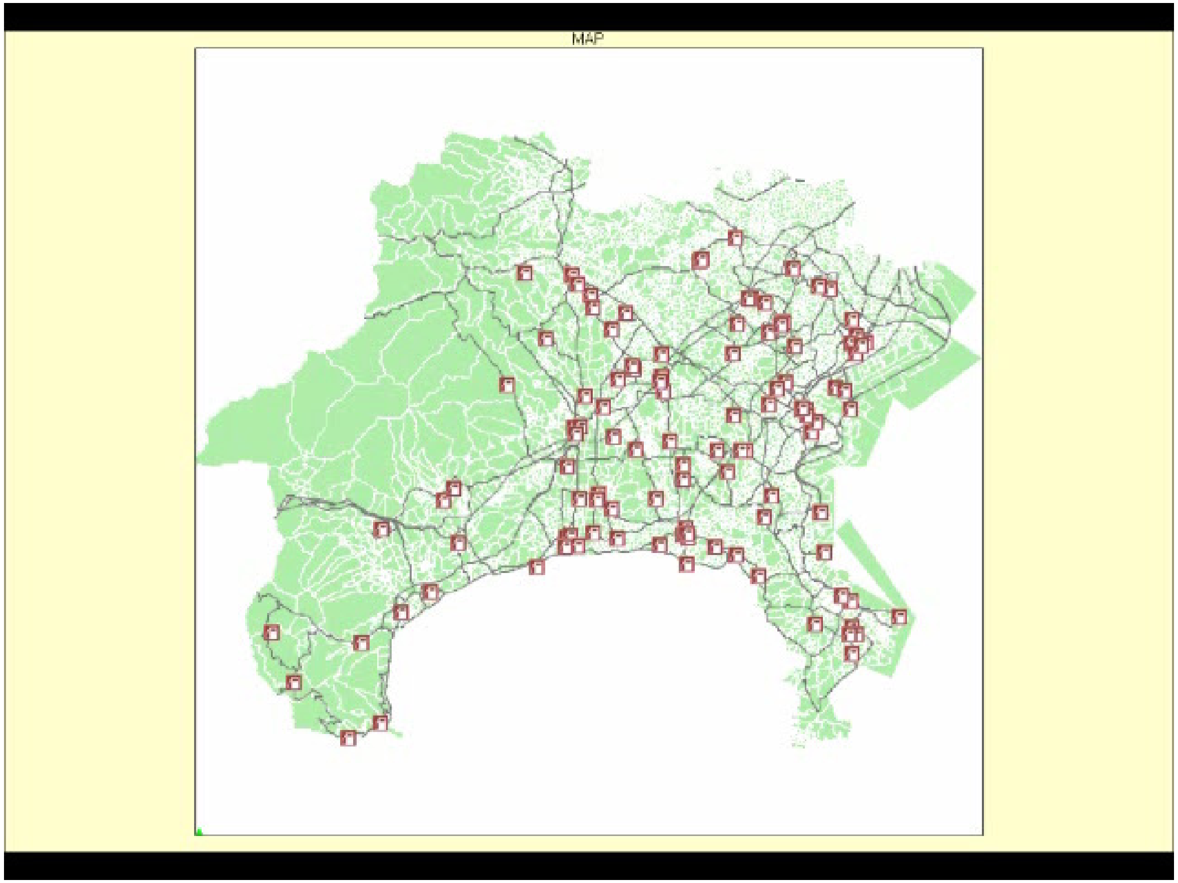
Pre-post tool

Display results



Demo. of traffic simulation

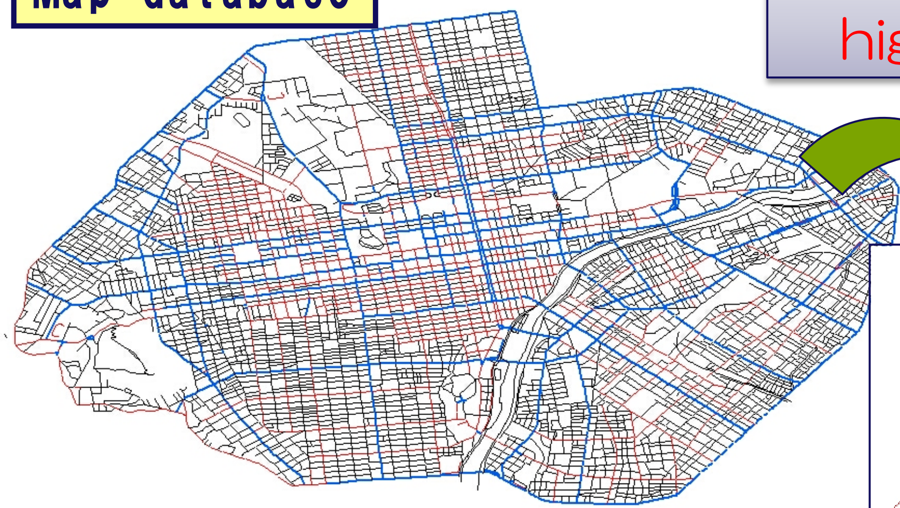
× : dead EV　　× : point where warning sign is on of dead EV
▲ : EV with warning sign on　　▲ : commuter use　　▲ : go home use
▲ : random use　　▲ : out-of-service EV　　charging ST icon : charging ST



Model of road network

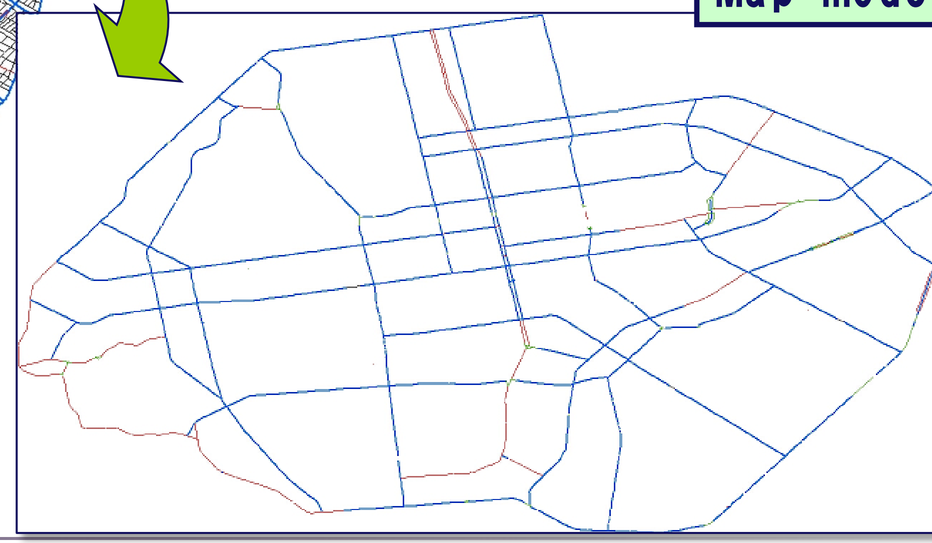
- Digital Road Map(Japan Digital Road Map Association)
- Digital Map 25000 (Geospatial Information Authority of Japan)、Open Street Map (http://www.openstreetmap.org/) are also available.

Map database



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

Map model



Blue	Rd. width more than 13m
Red	Rd. width of 5.5m～13m

Rd. gradient based on elevation data

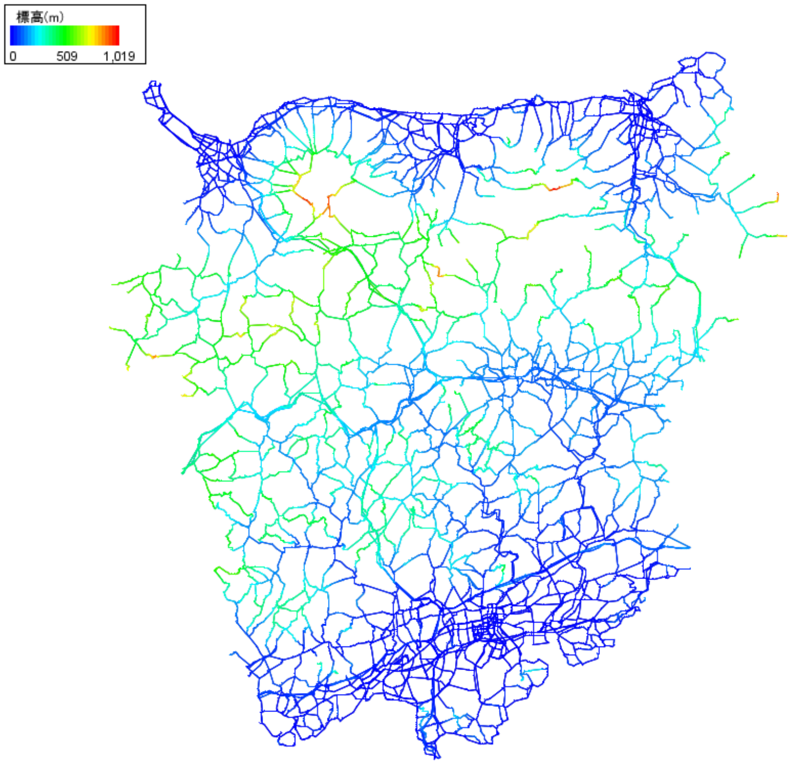


Fig. Elevation of Tottori and Okayama prefs.

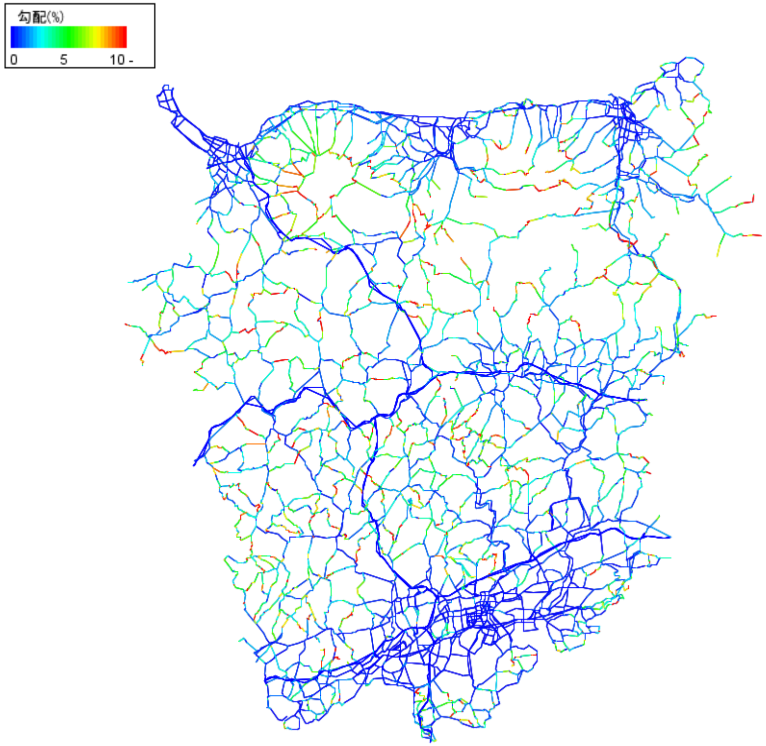


Fig. Rd. gradient of Tottori and Okayama prefs.

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)

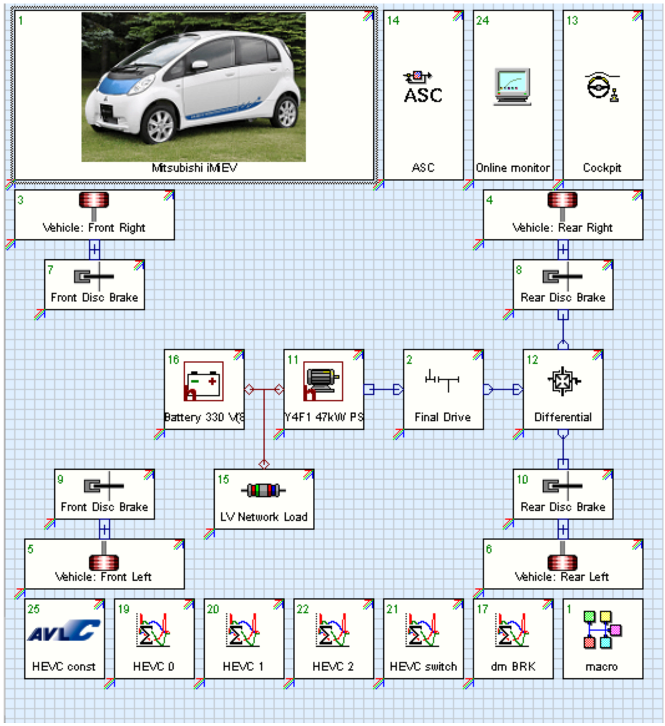


Fig. Simulation model of i-MiEV on CRUISE.

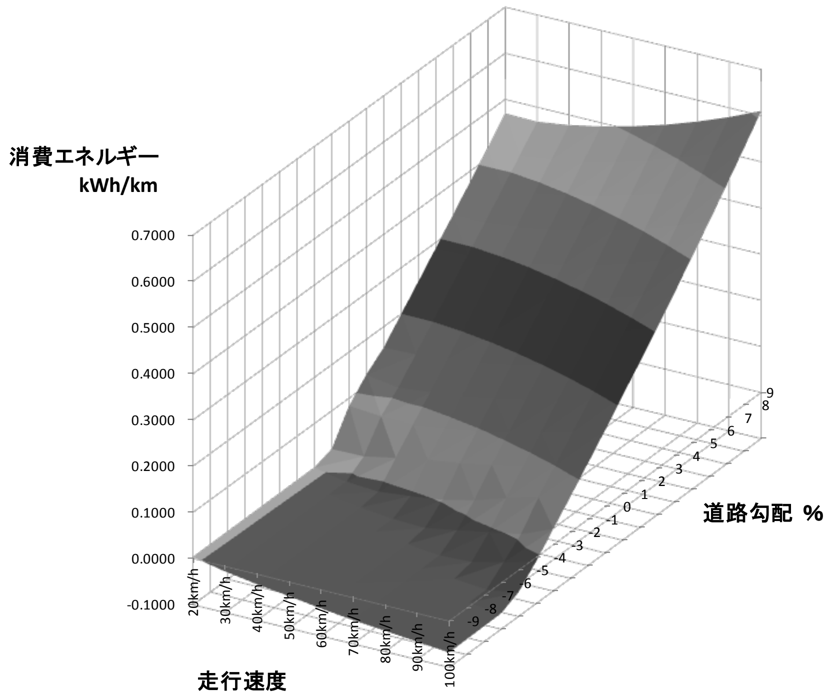
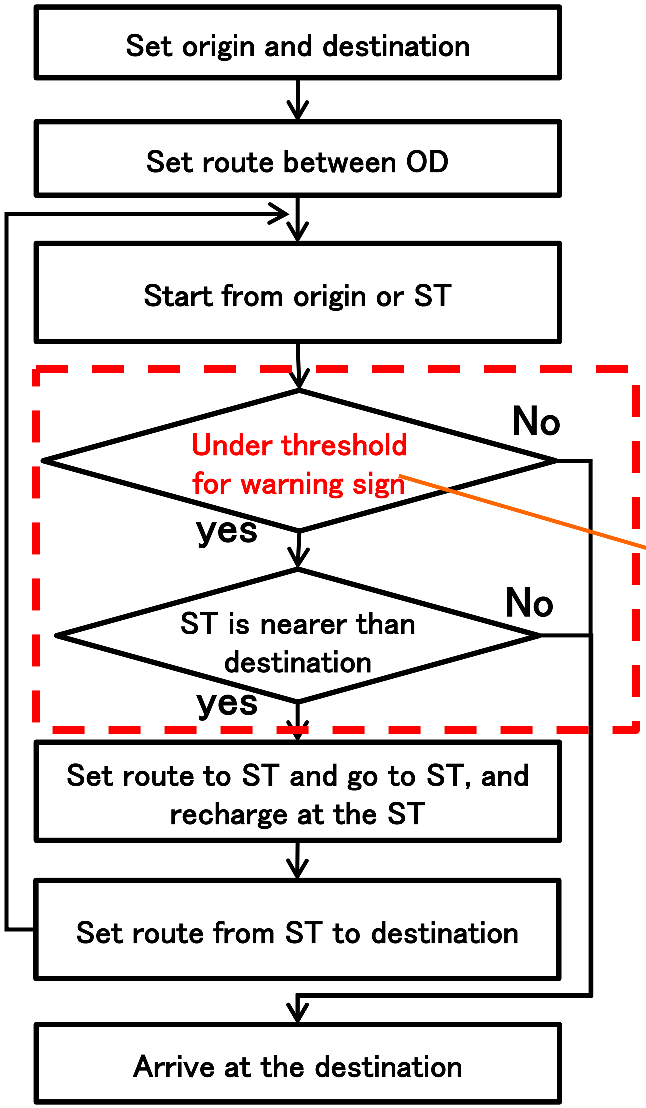


Fig. Mileage function applied in traffic simulation

Algorithm of charging behavior and EV conditions

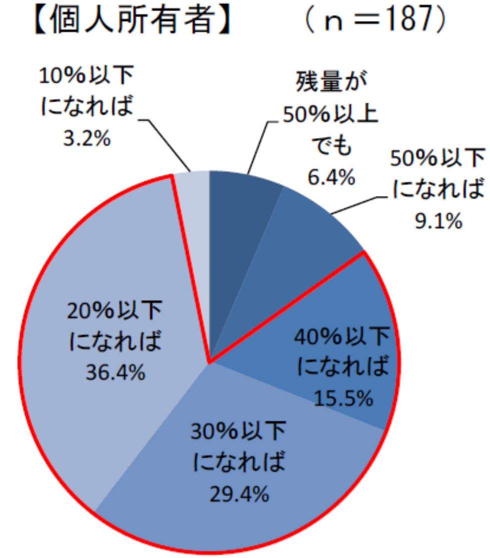


EV conditions	value
Battery capacity C_i (kWh)	16
Initial state of charge SOC_i^{start}	1.0
Fuel mileage L^{fm} (km/kWh)	7.5
Accessary power P^{ac} (kW)	3.0
Threshold for warning sign E^{alarm} (kWh)	8.0
velocity normal rd./hwy. (km/h)	45/80
Traffic jam effect	on

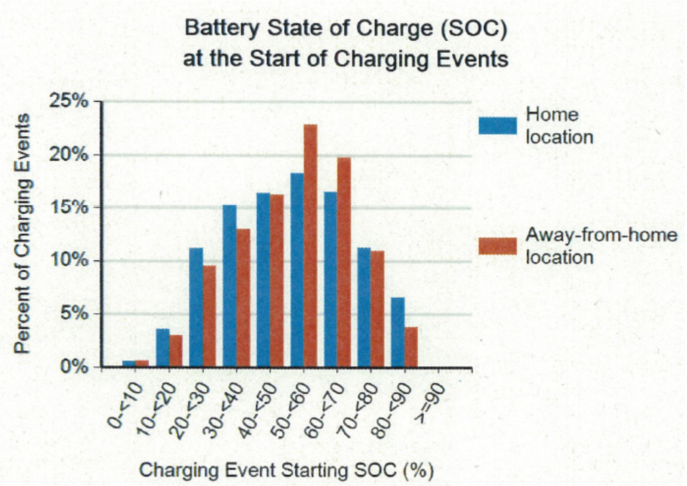
EV starts the charging behavior to nearest ST just after warning sign on

Threshold of battery energy for warning sign

- SOC≦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%～60% at the start of charging is maximum. (http://avt.inl.gov/evproject.shtml)
- SOC≦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.



Fig：condition of charging behavior in Japan



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

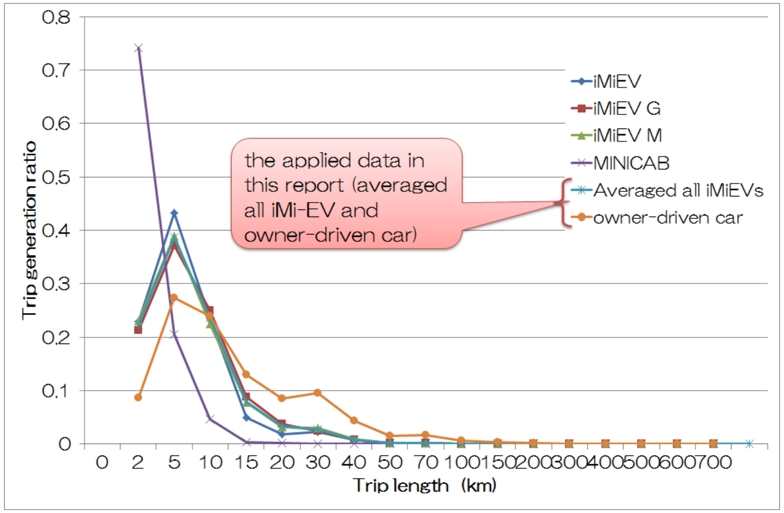


Fig. Distribution of trip length

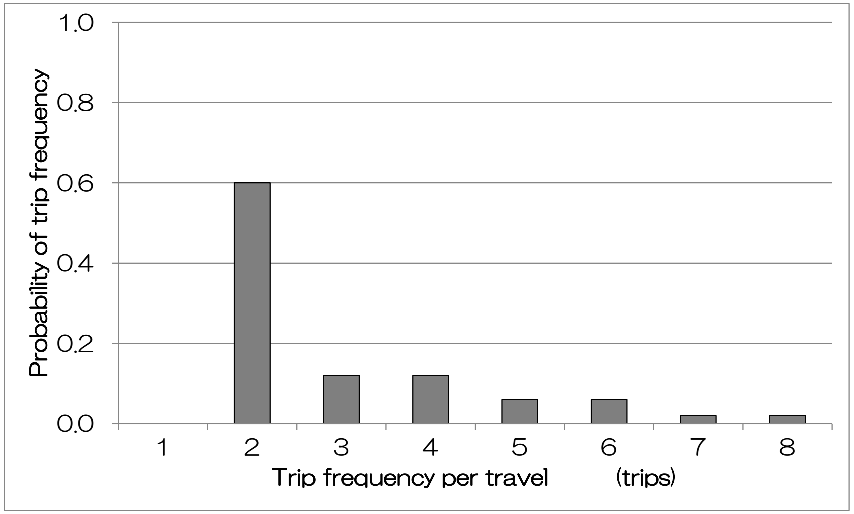


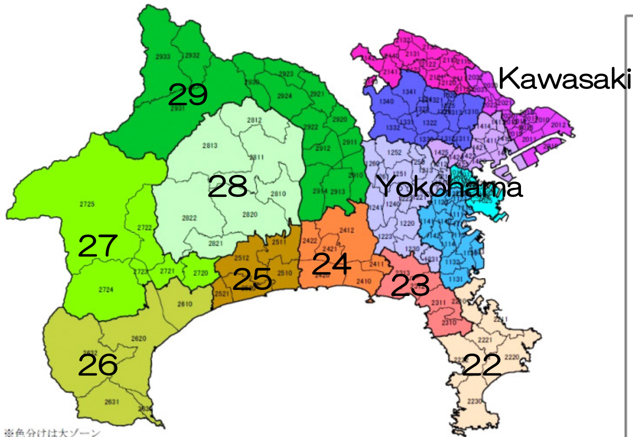
Fig. Distribution of trip frequency

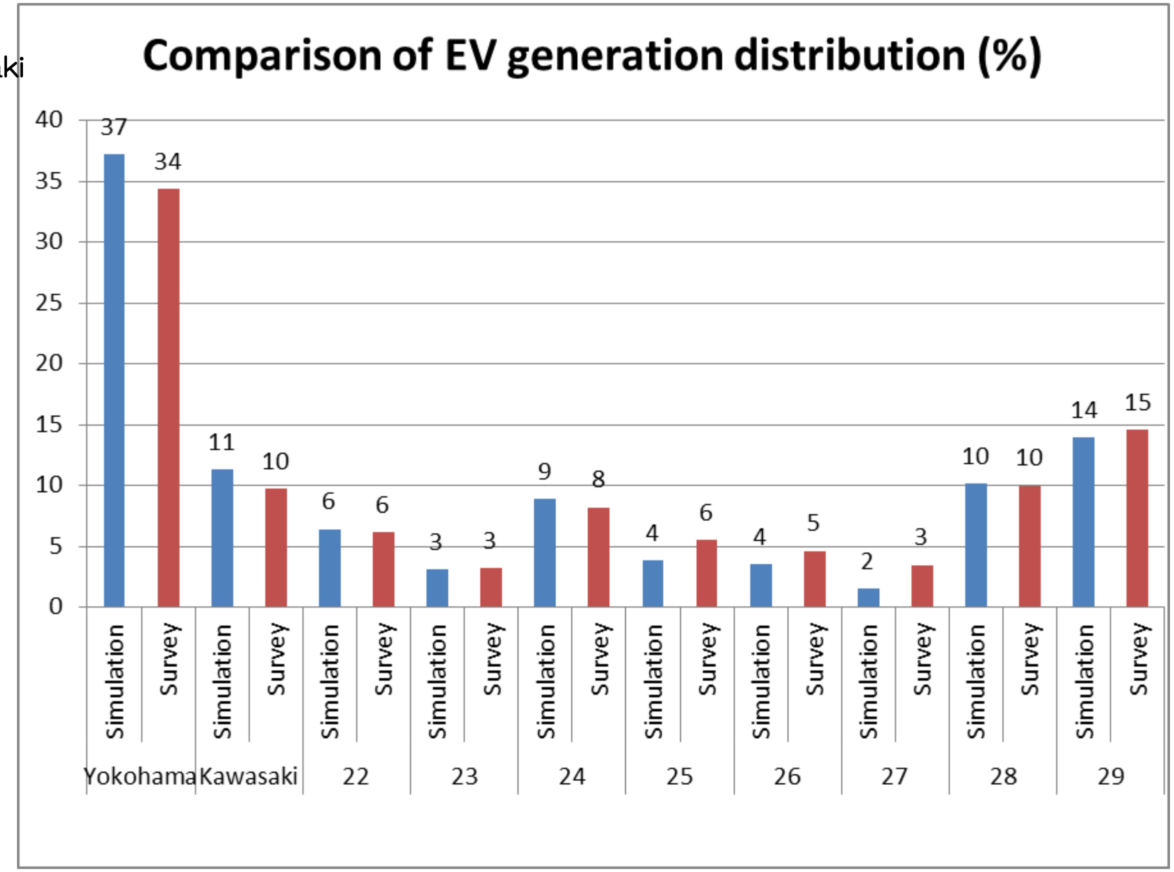
Ref.: Disclosed data from JARI to METI obtained in the standardization project of basic technology for integrated battery system (New Energy Promotion Council)

Ref. The investigation committee for transportation system for Imabari city

Validation of traffic simulation 1

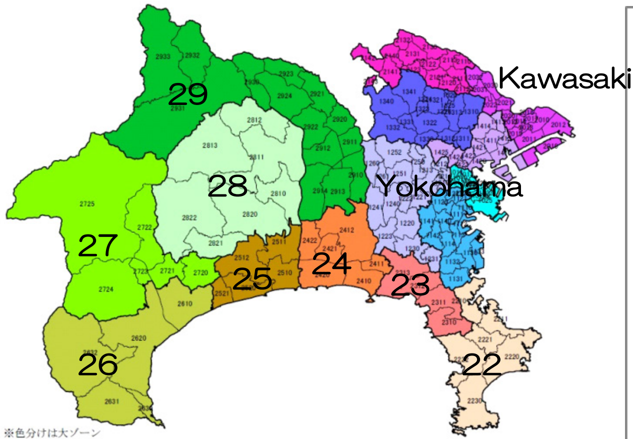
- Simulation results(simulation) is compared with person trip survey(survey) for validation

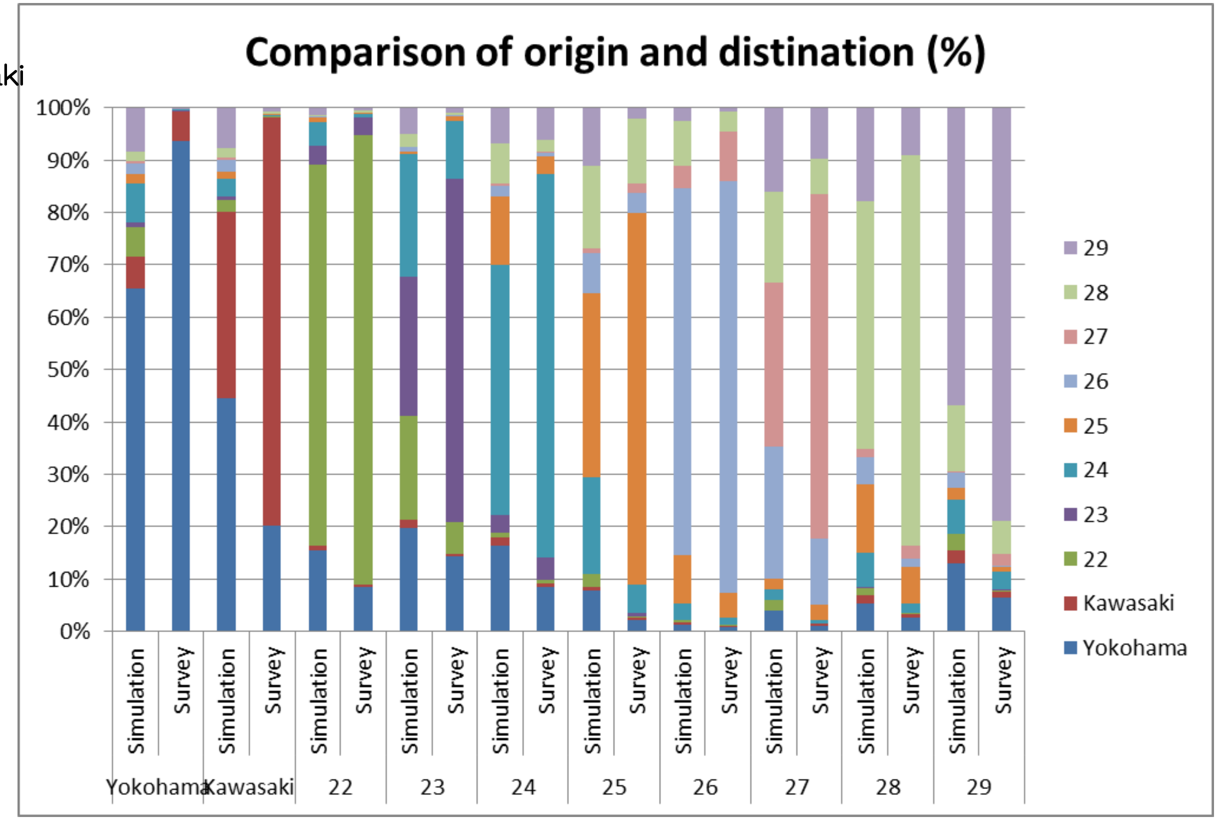




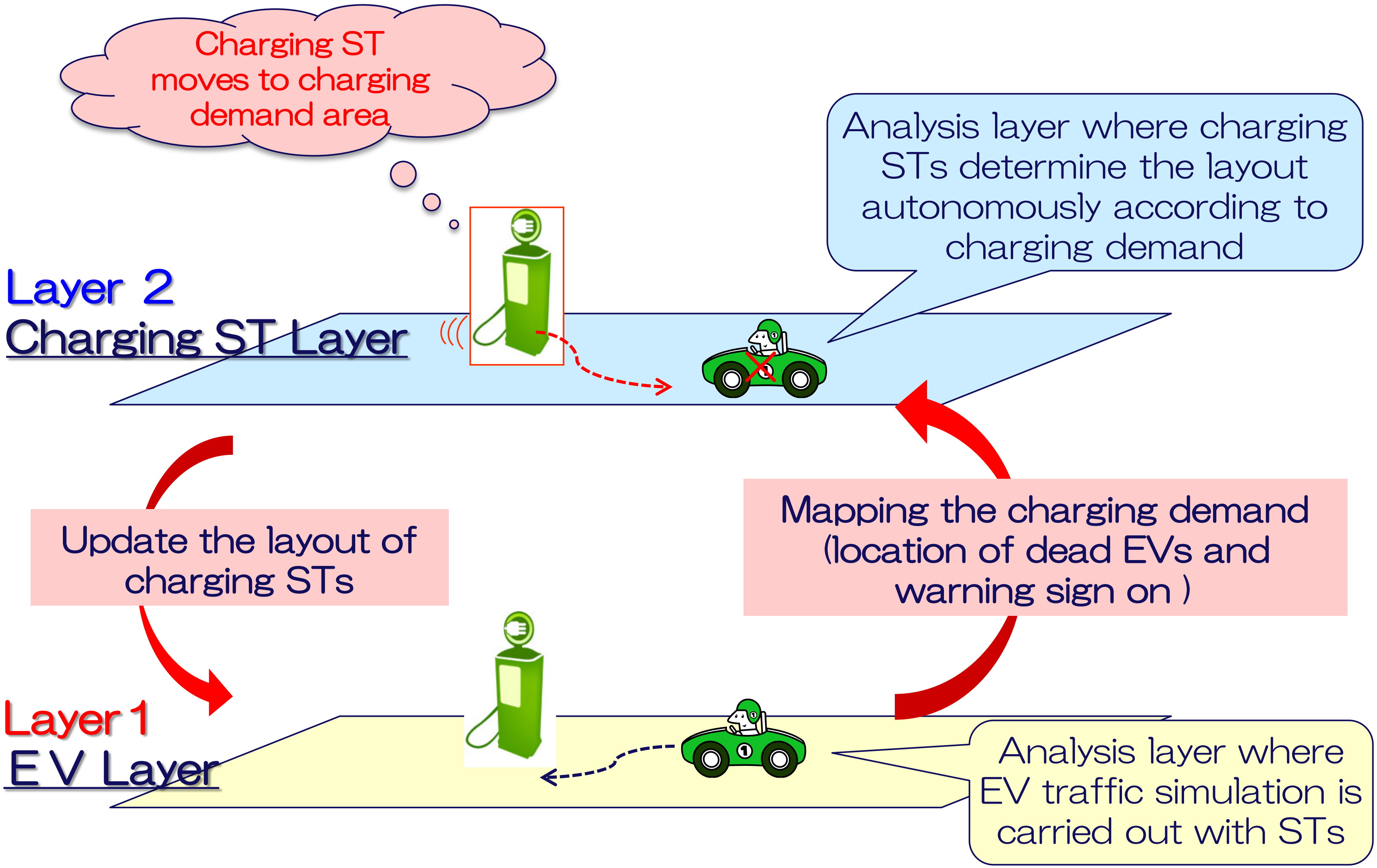
Validation of traffic simulation 2

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

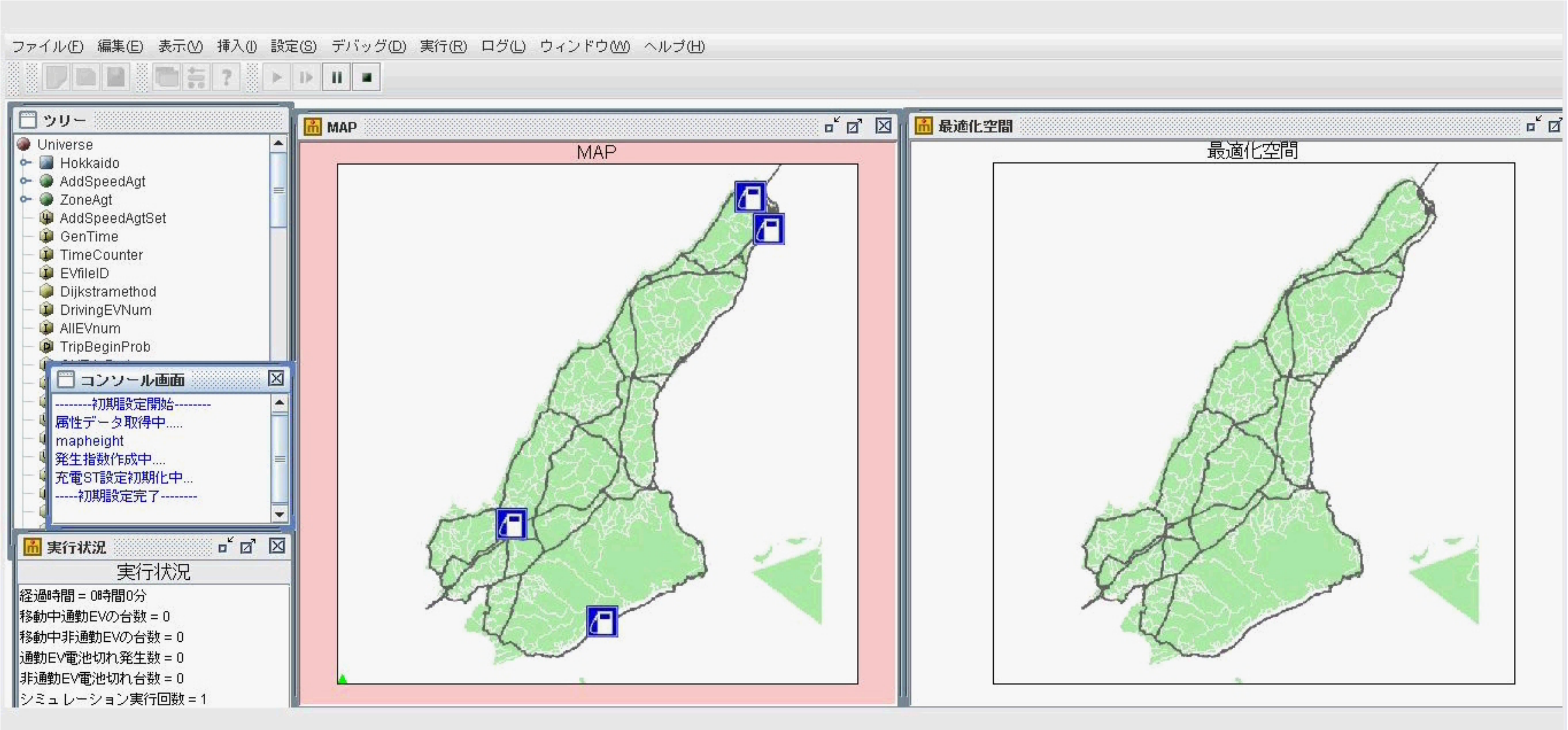




Algorithm for relocation of ST



Demo. of relocation of ST



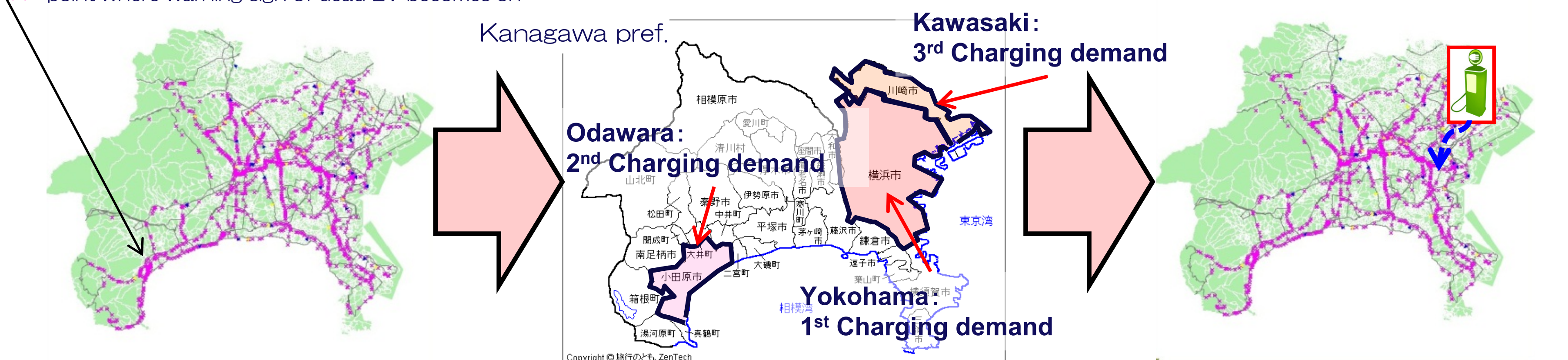
Algorithm for optimizing layout of STs

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

× : point where warning sign of dead EV becomes on



①EV traffic simulation

②ST is tentatively placed according to the ranking

③STs 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：～5.0×10^{-4}%
    - Annual rescue No. for empty fuel：84420(JAF 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

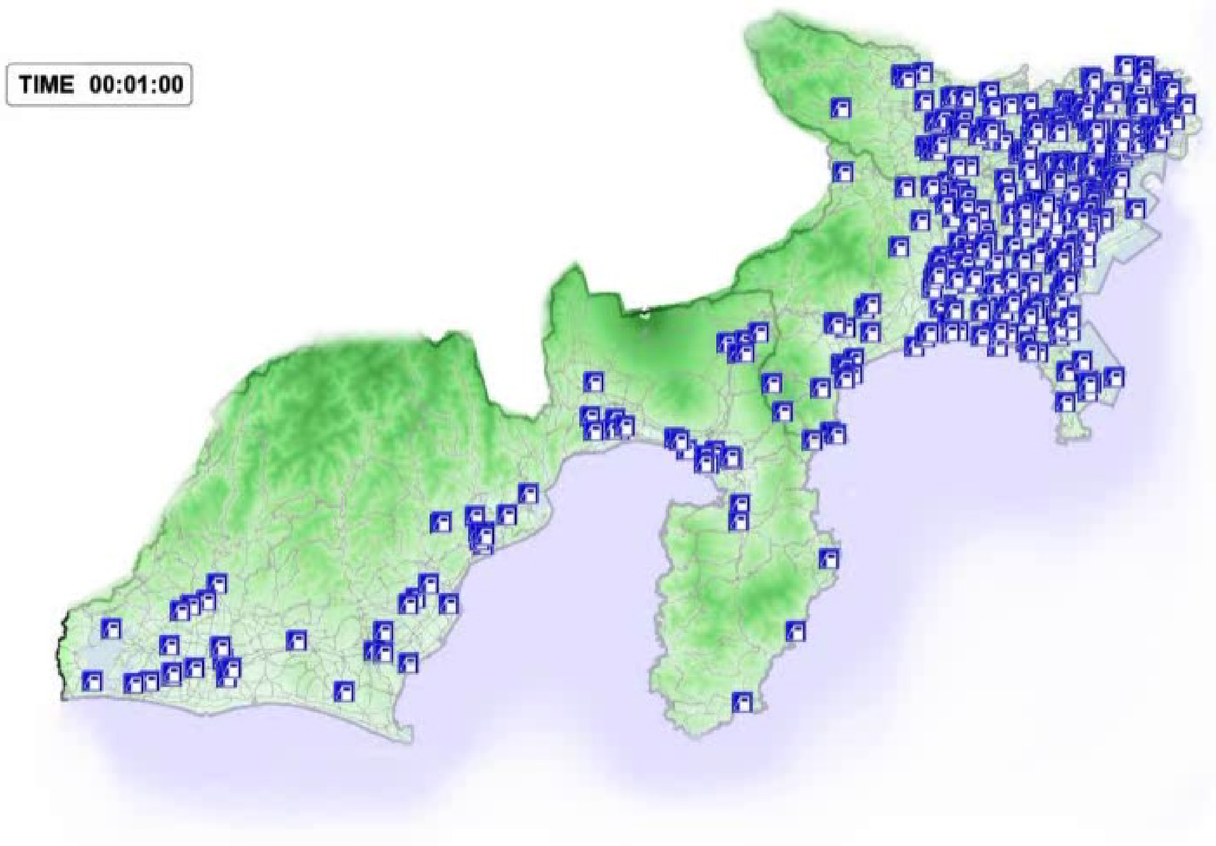
  - Several layouts exist corresponding the dead EV rate of 1%
  - Highway, National Rd., major local Rd. is considered
  - Simple route selection for minimum time from origin and destination
  - Prediction of charge demand is not precise enough to specify the location of ST

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

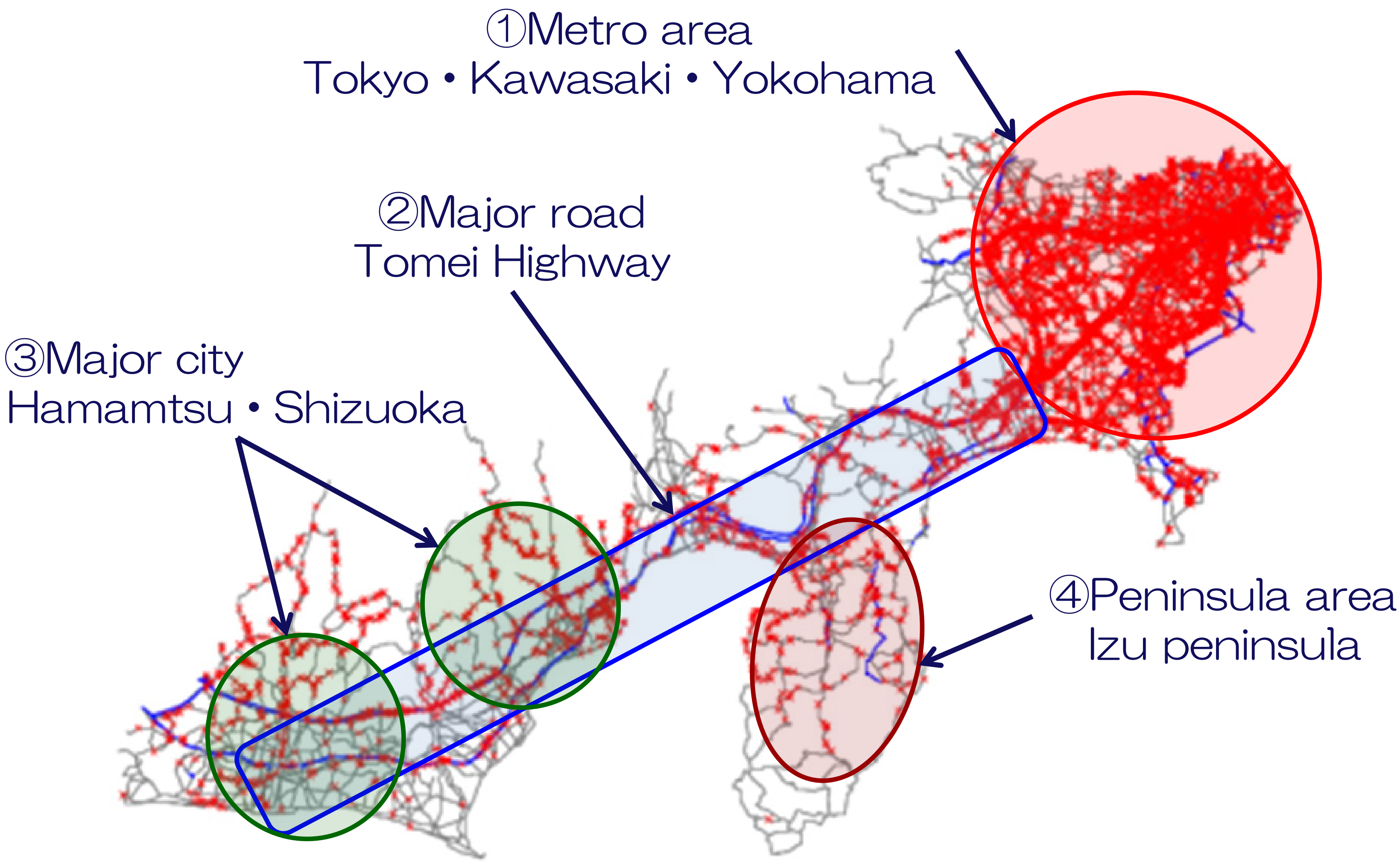
Analyzed regions for ST layout

- 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 prefs.(urban and rural area)
- Selected regions for analysis(6region with10pref.)
  - Tottori and Okayama prefs.
  - Osaka pref.
  - Gifu and Aichi prefs.
  - Tokyo, Kanagawa and Shizuoka prefs.
  - Tochigi pref.
  - Aomori pref.

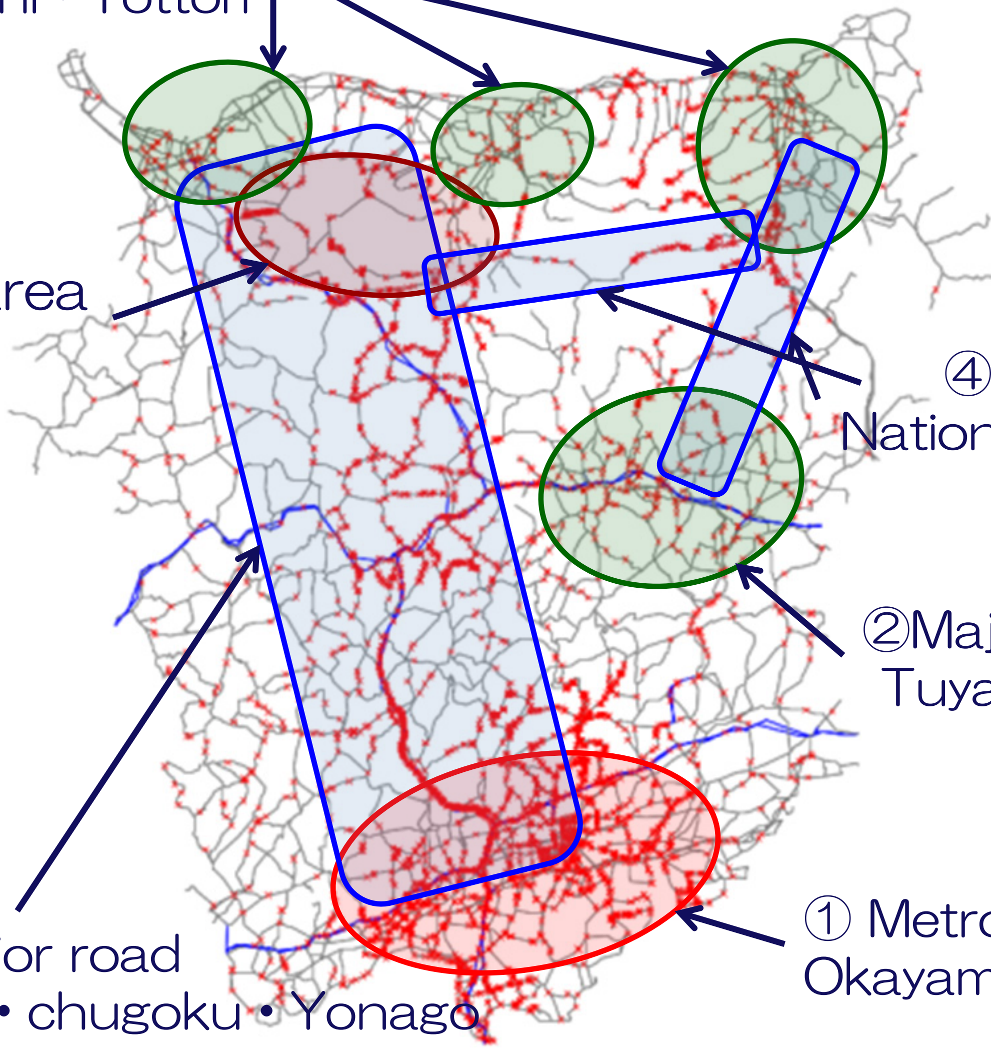
Demo. of Tokyo-Kanagawa-Shizuoka prefs. case



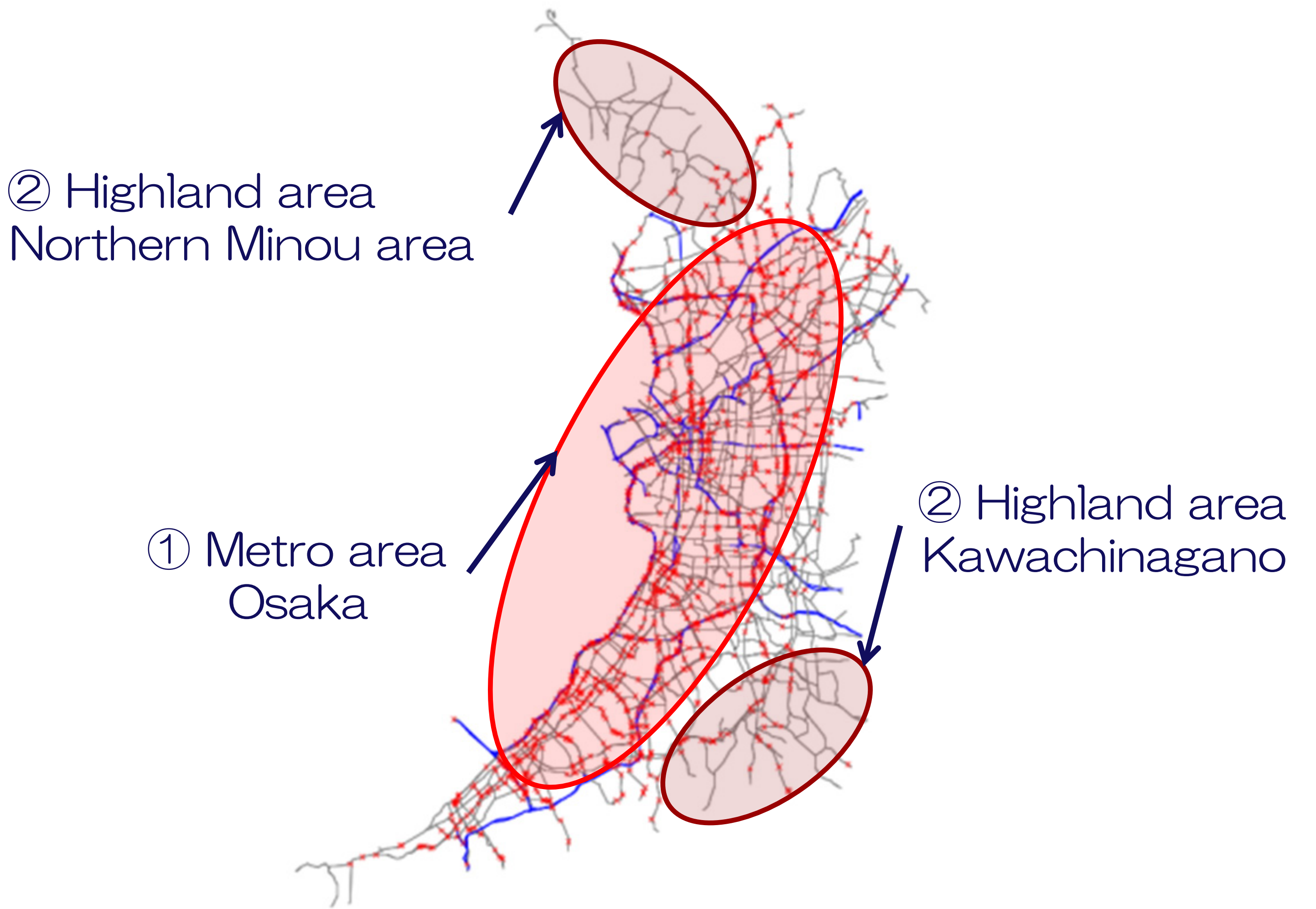
Tokyo-Kanagawa-Shizuoka prefs. case



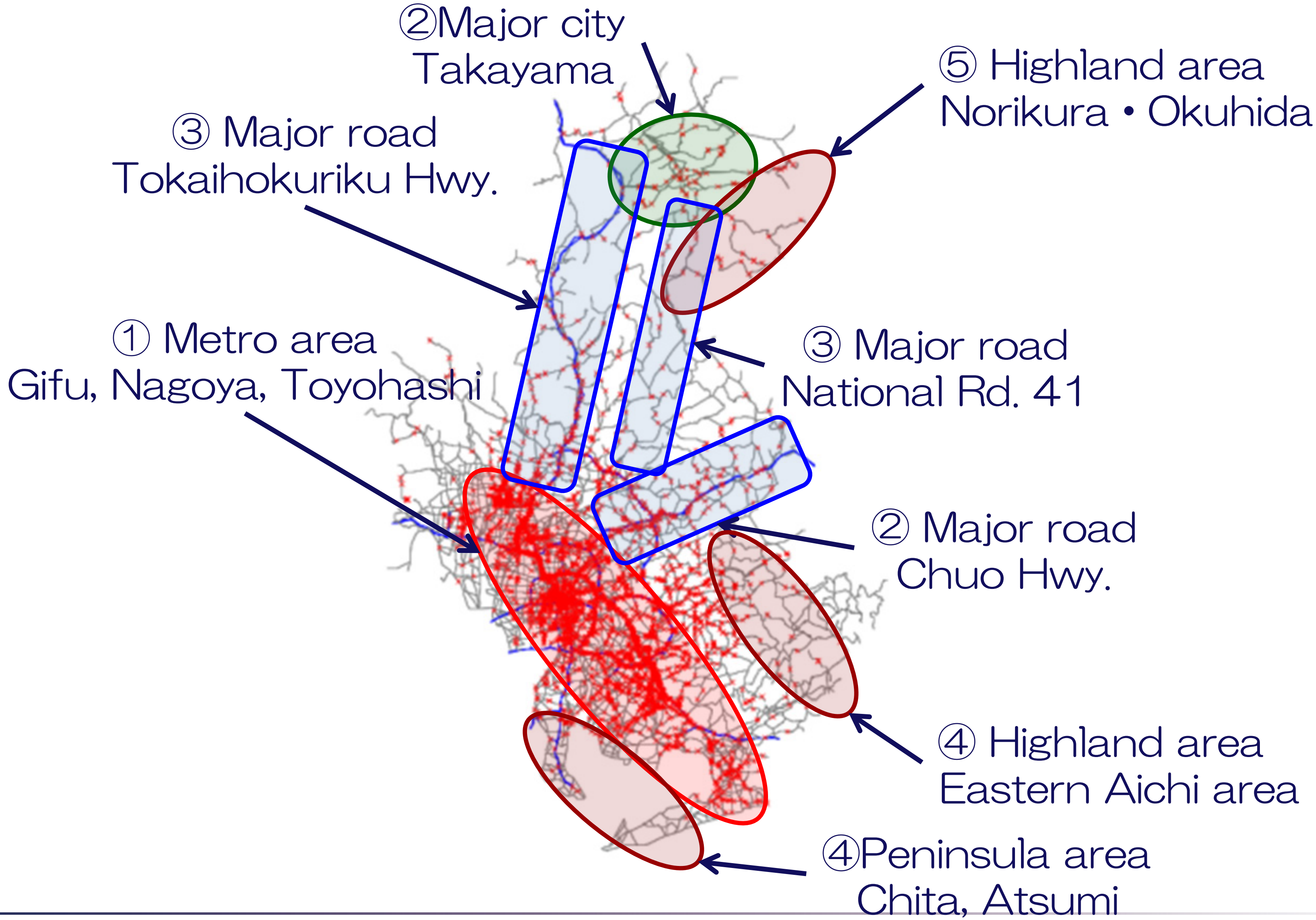
Tottori and Okayama prefs. case



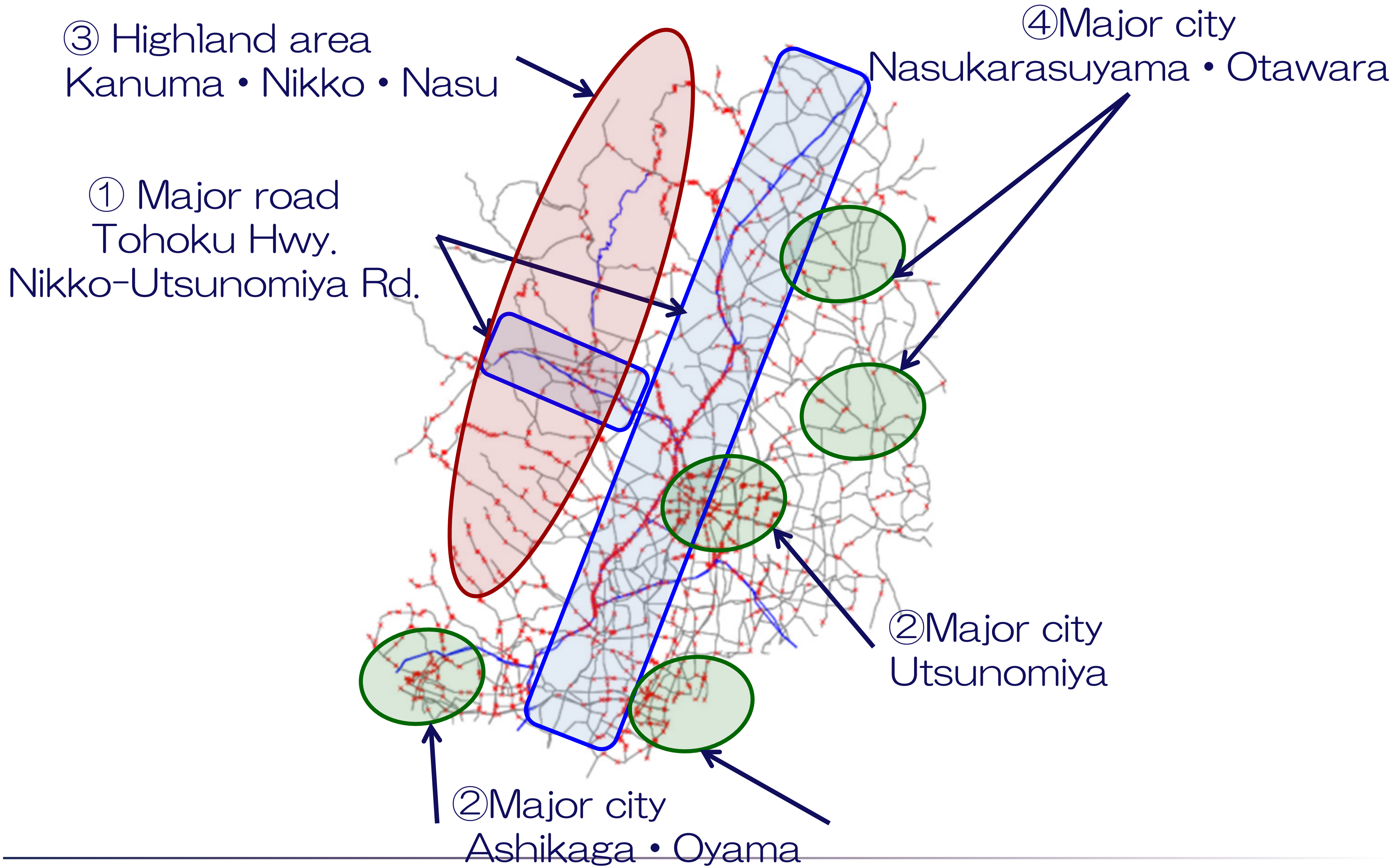
Osaka pref. case



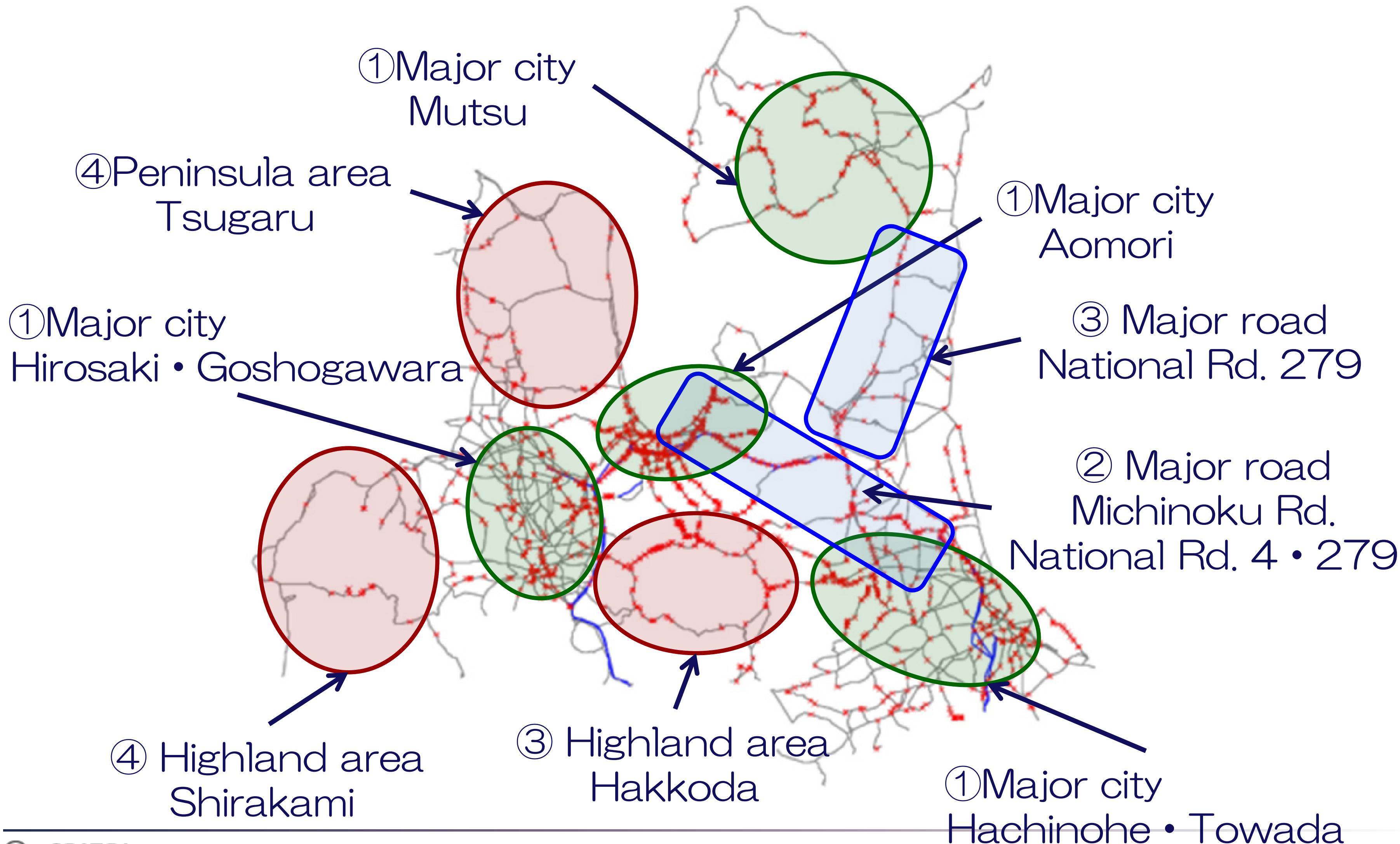
Gifu and Aichi prefs. case



Tochigi pref. case



Aomori pref. case



Procedure of ST placement

Pattern of ST placement based on the analysis results

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

②Placement to the major city

③Placement to the major road between major cities

④Placement to peninsula and highland area⑤Placement 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

$$= (\text{Population density}[\text{person}/km^2]) \times (\text{company density }[/km^2]) \times (\text{area}[km^2])$$

- 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

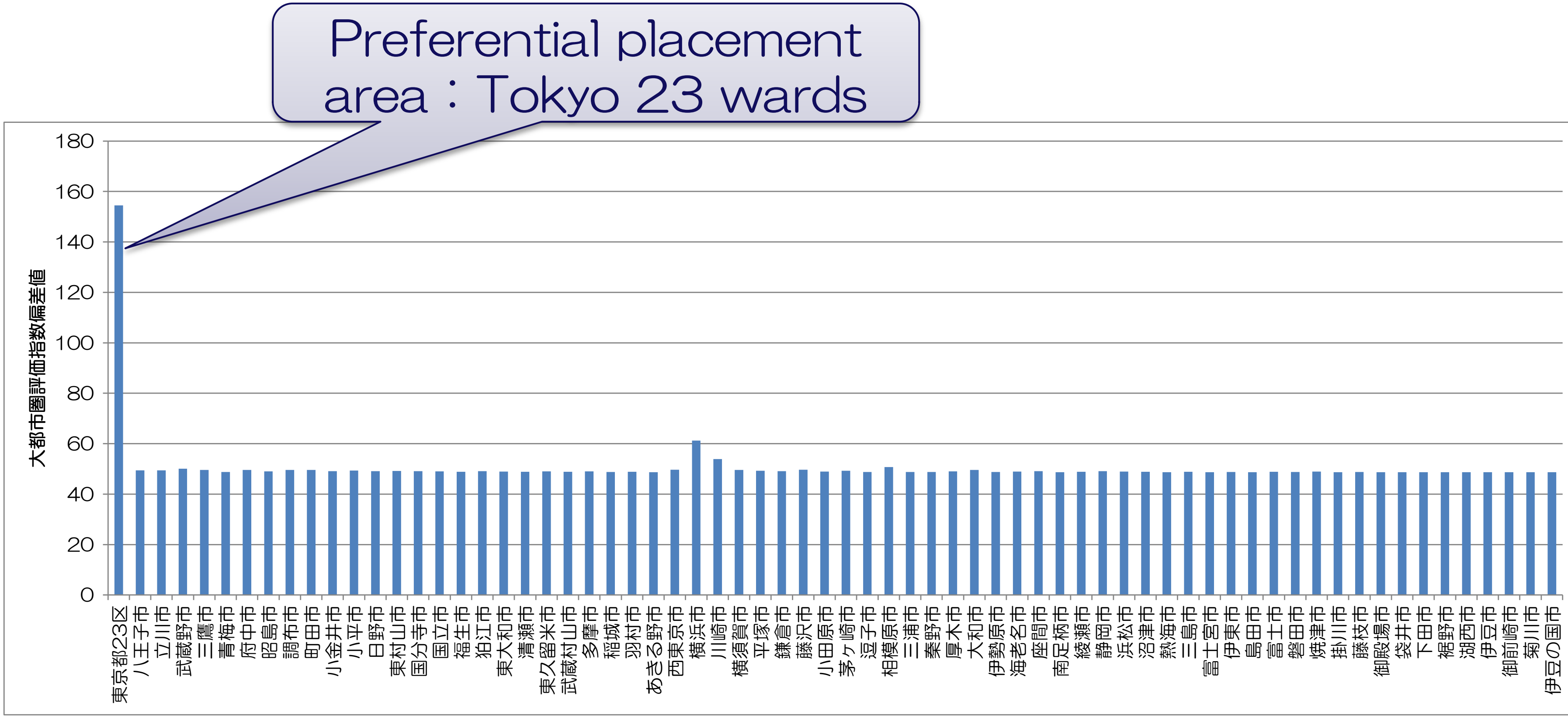


Fig. Standard deviation score of evaluation index for Tokyo-Kanagawa-Shizuoka prefs.

Standard deviation score for all cities

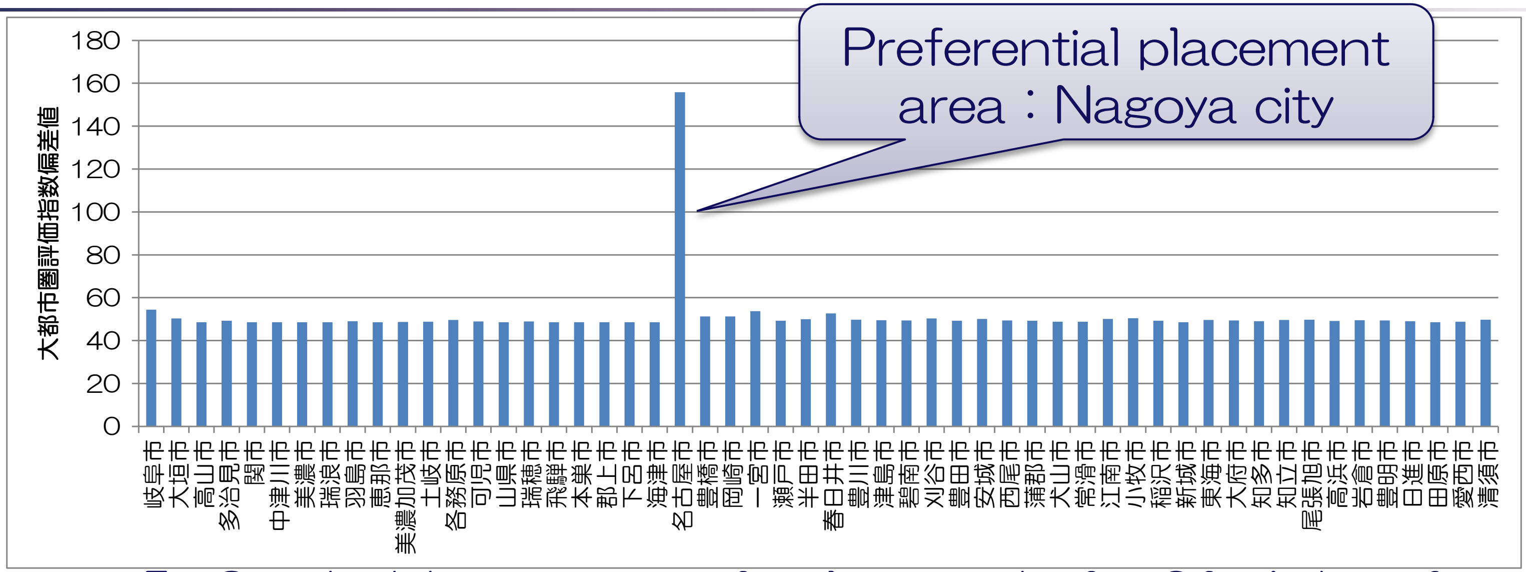


Fig. Standard deviation score of evaluation index for Gifu-Aichi prefs.

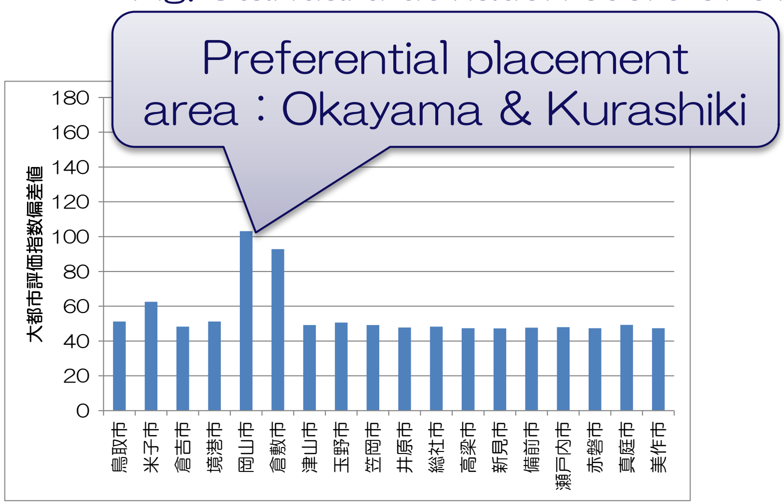


Fig. Standard deviation score of evaluation index for Tottori-Okayama prefs.

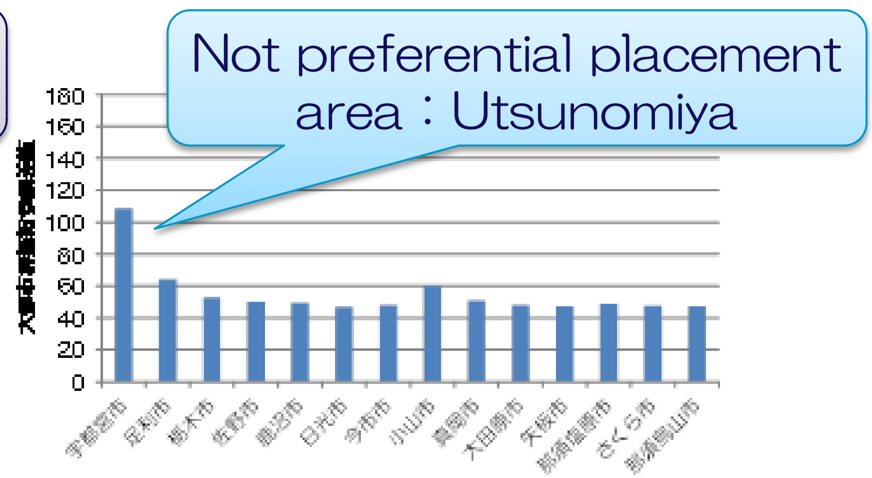


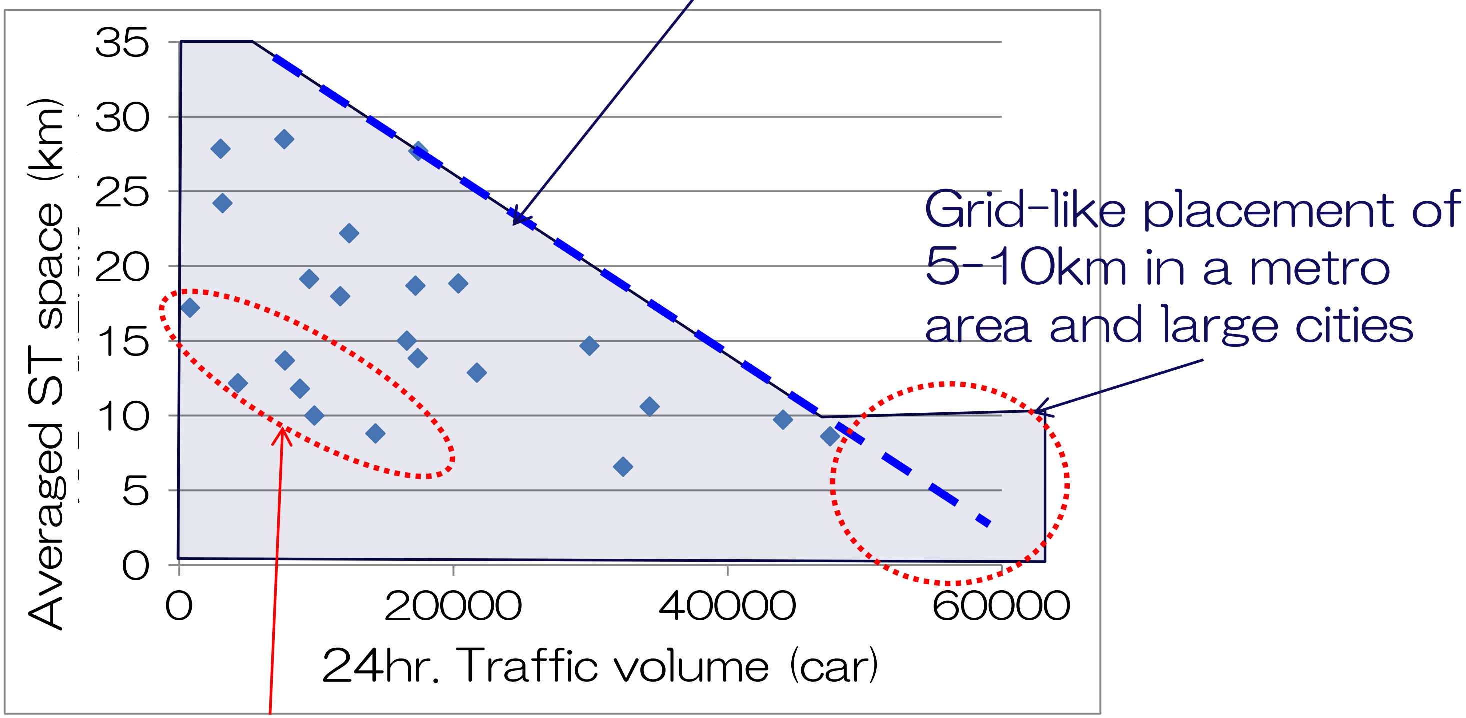
Fig. Standard deviation score of evaluation index for Tochigi pref.

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%
- (ST space) ≦-0.00064×(24hr. traffic volume)+38.8

Upper limit of ST space

(ST space [km])
≦ -0.00064×(24hr. traffic volume [car])+38.8



Highland area(Okutama, Fuji foot area) and peninsula (Izu) without Hwy.

Placement of ST in the major city

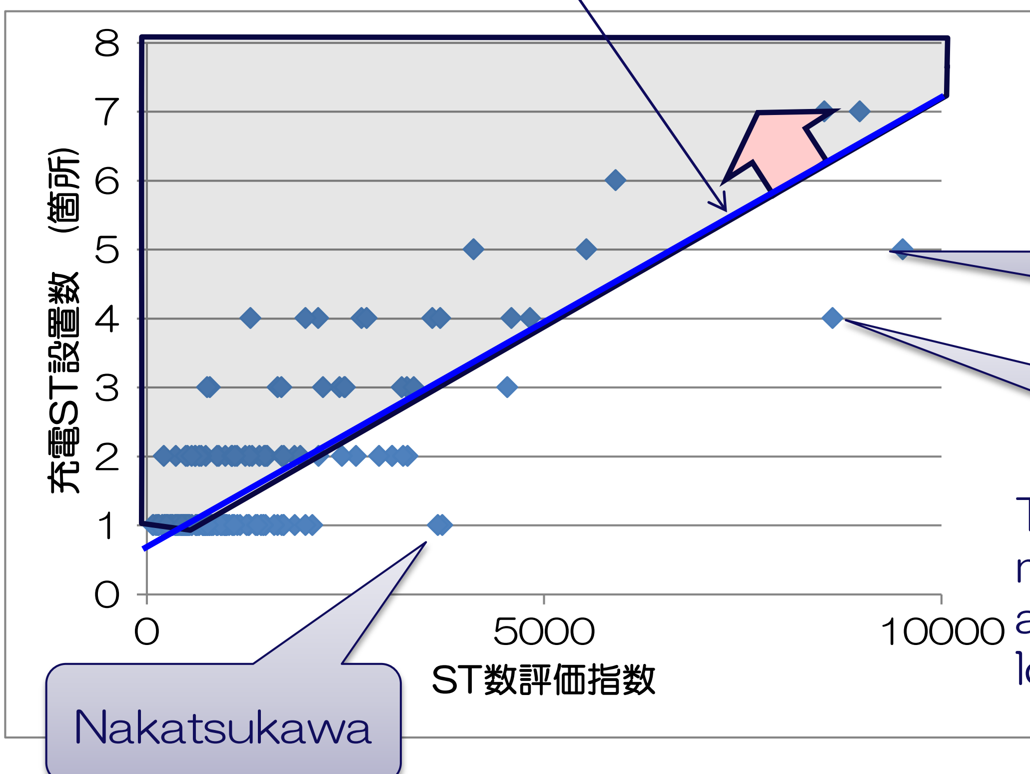
- No. of ST in a city required for fuel empty risk less than 1% is evaluated as for about 400 cities in the analyzed prefectures.
- The more frequently the city is selected as origin and destination, The larger the charging demand.
  - Frequency selected as origin is assumed to be proportional to the 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

$$= (\text{area [km}^2])^{0.68} \times (\text{population [person]})^{0.2} \times (\text{No. of company})^{0.19}$$

No. of ST for major cities

- ST index＝(area [㎞^{2}])$^{0.68}$× (population [人])$^{0.2}$ × (No. of company)$^{0.19}$

(No. of ST a city) ≧ 0.0006x(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

We had kind instruction from and cooperation with the automobile division of Ministry of economy, trade and industry, Next-generation vehicle promotion center, Mitsubishi research institute, Japan automobile res. inst., Kozo Keikaku Inst. Inc. on carrying out this sponsored study.

We would like to express our appreciation to everyone concerned with this study.

Thank you for your attention.

If you have any questions or comments, please contact Hiwatari

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