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Optimal Location Model of Electric Vehicle Charging Facility based on the Flow-Capturing Location-Allocation Model

Case study by using the data of road network of Bangkok, Thailand

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Abstract

Most facility location problems assume the static demands like the population and express the demands to a target network. In the case of the electric vehicle (EV) charging facilities assuming the vehicles as the demands, it is realistic to express the demands as the traffic flow to a target network. The facility location problem dealing with these demands is proposed as "the flow-capturing location-allocation model (FCLM)" by Hodgson *et al.*. However, since the EV has the constraint that the driving distance is short, it is difficult to straightforwardly apply the FCLM assuming the gasoline-powered vehicle as the demands to the EV charging facility. In this paper, we propose a modifying model

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of the FCLM which takes into the consideration of the constraint of the EV. We also confirm the usefulness of modifying model by using the data of road network of Bangkok, Thailand. From comparing between the FCLM and our model by using several evaluation indices, we conclude that our modifying model can efficiently locate facilities to a road network in the case of targeting vehicle (EV) that has the short driving distance.

Mathematics Subject Classification: 90B06; 90B20; 90B80
Keywords: Location; Flow-capturing location-allocation model; Charging facility; Integer programming

1 Introduction

This is the text of the introduction. Since global warming caused by greenhouse gases is recently an important issue of world-wide environment, the environmental program is needed to take as soon as possible. In particular, the road transport sector was responsible for 17% of global CO_2 emissions in 2013 [1]. In Southeast Asia, energy demand in transport sector almost doubled from 2000 to 2016 [2]. In addition, the total stock of electric vehicles (EV) is less than other countries (*e.g.*: the estimated stock in the region of European Union is over 5 million and that of Southeast Asia is about 7000 at 2016 [2]). For that reason, the further popularization of EV is desired in Southeast Asia. Although the performance improvement of EV itself is important to popularize EV, to enrich the EV charging facilities to an urban area is most important. However, it is costing to construct a lot of charging facilities. Therefore, the location plan containing the fixed number of facilities, such as the available to many users, is required instead of locating the excessive number of facilities without a plan.

There are many researches of the facility location problem. In such researches, the problem of static demands such as the population is handled (*e.g.*: p-median and maximal covering problem). On the other hand, the EV charging facilities can regard the vehicles flowing a path between origin and destination (OD) as the demands. A road network flowing vehicles can be expressed given that regard an intersection and road as a node and link, respectively. At first glance, it seems to be better to locate facilities on roads as maximizing traffic flow. However, the phenomenon called "Cannibalization" that same traffic flow is consumed by the distant facilities is occurred. In the flow-capturing problems, it is important to locate facilities considering the cannibalization.

There are also many researches handling demands as the traffic flow [3, 5, 4]. The flow-capturing location-allocation model (FCLM) proposed by Hodgson *et al.* [6] is widely known. The FCLM has a structure to locate facilities avoiding the cannibalization aptly. Hodgson *et al.* [7] conducted the basic research by using the real road network in Edmonton, Canada under the conditions that the traffic flow exists on the shortest path between an OD pair, and the facilities are located on nodes. In addition, Hodgson *et al.* compared the location efficiency of facility targeting vehicles between the FCLM and p-median [8].

If we apply the facility location model to the EV charging facilities, we have to consider the issues unique to EV. EV has the constraint that the driving distance is shorter than that of gasoline-powered vehicle. Thus, the multiple facilities should be located on a sufficiently long path so that EV drives from an origin to a destination without running out of battery. The FCLM did not consider this constraint.

Kuby *et al.* [9] conducted the research related to a model locating facilities considering the driving distance of alternative-fuel vehicles. Kuby *et al.* proposed the model as the flow-refueling location model (FRLM) installed the constraint of the driving distance. The FRLM is modeled based on the FCLM. In addition, the FRLM considers the driving distance with giving combinations of the facilities location points to each path beforehand. Moreover, they conduct a case study by using the interurban road network of Florida, USA targeting fuel cell vehicles [10].

The target vehicles in our research is EV. Moreover, the difference between our research and previous researches is the using network type. The road network inside urban area has a feature of high density of OD pairs to a narrow space comparing the interurban road network. In addition, many researches based on the FCLM assume to locate a facility on a node. However, in the road network inside urban area, it is more realistic to assume that a facility is located on a link which shows the road.

In this paper, based on the FCLM model proposed by Hodgson *et al.*, we modify the model to locate the required number of facilities with a path depending on distance of the path without giving combinations of facilities location points. We also confirm the usefulness of modifying model by using the data of road network of Bangkok, Thailand.

The paper is organized as follows. In section 2, we briefly give an overview of the FCLM, which is basic concept of our model. After that we explain our modified model based on the FCLM. In section 3, we explain the method of numerical experiment by using the data of road network of Bangkok, Thailand. We also explain the evaluation method to compare between our modified model and the FCLM by using each result. The experimental results and discussion are presented. Section 4 is devoted to a summary.

2 Proposed method

In this section, we briefly review the flow-capturing location-allocation model (FCLM), which is basic concept of our model. After that we explain our modified model based on the FCLM.

2.1 Review of the flow-capturing location-allocation model

Hodgson *et al.* [7] proposed the flow-capturing location-allocation model (FCLM) that maximizes the summation of traffic flows captured by the facilities. The FCLM is modeled based on the maximal covering location problem (MCLP) proposed by Church *et al.* [11]. The FCLM assumes dynamic demands as the traffic flow, in contrast the MCLP assumes static demands as the population.

One of the features of the FCLM is to avoid the cannibalization. This is under the idea if the traffic flowing a certain route uses a facility once, the possibility it uses other facility existing same route is small. From this feature, the FCLM matches for the facilities arranged along roads such as gasoline station or convenience store.

We define the symbols for formulating the FCLM as follows :

j :the element of OD pair (the route is the shortest path),
J :the set of OD pairs,
f_j :the amount of the flow on the shortest path between OD pair j [trip/day],
i :the element of the node,
I :the set of nodes,
N_j :the set of nodes that can capture f_j
(the set of nodes in the route between OD pair j),
p :the number of facilities located a network.

Note that since it is considered one trip when one vehicle travels between an OD, we express an unit of flow f_j as the number of trips per day.

Furthermore, we define 0-1 integer variable as :

$$x_i = \begin{cases} 1 & \text{a facility is located on the node } i, \\ 0 & \text{otherwise.} \end{cases}$$

$$y_j = \begin{cases} 1 & f_j \text{ is captured,} \\ 0 & \text{otherwise.} \end{cases}$$

Based on these, the FCLM is formulated as :

$$\text{max.} \quad Z = \sum_{j \in J} f_j y_j, \tag{1}$$

$$\text{s. t.} \quad \sum_{i \in N_j} x_i \geq y_j \quad \forall j \in J, \tag{2}$$

$$\sum_{i \in I} x_i = p, \tag{3}$$

$$x_i, y_j \in \{0, 1\}. \tag{4}$$

The objective function (1) describes the maximization of the total captured flow by p facilities excepting for the cannibalization. The constraint (2) describes to locate 1 or more facilities on a captured path. In addition, the constraint (3) describes that the total number of facilities located on a road network equals to p. Furthermore, the constraint (4) determines the domain of x_i and y_j.

Focusing on the objective function (1) and the constraint (2), it is found that the objective function does not increase even if two or more facilities are located on a same path. With this construction of the FCLM, it becomes possible to avoid the cannibalization.

2.2 Proposed modification of the FCLM

On the ground that the driving distance per charge of EVs is short, there is the constraint for the EV charging facilities that the multiple facilities should be located at appropriate interval on a sufficiently long path. The FCLM is modeled as decreasing the number of facilities located on a same path for avoiding the cannibalization. Therefore, the FCLM cannot be applied to the EV charging facilities straightforwardly. For this reason, we modify the FCLM to locate the multiple facilities on a sufficiently long path invariably. Hereinafter, we refer to the model as "Our Model". Concretely, the threshold for determining a sufficiently long path is decided and the required number of facilities for a path is calculated by using the threshold and the distance of each path. Note that if we consider a realistic problem, the threshold is calculated from the driving distance of target vehicles.

To get prepared for defining "Our Model", we define several elements as follows. The matrix R that expresses the relationship between link k and path between OD pair j is defined as:

$$R = \begin{pmatrix} r_{11} & \dots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{j1} & \dots & r_{jk} \end{pmatrix}, \ k \in K, \tag{5}$$

where K is a set of link and r_{jk} is defined as:

$$r_{jk} = \begin{cases} 1: & \text{if link } k \text{ exists on path between OD pair } j, \\ 0: & \text{otherwise.} \end{cases} \tag{6}$$

The vector f that has the elements f_j expressing the traffic flow on path between OD pair j is defined as:

$$f = \begin{pmatrix} f_1 \\ \vdots \\ f_j \end{pmatrix}. \tag{7}$$

The vector x has the elements x_k expressing facility location on a link k and the vector y has the elements y_j expressing capture of the flow by path between OD pair j, respectively. They are defined as:

$$x = \begin{pmatrix} x_1 \\ \vdots \\ x_k \end{pmatrix}, \qquad y = \begin{pmatrix} y_1 \\ \vdots \\ y_j \end{pmatrix}, \tag{8}$$

where x_k and y_j are variables defined as:

$$x_k = \begin{cases} 1: & \text{if a facility is located at link } k, \\ 0: & \text{otherwise.} \end{cases} \tag{9}$$

$$y_j \in \mathbb{Z} : \text{the number of facilities capturing flow } f_j \text{ of a path between OD pair } j. \tag{10}$$

In addition, we define the elements d_j and d, which express the distance of path between OD pair j and the threshold for determining a sufficiently long path, respectively. Then, the number of facilities required on path between OD pair j is defined by using d_j and d as:

$$p_j = \left\lceil \frac{d_j}{d} \right\rceil, \tag{11}$$

where $\lceil * \rceil$ is the ceiling function. The vector that has the elements p_j is defined as:

$$p = \begin{pmatrix} p_1 \\ \vdots \\ p_j \end{pmatrix}. \tag{12}$$

We also define the 0-1 integer constant l_j for deciding the path that p_j facilities must be located as:

$$l_j = \begin{cases} 1: & \text{if } p_j \geq 2, \\ 0: & \text{if } p_j < 2. \end{cases} \tag{13}$$

The vector that has the elements l_j is defined as:

$$l = \begin{pmatrix} l_1 \\ \vdots \\ l_j \end{pmatrix}. \tag{14}$$

"Our Model" is formulated as:

Maximize :

$$Z = f^{\mathrm{T}}y, \tag{15}$$

subject to :

$$Rx \geq y, \tag{16}$$

$$\sum_{k \in K} x_k = p, \tag{17}$$

$$x \in \{0, 1\}, \tag{18}$$

$$y = \begin{cases} p_j : \text{ if } l_j = 1, \\ \{0,1\} : \text{ if } l_j = 0. \end{cases} \tag{19}$$

$$\begin{aligned} \text{max.} \quad & Z = f^{\mathrm{T}}y, && (20) \\ \text{s. t.} \quad & Rx \geq y, && (21) \\ & \sum_{k \in K} x_k = p, && (22) \\ & x \in \{0, 1\}, && (23) \\ & y = \begin{cases} p_j : \text{ if } l_j = 1, \\ \{0,1\} : \text{ if } l_j = 0. \end{cases} && (24) \end{aligned}$$

The major difference between "Our Model" and the FCLM is the domain of variable y_j. By deciding the domain of variable y_j like the constraint (24), it is possible to locate the required number of facilities on the path determined a sufficiently long path. Since y_j is the number of locations of facilities on j in substance, "Our Model" can locate p_j facilities on a sufficiently long path with avoiding the cannibalization as much as possible.

In addition, the FCLM expresses a traffic flow at a node, on the other hand, "Our Model" expresses it at a link. This is because it is more natural to locate a facility on a road than an intersection.

3 Numerical experiments

To confirm the usefulness "Our Model", we perform the numerical experiments by using the data of road network of Bangkok, Thailand.

We perform it by a relaxed linear programming for solution method. Typically, an approximate method is applied to large scale combinatorial optimization problems. However, the scale of problems which can be solved by exact solution method increased with the performance improvement of a computer. To use an exact solution method, a solution is not changed by a difference of solution methods since a global optimal solution can be obtained. Therefore, by using an exact solution method, it is more easier to verify the effects to solution by the model or network than using an approximate method. Recently, we conducted the research of the method applying an exacts method to a constraint satisfaction problem [12]. Utilizing the knowledge obtained in [12], we use the method of combined the simplex method and branch and bound, which is an exact method.

3.1 Data

In the experiments, we use the road network of Bangkok, Thailand as a case study. The data used for the experiments are targeting three networks N1, N2 and N3 extracted from the road network as shown in Fig. 1. The detail data of each network are shown on Tables 1 and 2, and the distribution of the path distance in each network is shown in Fig. 2. Note that all paths are bidirectional. In Fig. 1 and Table. 2, we distinguish the road classes, however, each road has no constraints or attributes especially.

In N1, the roads are scattered to whole network. The right side of N2 is an urban area and the left side is a suburban area. The left side of N3 is an urban area and the right side is a suburban area. You can observe that the network of an urban area is dense and a suburban area is sparse. The area increases in the order of N1, N3, and N2, respectively. However, the number of OD pairs is the largest in N2. In addition, from Fig. 2, the paths distance of N1 is scatter. Conversely, the paths distance of N2 is concentrated in around 14,845 [m] - 18545 [m]. N3 has many shorter paths than N1 and N2. By observing the simulation results by using these N1, N2 and N3 networks, we will confirm the tendency of locations by models.

The threshold d determining long distance paths is the driving distance of target EVs and it is set to extract long distance path of the top 20%. This is because the networks applied model in this experiments is small and the road distance of real EVs ends up longer than the maximum path length possessed by the networks. In addition, we do not use same driving distance among all networks since we evaluate a performance of models by making a ratio of long distance path to all paths the same in each network. Furthermore, we could not prepare an actual data of OD traffic volume and it was difficult to estimate it. Therefore, in order to prevent the evaluations of models from being influenced by OD traffic volume, we assume it as unit traffic volume 1[trip/day]. This is because the network to which the model is applied in this experiments is small and the driving distance of EVs ends up becoming longer than the maximal path distance that the network has when the threshold is too large.

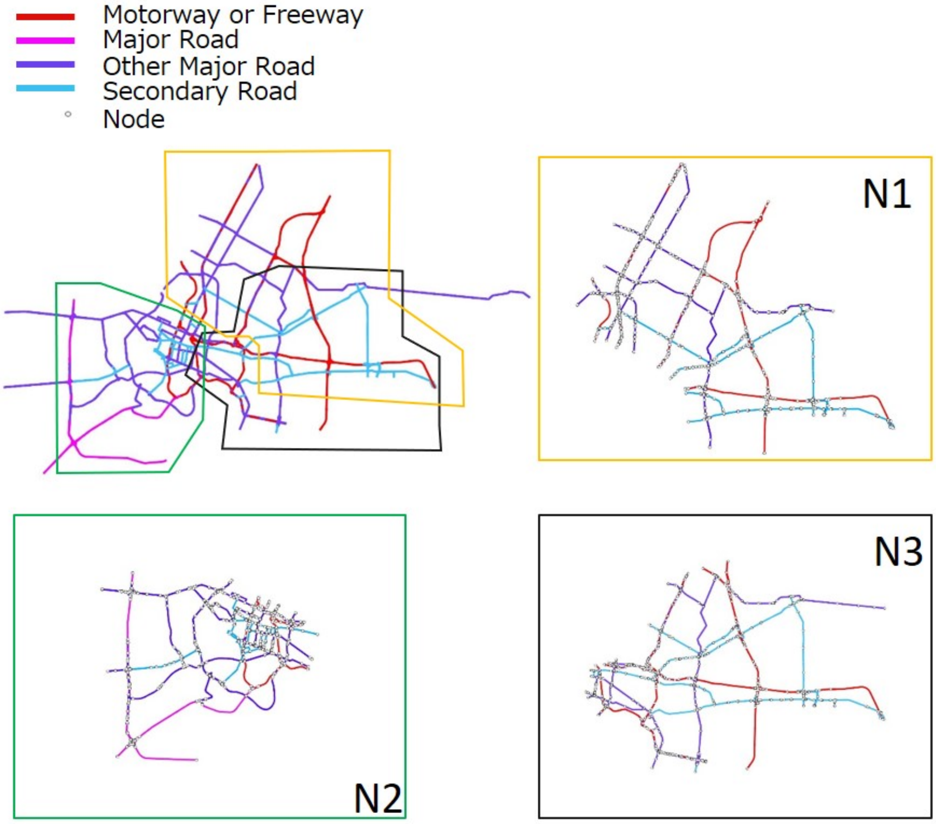

Figure 1: Road network of Bangkok, Thailand

Table 1: Data of each network

Network	Nodes	Links	OD pairs	Driving distance d [m]	Scale [m]
N1	1,182	1,789	5,598	27,442	33,991×30,243
N2	1,131	1,836	6,074	19,282	23,208×19,594
N3	1,178	1,811	5,642	21,101	32,006×22,026

Table 2: Road classification

	N1		N2		N3	
Road classification	Number	Ratio(%)	Number	Ratio(%)	Number	Ratio(%)
Motorway or Freeway	213	11.807	105	5.642	255	13.950
Major Road	0	0.000	98	5.266	0	0.000
Other Major Road	986	54.656	1,186	63.729	874	47.811
Secondary Road	605	33.537	472	25.363	699	38.239
Total	1,804	100.000	1,861	100.000	1,828	100.000

3.2 Evaluation methods

In numerical experiments, we prepare three evaluation methods and compare “Our Model” with the FCLM by using each result. We use the following three evaluation methods.

3.2.1 Method 1 - Evaluation of the location points of facilities

In method 1, we show the location points of facilities on an actual map to assess obtained results qualitatively. In addition, in each model, we observe and evaluate how facilities are located on each road class with concrete numerical values. All results of method 1 is shown in the case of $p = 30$.

3.2.2 Method 2 - Evaluation of the transition of the amount of captured flows

In method 2, we observe the transition of the following three evaluate indices by changing the number of facilities p. We compare “Our Model” with the FCLM.

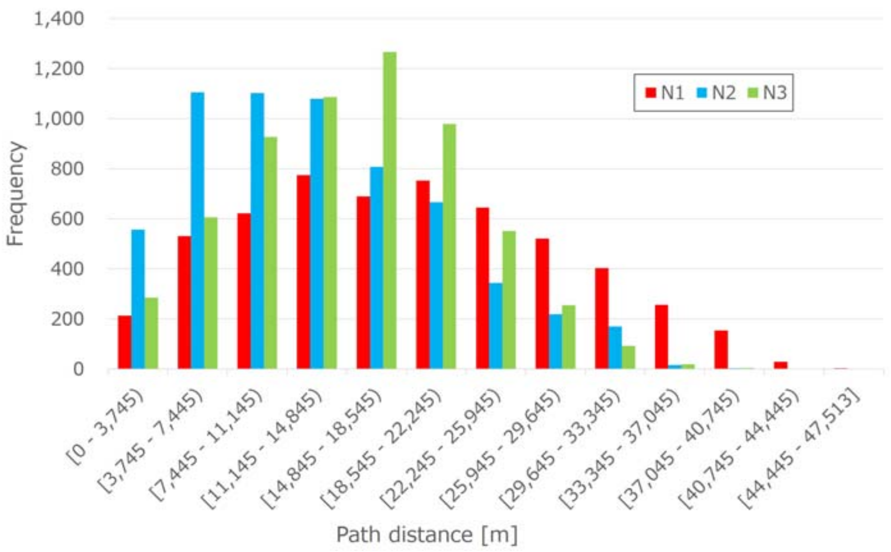

Figure 2: Distribution of the path distance in each network

Total captured demands

Total captured demands describe the total amount of captured flows by all facilities including cannibalization:

$$\text{The FCLM : TotalCap} = \sum_{j \in J} \sum_{i \in R_j} f_j x_i, \tag{25}$$

$$\text{Our Model : TotalCap} = \sum_{j \in J} \sum_{k \in R_j} f_j x_k, \tag{26}$$

where R_j is the set of a node i or link k existing on the path between OD pair j.

Actual captured demands

Actual captured demands describe the actual amount of captured flows that the value subtracted the amount of the cannibalization from total captured demands:

$$\text{The FCLM : ActualCap} = \sum_{j \in J} f_j y_j p_j. \tag{27}$$

$$\text{Our Model : ActualCap} = \sum_{j \in J} f_j y_j. \tag{28}$$

The calculation method is different in the FCLM and “Our Model” since we evaluate two models equally. “Our Model” is considered to locate the multiple facilities on a sufficiently long path not to occur the cannibalization. On the other hand, in case that the multiple facilities are located on a path, the FCLM is modeled to be premised on occurring the cannibalization on no matter what a path. Thus, we allow the evaluation indices to match between “Our Model” and the FCLM by multiplying the amount of flow by the required number of facilities p_j on path between OD pair j in the index of the FCLM.

Captured rate

Captured rate describes the capture rate by the facilities:

$$\mathrm{CapRate} = \frac{\mathrm{ActualCap}}{\mathrm{TotalCap}}. \tag{29}$$

3.2.3 Method 3 - Evaluation related to the location points of multiple facilities on a sufficiently long path

If the multiple facilities are located on a sufficiently long path, realistically, it is not better that the distance between facilities is too short or too long. Charging facilities should be located on a path at appropriate interval not to run out of battery of EV. Thus, in method 3, we determine the appropriate interval between facilities on a sufficiently long path. Moreover, we obtain the error distance between the actual interval and the appropriate interval. It becomes possible to observe the facility located at how long intervals.

The appropriate interval appD_j on path between OD pair j is defined as:

$$\mathrm{appD}_j = \left\lceil \frac{d_j}{p_j} \right\rceil. \tag{30}$$

The actual interval l is defined as actD_{jl} on path between OD pair j. This is because paths existing the networks do not contain elements (height difference, etc.) that are taken into consideration other than the path distance. Therefore, it is a definition based on the idea that facilities are arranged at equal, the possibility of running out of battery is low. Then, the error distance errD_{jl} of interval l of facilities on path between OD pair j is defined as:

$$\mathrm{errD}_{jl} = \mathrm{appD}_j - \mathrm{actD}_{jl}. \tag{31}$$

By definition of Eq.(eq:errD), the interval of facilities is longer than the appropriate distance if $\mathrm{errD}_{jl} > 0$ and shorter than the appropriate distance if $\mathrm{errD}_{jl} < 0$. In addition, we define a evaluation index that measures the performance of models relating error distance by calculating the root mean square of the total error distance :

$$\sigma = \sqrt{\frac{1}{|J|}\sum_{j\in J}\sum_{l\in L_j}{\mathrm{errD}_{jl}}^2}, \tag{32}$$

where $|J|$ indicates the number of elements of the set J and L_j indicates the set of section between facilities of path j. By definition of both errD_{jl} and σ, these evaluation indices show the better result if these become closer to 0.

3.3 Results

3.3.1 Result 1 - Evaluation of the location points of facilities

The results obtained by method 1 are shown in Figs. 3-5. The size of circle on the maps describes the amount of flows captured by the facility located at center of the circle. In this experiment, the amount of captured flows means the number of captured OD pairs, because the only shortest path exists on OD pairs and the unit demand is flowing on the path.

In any networks, in the FCLM, the facilities tend to concentrate on some points. On the other hand, in case of “Our Model”, there are no tendency like the FCLM and the facilities are located in scattered. Since “Our Model” is modeled not to occur the cannibalization if the number of facilities located on a sufficiently long path are p_j or less, we can confirm these results.

In Table 3, we show the number of facilities arranged in which kind of road class as x. In addition, Fig. 6 shows the ratio of each road class occupying in the network and the number of facilities located on the road class. From Fig. 6, we can confirm that the tendency that the ratio of each road class occupying in the network coincides with the ratio of the number of facilities located on each road class. In the result obtained by the FCLM in N3, however, the ratio of the other major road and the secondary road is reversed. From N3 of Fig. 1, it is found that the secondary road is scattered on whole of the network and many junctions and intersections are seen. The FCLM has the tendency that facilities are located at the point paths gather. Therefore, these results are

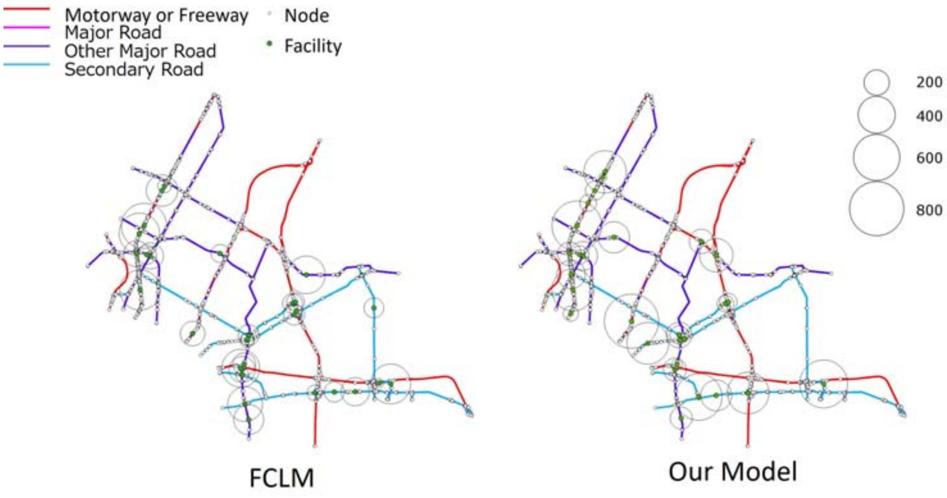

Figure 3: Actual locations of facilities in N1

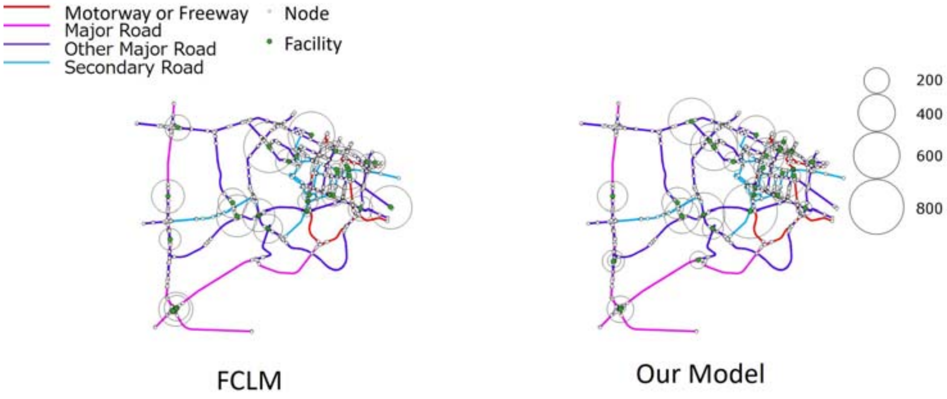

Figure 4: Actual locations of facilities in N2

obtained in N3. From these results, it was found that the location of facilities is influenced more by the network structure such as junctions and intersection than the characteristic inherent of each road class.

3.3.2 Result 2 - Evaluation of the transition of the amount of captured flows

The results obtained by method 2 are shown in Figs. 7-12. In “Our Model”

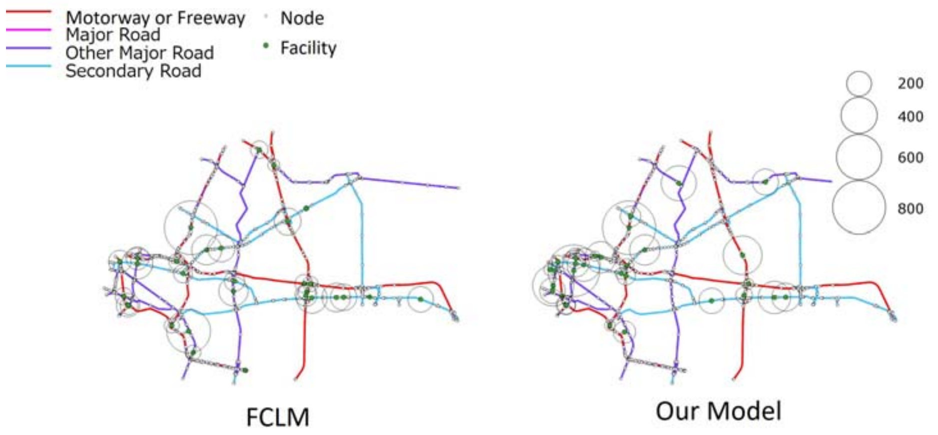

Figure 5: Actual locations of facilities in N3

Table 3: The number of facilities and its ratio located at each road class

	N1				N2				N3			
	FCLM		Our Model		FCLM		Our Model		FCLM		Our Model	
Road classification	x	Ratio(%)	x	Ratio(%)	x	Ratio(%)	x	Ratio(%)	x	Ratio(%)	x	Ratio(%)
Motorway or Freeway	1	3.333	1	3.333	1	3.333	0	0.000	7	23.333	5	16.667
Major Road	0	0.000	0	0.000	3	10.000	2	6.667	0	0.000	0	0.000
Other Major Road	16	53.333	17	56.667	17	56.667	20	66.666	10	33.333	13	43.333
Secondary Road	13	43.333	12	40.000	9	30.000	8	26.667	13	43.333	12	40.000
Total	30	100.000	30	100.000	30	100.000	30	100.000	30	100.000	30	100.000

of Figs. 7-12, several results do not exist on a certain area, because the feasible solutions could not be obtained if the number of facilities p was small. In the results obtained by the FCLM, since we define ActualCap to consistent with the FCLM and “Our Model” as explained in section 3.2.2, there is the case that the value of ActualCap decreases, though the number of facilities increases.

From Fig. 7-9, the case that TotalCap decreases is confirmed at certain points, though there is the tendency that TotalCap increases with p in any network or model. This is because in case that the location points exist to increase RealCap even if TotalCap decreases, a facility is located on that point. On the other hand, since the facilities located on the network increase and the uncaptured paths decrease, all paths are finally captured. Then, RealCap increases logarithmically. Moreover, it is possible to confirm that CapRate

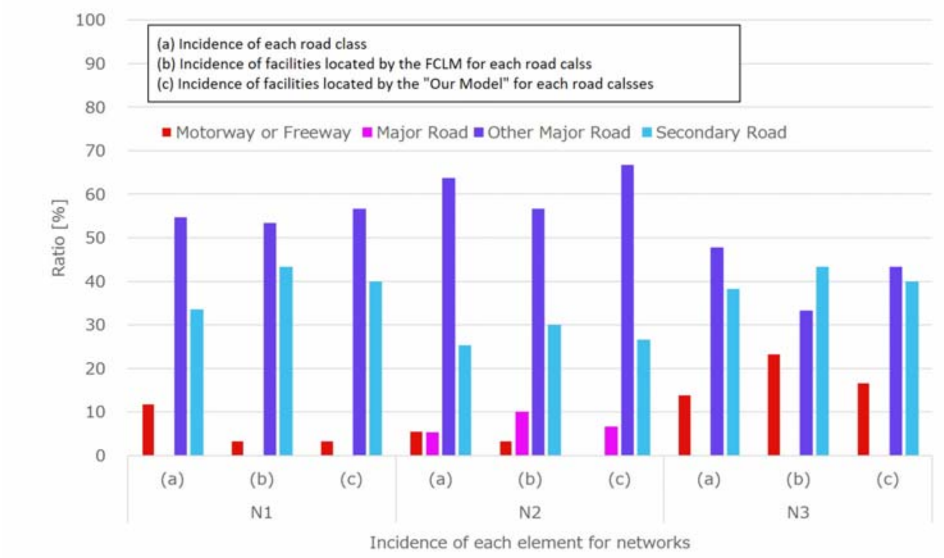

Figure 6: Incidence of roads and facilities for each network

decreases with the increase of the number of facilities p. However, the graph of CapRate does not become a clean curve since it is influenced by TotalCap.

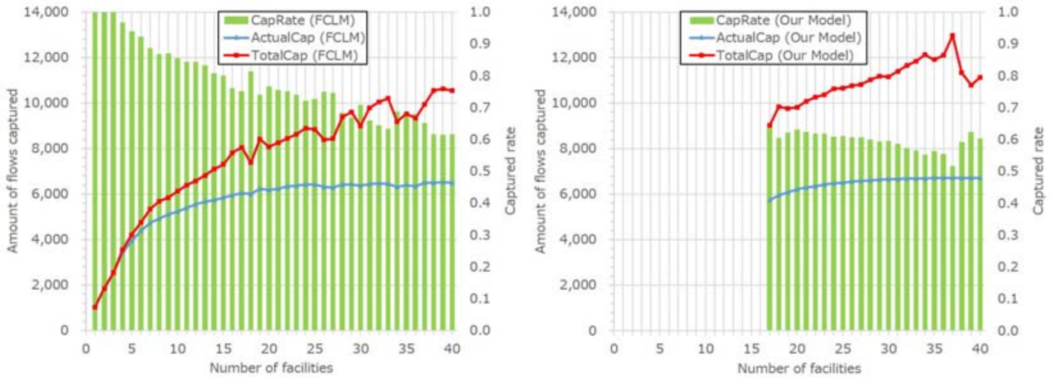

Figure 7: Transition of the amount of captured flows in N1

Figs. 10-12 focus on ActualCap in particular and compare the results of two models. If the number of facilities p is small, the FCLM locates the facilities efficiently than “Our Model”. “Our Model”, however, locates the facilities more efficiently than the FCLM if the number of facilities p is sufficiently large. Table 4 shows the value of ActualCap concretely. “Ratio” on Table.4 indicates

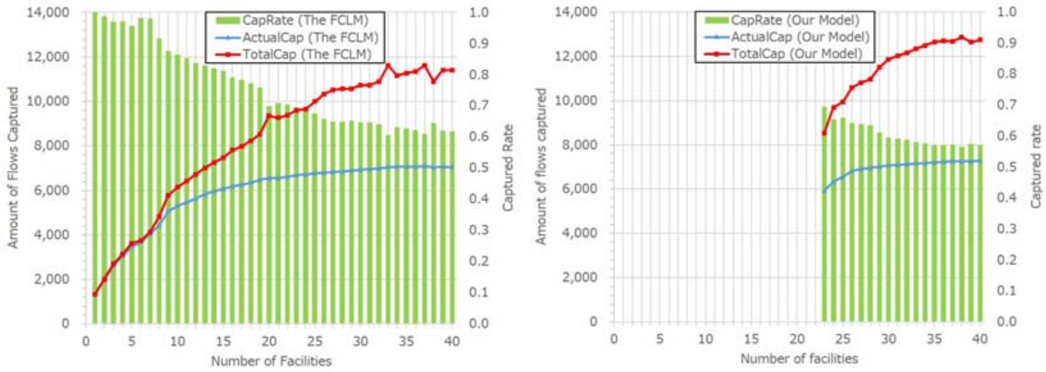

Figure 8: Transition of the amount of captured flows in N2

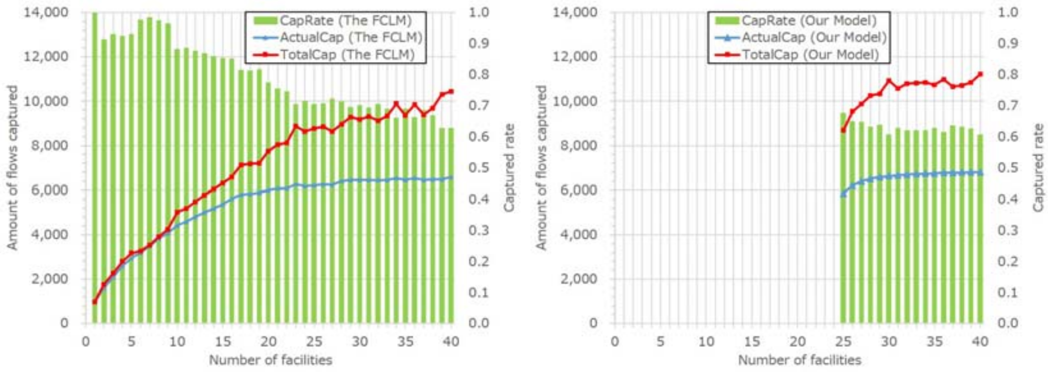

Figure 9: Transition of the amount of captured flows in N3

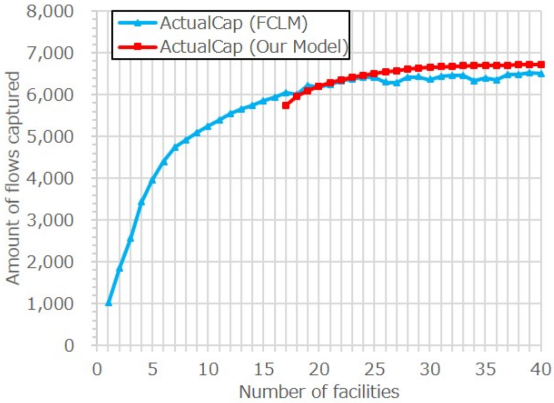

Figure 10: Transition of the values of ActualCap in N1

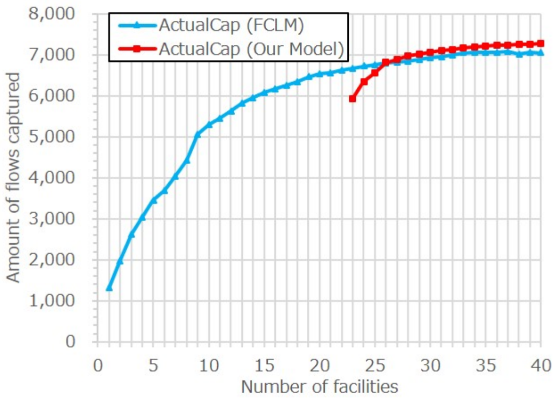

Figure 11: Transition of the values of ActualCap in N2

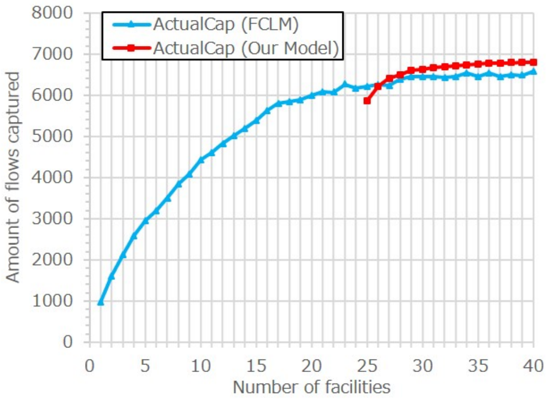

Figure 12: Transition of the values of ActualCap in N3

how many % ”Our Model” captures the traffic flow rate compared to the FCLM. From $p = 20$, $p = 26$ and $p = 27$ in N1, N2 and N3, the value of ”Our Model” begins to exceed the FCLM. Thereafter, the ratio tends to increase. In realistic problems, it is assumed that the number of facilities located on a network is sufficiently large. Therefore, from Figs. 10-12 and Table 4, “Our Model” has more validity in location-allocation of the EV charging facilities than the FCLM.

However, there is the difference of the amount of captured flow between “Our Model” and the FCLM. In addition, we cannot assess whether the model is available to what kind of network since the number of networks used for experiments is small. Thus, we will have to conduct more experiments by using various types of networks in order to analyze the model in more detail.

Table 4: Comparison of ActualCap between the FCLM and “Our Model”

	N1			N2			N3		
p	FCLM	Our Model	Ratio(%)	FCLM	Our Model	Ratio(%)	FCLM	Our Model	Ratio(%)
18	6,004	5,957	-0.78	6,351	-	-	5835	-	-
19	6,229	6,087	-2.28	6,465	-	-	5886	-	-
20	6,188	6,199	0.18	6,542	-	-	5999	-	-
21	6,233	6,279	0.74	6,564	-	-	6072	-	-
22	6,332	6,350	0.28	6,618	-	-	6070	-	-
23	6,372	6,415	0.67	6,676	5,920	-11.32	6266	-	-
24	6,408	6,469	0.95	6,726	6,341	-5.72	6171	-	-
25	6,418	6,504	1.34	6,758	6,555	-3.00	6202	5868	-5.39
26	6,297	6,541	3.87	6,792	6,812	0.29	6255	6202	-0.85
27	6,290	6,577	4.56	6,828	6,898	1.03	6241	6402	2.58
28	6,416	6,605	2.95	6,849	6,967	1.72	6389	6497	1.69
29	6,427	6,628	3.13	6,888	7,023	1.96	6457	6594	2.12
30	6,362	6,649	4.51	6,937	7,071	1.93	6442	6628	2.89
31	6,445	6,667	3.44	6,949	7,104	2.23	6453	6660	3.21
32	6,460	6,678	3.37	6,988	7,135	2.10	6437	6686	3.87
33	6,452	6,688	3.66	7,051	7,163	1.59	6443	6714	4.21
34	6,321	6,695	5.92	7,055	7,187	1.87	6543	6736	2.95
35	6,402	6,701	4.67	7,062	7,210	2.10	6460	6755	4.57
36	6,346	6,705	5.66	7,068	7,231	2.31	6541	6769	3.49
37	6,482	6,709	3.50	7,092	7,246	2.17	6442	6779	5.23
38	6,485	6,713	3.52	7,027	7,257	3.27	6487	6788	4.64
39	6,525	6,715	2.91	7,072	7,263	2.70	6484	6794	4.78
40	6,505	6,717	3.26	7,051	7,269	3.09	6576	6800	3.41

3.3.3 Result 3 - Evaluation related to the location points of multiple facilities on a sufficiently long path

The results obtained by method 3 are shown in Figs. 13-18 and Table 5. These figures and table correspond to the histogram of the distribution of error distance, the distribution of the error distance by the path distance and the dispersion of the error distance from the reference value 0, respectively.

Since there is the case that each path has the multiple intervals of facilities, in Figs. 16-18, we assume the average of the error distance of each interval of a certain path as the error distance of the path.

Table 5: Value of σ

	N1	N2	N3
Our Model	5,291.31	4,463.80	4,087.66
The FCLM	6,677.81	5,033.13	4,957.47

From Figs. 13-18, the data of the FCLM is less than “Our Model” in any network, because there is the case that only 1 or 0 facility located on a path even if the multiple facilities must be located on the path in the FCLM. In addition, from Table 5, the value of σ of “Our Model” in any network is also smaller than that of the FCLM. This result suggests that “Our Model” holds the appropriate distance.

From Figs. 13-15, it is found that “Our Model” obtains many data distributed around 0 compared with the FCLM in any network. Since the FCLM does not assume to locate the multiple facilities on a sufficiently long path, the facilities are located at where there are many paths. For this reason, the error distance obtained by the FCLM scattered.

As the results, we show the possibility that “Our Model” has the effectiveness compared with the FCLM if we handle the problem targeting the facilities like the EV charging facilities.

However, from Figs. 16-18 , we found that “Our Model” has less dispersion than the FCLM’s. Moreover, “Our Model” has the tendency that the interval of facilities is located at shorter than the appropriate distance. This is because the appropriate distance of each path becomes longer in proportion to a distance of the path. However, the facilities are arranged on a path regardless of the distance of the path in “Our Model”. Therefore, to achieve a further improvement of “Our Model” , we have to introduce the minimization the error of the distance between facilities and the appropriate distance to the objective function.

4 Conclusion and Outlook

In this paper, we proposed a model of the flow-capturing facility location

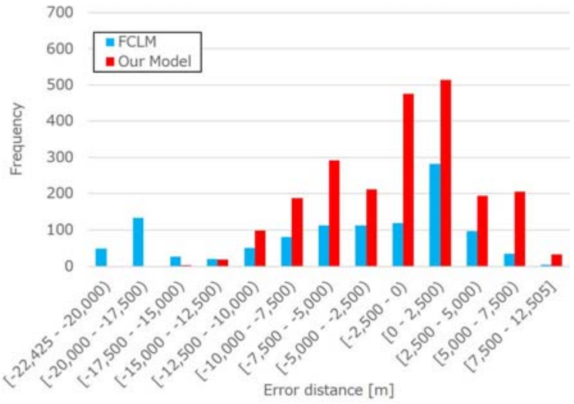

Figure 13: Distribution of the error distance by each model in N1

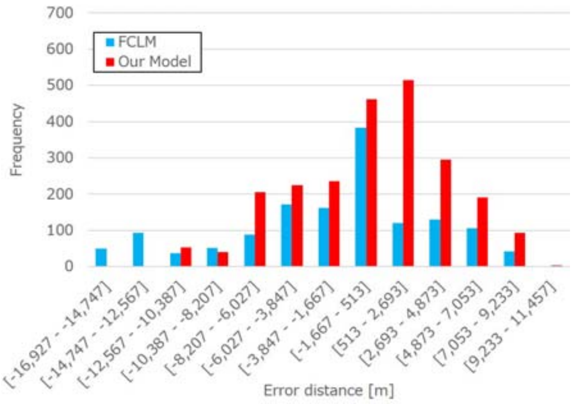

Figure 14: Distribution of the error distance by each model in N2

problem targeting the EV charging facilities. The FCLM proposed by Hodgson *et al.* is the fundamental model handling the facility such as a refueling station. However, the model was not considered the driving distance of vehicles. The feature of EV is the point that the driving distance is shorter than existing gasoline-powered vehicle. Thus, it is difficult to apply the FCLM to optimal location of the EV charging facilities, straightforwardly. Therefore, we proposed the model introduced the constraint that must locate the number of facilities required on a sufficiently long path.

As the result of the numerical experiments by using the data of road network of Bangkok, Thailand, it was found that “Our Model” could efficiently locate facilities to a road network in case of targeting the vehicle that had the

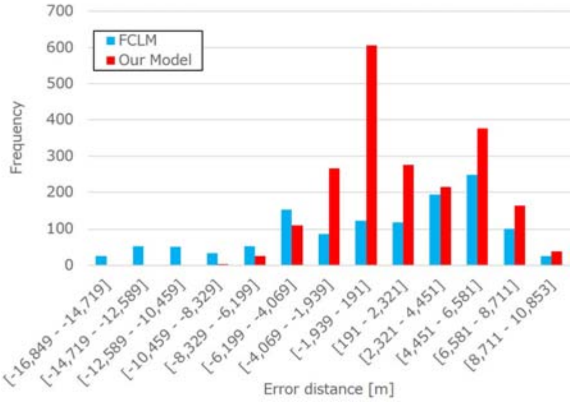

Figure 15: Distribution of the error distance by each model in N3

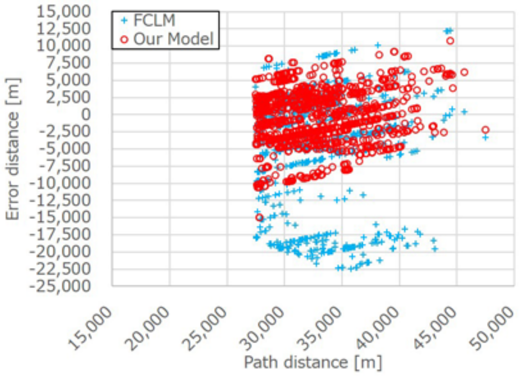

Figure 16: Distribution of the error distance in each path distance in N1

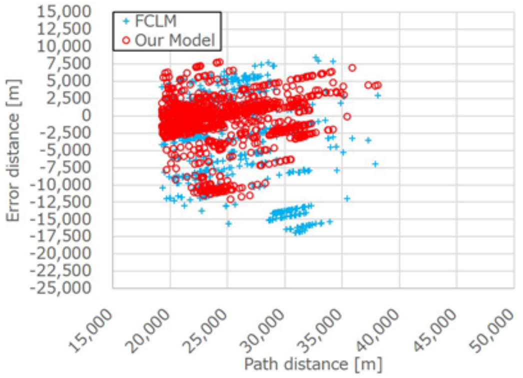

Figure 17: Distribution of the error distance in each path distance in N2

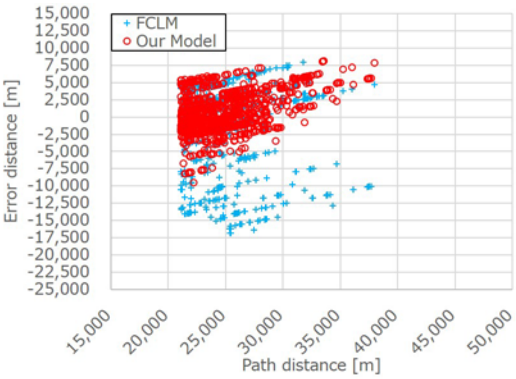

Figure 18: Distribution of the error distance in each path distance in N3

short driving distance (such as EV). In addition, we focused on the interval of facilities located on a certain path and compared the tendency with the results obtained by "Our Model" and the FCLM. As the result, it was confirmed that "Our Model" located facilities on a sufficiently long path in close to the appropriate interval compared with the FCLM. It was also confirmed that the results obtained by "Our Model" were arranged facilities all over to a entire road network.

"Our Model" proposed in this paper did not optimize the interval between facilities located on a sufficiently long path. In the future, to make the model more realistic, we have to propose a model minimizing the error between the actual interval and the appropriate distance. In addition, if we extract OD pairs from a road network, we have to do not only random extraction but also the valid extraction. Since EV also has the constraint that the charging time is long, we also have to research a model considering the capacity of the facility.

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