

Charging Station Location Optimization of Electric Ship Based on Backup Coverage Model

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ABSTRACT: In terms of electric ship energy requirement in navigation, the ship charging station location is especially important. In this paper, a multi-period ship charging station location optimization model is proposed to make location decision in overall, from initial possible station sites chosen to the capacity determination for the final location sites. In the first phase, from the perspective of external environment, find out all possible ship charging station candidate sites through the feasible analyze. In the second phase, taking the ship charging demands into consideration, the final ship charging station sites can be selected among the candidate sites based on backup coverage model. In the last phase, regarding the cost of construction and service capability for different grade as the main factor in capacity determination, the optimal capacity of each final ship charging station are determined by means of optimization method. Finally, an example of Yanqi lake in China is used to verify the validity of the proposed methodology. The reasonable location of charging station could ensure the electric energy supply and avoid congestion caused by ship charging gathering. The model can be easily generalized to other problems regarding facility allocation based on user demand.

1 INTRODUCTION

Despite all the acknowledged advantages in terms of environmental impact reduction, energy efficiency and noise reduction, the electric mobility market is below expectations, especially for the electric ship.

In fact, electric vehicles have limitations that pose several important challenges for achieving a sustainable mobility system: among them, the availability of an adequate charging infrastructure is recognized as a fundamental requirement and appropriate approaches to optimize public and private investments in this field are to be delineated.

As a kind of popular electric ship, the battery ship is applied in small scale passenger transportation and cargo transportation system, such as tourist ship in environment sensitive area. For the development of

battery ship, the ship charging station location is becoming important. The principle and requirement of ship charging station location is different from vehicles in land, due to the navigation environment and ship charging demand distribution deployment law. The energy requirement for each one of the subareas is estimated in terms of the electric energy used by the equivalent fleet of electric vehicles to reach their destination.

Hogan and ReVelle [1] introduced the idea of backup coverage into location models. These models were developed in the context of siting emergency facilities that are required to serve a given population. Araz C [2] proposed a multi-objective maximal covering location model, three objectives are maximization of the population covered by one vehicle, maximization of the population with backup

coverage and minimization of the total travel distance from locations at a distance bigger than a prespecified distance standard for all zones. Zhu Z H [3] proposed a novel model for the charging station location problem of plug-in electric vehicles. With the objective of minimizing the total cost, the proposed model simultaneously handles the problem of where to locate the charging stations and how many chargers should be established in each charging station. Xiang Y [4] develops a novel solution to integrate electric vehicles and optimally determine the siting and sizing of charging stations (CSs), considering the interactions between power and transportation industries. A two-step screening method with the environmental factors and service radius of electric vehicle charging stations considered is presented to identify the candidate sites of electric charging stations [5]. Hamaide B [6] considers the case of land heterogeneity in terms of the risk of large disturbances that threaten species even within a reserve, proposed a reserve site selection model. A traffic-flow capture model integrated with traffic flow data was proposed in reference [7] to help locate CSs. Reference [8] introduced a charging traffic flow, which contains both spatial and temporal properties of a charging load, as a discrete sequence to describe charging start events. Wang Sunwei [9] proposed a multi-objective optimization layout model to optimize the locations of emergency resource stations. Jinfen Zhang, Xinping Yan and Zhang Di [10] focuses on the assessment of MSA performance in term of safety with Belief Rule-base (BRB) methodology. Shanshan Fu, Xinping Yan and Zhang Di [11] proposed a framework of quantitative risk assessment to estimate the potential risk of LNG-fueled vessels leakage.

In this paper a multi-period methodology of ship charging station model is proposed to make the location decision in overall, from initial possible station sites chosen to the capacity determination for the final location sites. The model can be easily generalized to other problems regarding facility allocation based on user demand.

2 PROPOSED METHODOLOGY

The ship charging station location procedure of ship charging stations is divided into three phase. In the first phase, from the perspective of external environment, find out all possible ship charging station candidate sites through the feasible analyze. In the second phase, taking the ship charging demands into consideration, the final ship charging station sites can be selected among the candidate sites based on backup location model. Lastly, regarding the cost of construction and service capability for different grade as the main factor in capacity determination of ship charging station, the optimal capacity of each final ship charging station are determined by means of optimization method.

2.1 Feasible analyze of ship charging station sites

From the perspective of external environment, the ship charging station sites should satisfy some certain basic requirements, including safety requirements,

geological condition, land planning, channel condition, navigation condition, and etc. In this paper, 6 aspects of the requirements are chosen to evaluate the feasibility of ship charging station sites. It should be noted that, as is different from electric car charging station place, the ship charging station should be built on the river shore for the convenience. The meaning and evaluate criterion of the requirements are depicted followed.

- Safety requirements: The sites should have fairly good safety to guarantee the safety and stability of electric supply. In this way, the charging station would gain the electric source successfully.
- Geological condition: The station sites are in good geological condition, available for electric grid laying and charging pile installment.
- Land planning: The station sites are allowed to construct power station by local government.
- Channel condition: The channel width should allow at least one ship berthing without disturbing the other ship navigation normally, as well as providing enough berths for ship charging. We should try to avoid meandering water area in sites seeking.
- Navigation condition: The average flow speed of the site should not more than 5m/s. If the site locates in a steep river area, it's obviously not benefit for the ship charging, suffering from charging disturbing. Usually, we are inclined to select sites in smooth waters.
- Surrounding population and facilities deployment: The people's daily life, such as smoking as well as cooking, may increase the fire risk of station. Bridge and buildings surrounding will increase the difficulty of electric wire laying. The sites without no population and facilities surrounding in a radiu of 10m is good.

According to the feasible analyze results, we can find out all ship charging station candidate sites for a study water area.

2.2 Location model based on backup coverage

After feasible analyze of external environment, ship charging station candidate sites are gained. However, the purpose of ship charging station is to provide the service for ships, the ship charging demands is especially important in the charging station location. Taking the ship charging demands into consideration, the final ship charging station sites can be selected among the candidate sites. In this section, a location model based on backup coverage is introduced to determine the ship charging station sites.

Hogan and ReVelle [1] introduced the idea of backup coverage into location models. Here, backup coverage means the presence within the distance standard of more than one facility, or more precisely, the number of times a demand zone is covered. The model was developed in the context of siting facilities that are required to serve a given demand. In such a situation, the unavailability of a facility within a time or distance standard would jeopardize performance of the system.

We can set up the ship charging station location model based on backup coverage. I ($i \in I$) and J ($j \in J$) are sets of demand zones and potential

facility sites, respectively, The decision variables in the location model are Y_i, U_i, X_j , subject to

$$\begin{aligned}
 Y_i &= \begin{cases} 1 & \text{if demand zone } i \text{ is covered at least once,} \\ 0 & \text{otherwise,} \end{cases} \\
 U_i &= \begin{cases} 1 & \text{if demand zone } i \text{ is covered at least twice,} \\ 0 & \text{otherwise,} \end{cases} \\
 X_j &= \begin{cases} 1 & \text{if a charging station is located in region } j, \\ 0 & \text{otherwise,} \end{cases} \\
 a_{ij} &= \begin{cases} 1 & \text{if } d_{ij} \leq S, \\ 0 & \text{otherwise,} \end{cases} \\
 \text{Max } Z_1 &= \sum_i h_i Y_i, \\
 \text{Max } Z_2 &= \sum_i h_i U_i, \\
 \text{s.t. } & \begin{cases} \sum_j a_{ij} X_j - Y_i - U_i \geq 0 & \forall i \in I, \\ U_i - Y_i \leq 0 & \forall i \in I, \\ \sum_j X_j = C \end{cases}
 \end{aligned} \tag{1}$$

where: S is the maximum coverage distance, d_{ij} is the travel distance or time from j to i , C is the number of location sites, h_i is the number of ships in demand zone i .

The goal of location is to realize the maximum of the first coverage number and the additional coverage number of charging station. The first two constraints of this model work in tandem to determine which zones receive backup coverage. The first constraint determines the number of facilities within the distance standard of a zone while the second constraint ensures that backup coverage can only be provided if first coverage is already in place. Available number of stations to be located is limited by the last constraint.

The maximum coverage distance S can be expressed as the endurance mileage. Based on the principle that the output energy of the battery is equal to the energy consumed by the ship, the endurance mileage of ship can be calculated by the formula:

$$S = V_s \frac{E \eta_B}{P_M} \tag{2}$$

where V_s is the shipping average speed; E is the energy of the battery pack, can be denoted by $E = C_R \cdot U_R$, C_R is the rated capacity, U_R is the Rated voltage; η_B is the discharge efficiency of ship battery pack; $P_M = P / \eta_M$, P_M is the total power consumption of electric motor, P is the rated power, η_M is the propulsion efficiency of the electric motor.

2.3 Capacity determination model for ship charging stations

The goal of the capacity determination model is to minimize total travel distance and the total construction cost of ship charging station.

$$\begin{aligned}
 \min Z_3 &= \sum_j \sum_m F_m X_{jm} \\
 \min Z_4 &= \sum_i \sum_j h_i a_{ij} X_{jm} d_{ij} \\
 \text{s.t. } & \begin{cases} \sum_j a_{ij} X_{jm} = 1 & \forall i \in I, j \in J, m \in M \\ \sum_j h_i a_{ij} X_{jm} \leq \sum_m C_m X_{jm} & \forall j \in J \\ \sum_j X_{jm} \leq 1 & \forall j \in J \\ \sum_j \sum_m X_{jm} = C \\ X_{jm} = \begin{cases} 1 & \text{if a charging station of grade } m \text{ is located in region } j, \\ 0 & \text{otherwise,} \end{cases} \end{cases}
 \end{aligned} \tag{3}$$

The Decision variables are X_{jm} . Where h_i is the number of ship in demand of charging in demand zone i ; F_m is the construction cost of charging station of grade m ; C_m is the service capabilities of charging station of grade m . M means the number of charging station grade.

The first constraint indicates that the ships in the demand zone should go to the same charging station of a fix grade in a certain time; the second indicates that the ship charging requirement the must be satisfied; the third constraint represents only one charging station of a grade can be constructed in candidate site.

3 NUMERICAL EXAMPLE

The proposed methodology of ship charging station is adopted in the Beijing Yanqi lake, which is the venue of the 2014 APEC meeting.

3.1 Step 1: candidate ship charging station sites

According to the external environment requirements depicted in section 2.1, altogether 5 charging station sites are selected as candidate charging sites. The feasible ship charging station sites along the Yanqi lake is shown in Figure1.

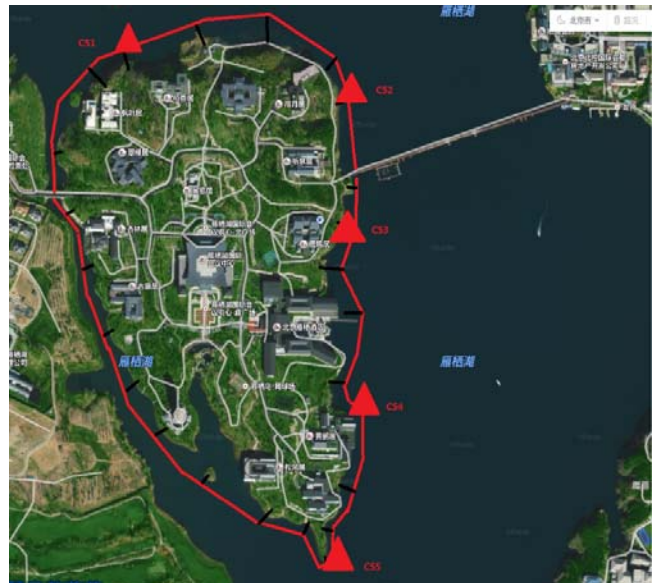


Figure 1. The feasible ship charging station sites

3.2 Step 2: Optimal location of ship charging stations

Supposing the charging demands is distributed along the lake evenly, the 6 demands are shown in figure 2.

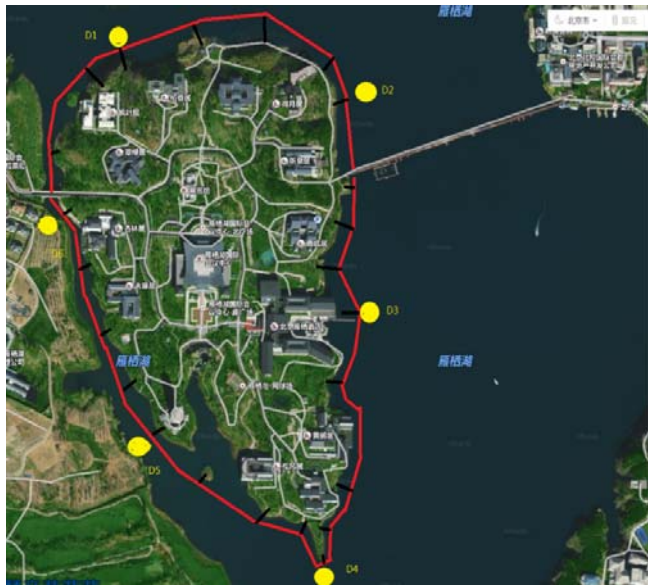


Figure 2 the ship charging demands.

In fact the number of ship in demand of charging is influenced by many factors, such as the deadweight and the ship navigation condition. In this section, we focus on the location method, the demand situation are seen as known before. The parameters in the location model based on backup coverage are given, $C=3, h_1=2, h_2=1, h_3=4, h_4=2, h_5=4, h_6=3$. Moreover, the distance between the black lines is defined as unit interval (about 0.15 kilometers) in figure 1. So, the distance d_{ij} between demand zone i and location sites j is shown in table 2.

Table 2. d_{ij}

	CS ₁	CS ₂	CS ₃	CS ₄	CS ₅
D ₁	0	4	6.5	9.5	11
D ₂	4	0	2.5	5.5	8
D ₃	8	4	1.5	1.5	4
D ₄	11	8	5.5	2.5	0
D ₅	7	11	9.5	6.5	4
D ₆	3	7	9.5	10.5	8

Take all the parameters into the model location model (1), we can solve the model by matlab7.0. The optimal ship charging station (CS) sites are CS₁, CS₄, CS₅. The charging station site CS₄ is near CS₅, which is far from CS₁.

3.3 Step 3: Capacity determination for ship charging stations

Supposing there are two kinds of ship charging station, the station of large scale is in grade 1, the station of small scale is in grade 2. The parameters in the capacity determination model for ship charging stations are given, $F_1=160, F_2=100, C_1=10, C_2=5$. Then, we can get the grade of each ship charging station, the grade of CS₄ is 1, the grade of CS₁ and CS₅ is 2. It means that, according to the demand situation of ship charging, one large scale station and two small scale

station should be built. In overall, the charging station located dispersedly.

4 CONCLUSION

In this paper, a multi-period ship charging station location optimization model is proposed to solve the location problem in overall, from initial possible station sites chosen to the capacity determination for the final location sites. In the first phase, from the perspective of external environment, find out all possible ship charging station candidate sites through the feasible analyze. In the second phase, taking the ship charging demands into consideration, the final ship charging station sites can be selected among the candidate sites based on backup location model. Lastly, regarding the cost of construction and service capability for different grade as the main factor in capacity determination of ship charging station, the optimal capacity of each final ship charging station are determined by means of optimization method. Finally, an example of Yanqi lake in China is used to verify the validity of the proposed methodology. The reasonable location of charging station could ensure the electric energy supply and avoid congestion caused by ship charging gathering. The model can be easily generalized to other problems regarding facility allocation based on user demand.

ACKNOWLEDGEMENT

The authors would like to thank the National Natural Science Foundation of China (NSFC) (No. 51209165) and the National Key Technology Support Program of China (No.2015BAG20B01 and No.2015BAG20B05) for their financial support in this research.

REFERENCE

- [1] Hogan K, ReVelle C. Concepts and applications of backup coverage. *Management Science* 1986;32:1434-44
- [2] Araz C, Selim H, Ozkarahan I. A fuzzy multi-objective covering-based vehicle location model for emergency services[J]. *Computers & Operations Research*, 2007, 34(3):705-726.
- [3] Zhu Z H, Gao Z Y, Zheng J F, et al. Charging station location problem of plug-in electric vehicles[J]. *Journal of Transport Geography*, 2016, 52:11-22.
- [4] Xiang Y, Liu J, Li R, et al. Economic planning of electric vehicle charging stations considering traffic constraints and load profile templates[J]. *Applied Energy*, 2016, 178:647-659.
- [5] Liu Zhipeng, Wen Fushuan, Xue Yusheng, et al. The Optimal Location and Constant Capacity of Electric Vehicle Charging Station [J]. *Automation of Electric Power Systems*, 2012, 36(3):54-59.
- [6] Hamaide B, Albers H J, Busby G. Backup coverage models in nature reserve site selection with spatial spread risk heterogeneity[J]. *Socio-Economic Planning Sciences*, 2014, 48(2):158-167.
- [7] Cruz-Zambrano M, Corchero C, Igualada-Gonzalez L, et al. Optimal location of fast charging stations in Barcelona: A flow-capturing approach[C]// *International*

- Conference on the European Energy Market. IEEE, 2013:1-6.
- [8] Yang S, Wu M, Yao X, et al. Load Modeling and Identification Based on Ant Colony Algorithms for EV Charging Stations[J]. IEEE Transactions on Power Systems, 2015, 30(4):1997-2003.
- [9] Wang Sunwei,Zhou Ronggui,Zhang Gaoqiang,Li Wei,et al.A Method of optimizing the locations of Flooding Emergency Resource Stations: Journal of Transport Information & Safety, 2015.33(5):119-127.
- [10] Zhang J, Yan X, Zhang D,Haugen S,Yang X. "Safety management performance assessment for Maritime Safety Administration (MSA) by using generalized belief rule base methodology"[J]. Safety Science, 2014, 63(4):157-167.
- [11] Fu S, Yan X, Zhang D,C Li,E Zio. Framework for the quantitative assessment of the risk of leakage from LNG-fueled vessels by an event tree-CFD[J]. Journal of Loss Prevention in the Process Industries, 2016, 43,pp.42-52.