Research on Site Selection Optimization of Hydrogen Refueling Station Based on GBDT Method

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Abstract. This study aims to provide a scientific method for private investors to invest in the construction of hydrogen refueling stations with the support of government subsidies. Firstly, the Gradient Boosting Decision Tree (GBDT) model was used to predict the future sales of hydrogen fuel vehicles in different areas of the city, and accordingly, the high-sales areas were identified as the priority candidate locations for the construction of hydrogen refueling stations. On the basis of the above, a site selection model for hydrogen refueling stations with the best economic benefits was further established. The model comprehensively considers the impact of geographical constraints, spatial constraints and the cost of hydrogen production on economic benefits. The study shows that this strategy not only helps private investors maximize their investment returns, but also helps to promote the rational layout and rapid development of hydrogen energy infrastructure, thereby supporting the growth of the hydrogen fuel vehicle industry.

Keywords: hydrogen refueling station location, GBDT model, sales forecast, economic benefits, hydrogen production methods

1 INTRODUCTION

With the gradual maturity of the hydrogen energy vehicle market and the government's strong support for green energy, the construction of hydrogen refueling stations has become a key part of promoting the development of the hydrogen energy economy. Proper location of hydrogen refueling stations can not only improve the supply efficiency of hydrogen fuel, but also significantly affect the popularity of hydrogen energy vehicles and the economic benefits of private investors.

In the process of selecting candidate hydrogen refueling stations, it is necessary to comprehensively consider a variety of economic indicators, which together form the framework of hydrogen refueling station site selection and provide a basis for the subsequent model establishment. In terms of economic indicators for hydrogen refueling stations, Krishna Reddi et al[1]. used a hydrogen delivery scenario analysis model to estimate the impact of different factors on the cost of refueling for different refueling technologies and configurations, and quantified the potential reduction of refueling

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costs in the future compared to the current cost of refueling in the United States. Jonathan X. Weinert et al[2]. estimated the near-term cost of a hydrogen fueling station or various types of hydrogen fueling stations, using a hydrogen fueling station cost and transportation cost model developed by the University of California, Davis, and Tongji University. Based on the life cycle of hydrogen, HeC[3] proposes a hydrogen refueling station siting model, and analyzes the impact of hydrogen refueling station location on the life cycle cost of hydrogen. Lin R[4] applied a variety of data sources, such as geographic information system (GIS) data, population data, and regional economic data, to the P-median site selection model, and selected hydrogen refueling stations in the Beijing area. Considering the interdependence between gas station siting and fuel transportation, IiL[5] proposes a hydrogen refueling siting model with multi-objective capacity constraints.

In terms of hydrogen refueling station planning and site selection, an ensemble optimization model composed of Generalized Bass Diffusion Model (GBDM) and Flow Capture Localization Model (FCLM) is proposed to address the interaction between the sales volume of hydrogen fuel cell vehicles (HFCV) and the number of refueling stations[6]. In the literature[7], a hydrogen refueling station location model considering vehicle scheduling and path decision-making is proposed. M. Fuse et al[8]. considered the needs of fuel cell passenger vehicles and fuel cell trucks and buses in site selection planning. In order to meet the HFCV load, a hydrogen refueling station and renewable energy planning model with the goal of minimizing investment cost is constructed[9]. Based on the literature[10], coupled with the transportation network, based on the Dijkstra algorithm, the shortest hydrogen refueling path is provided for HFCV users, and the distribution model of hydrogen refueling stations is constructed to fully meet the needs of users, and the robustness between HFCV users and the distribution network is strengthened, but the model ignores other components of hydrogen refueling station interests.

Previous studies have often considered market demand forecasts or economic benefits of hydrogen refueling stations in isolation, lacking a systematic analytical framework to synthesize these key elements. In addition, few existing studies utilize advanced machine learning techniques to predict the market demand for hydrogen-fueled vehicles, which may lead to limited accuracy of prediction results. At the same time, the choice of hydrogen production method often does not fully take into account the close connection with market demand forecasts, which may affect the economic and environmental benefits of hydrogen refueling stations.

In order to fill this research gap, this paper proposes a site selection model with the best economic benefits, which combines the hydrogen production method and the hydrogen production site to select the location with the best economic benefits as the optimal hydrogen refueling station, so as to provide a scientific decision-making tool for government decision-makers, urban planners and related enterprises, and promote the market penetration and sustainable development of hydrogen fuel vehicles.

2 PROBLEM DESCRIPTION

In view of the relationship between isolated market demand prediction and the economic benefits of hydrogen refueling stations, the lack of advanced algorithms to predict the sales volume of hydrogen fuel vehicles, and the lack of linking the cost of hydrogen production with economic benefits, this paper proposes a comprehensive analytical framework. spatial constraints, etc.), establish a site selection model for hydrogen refueling stations with the best economic benefits, and select the location with the best economic benefits as the optimal hydrogen refueling station by combining the hydrogen production method and the hydrogen production site.

This article is based on the following assumptions:

1) Market stability assumption: During the forecast period, the market development trend and policy environment of hydrogen fuel vehicles remain relatively stable, and there are no major fluctuations or unforeseen events affecting market demand.

2) The assumption of technological development stationarity: the development rate of related technologies for hydrogen-fueled vehicles and hydrogen refueling stations remains stable over the time planned by the model, regardless of the cost reduction or service capacity improvement that may result from rapid technological progress.

3) Government policy assumptions: The subsidies and support policies provided by the government remain unchanged during the forecast period, and the government budget constraints are known and fixed.

4) Demand forecasting assumptions: The GBDT method can accurately predict future market demand, and the historical data used is accurate and representative of future market trends.

5) Costing assumptions: The calculation of construction and operating costs is based on existing technology and market prices, without taking into account possible cost fluctuations in the future.

6) Traffic flow assumptions: The distribution of traffic flow and hydrogen-fueled vehicles will remain stable during the forecast period, with no large-scale regional changes.

7) Behavioral consistency assumption: Consumers' purchasing behavior and hydrogen refueling habits for hydrogen fuel vehicles will be consistent in the future, that is, existing purchase and refueling patterns can reflect future consumer behavior.

8) Competitive environment assumption: The market is a static competitive environment without considering the impact of other competitors' market behavior on sales volume and service demand.

9) Environmental and safety assumptions: The construction and operation of hydrogen refueling stations comply with all environmental and safety standards and will not incur additional costs due to non-compliance.

3 MODEL BUILDING AND ANALYSIS

The objective function in this document is the maximum net present value, which is expressed as follows:

$$\max NPV = \sum_{i=1}^{n}(\frac{R_i - C_{oper,i} + S_i}{(1+d)^t} - C_{setup,i})$$

$$S.t. d_{min} \leq d_i \leq d_{max}, \forall i \in \{1,2,\ldots,n\} \quad (1)$$

$$\sum_{j \in J} \omega_{ij} \geq \omega_i \quad (2)$$

$$\sum_{t \in T} \omega_{ijt} = \omega_{ij} \quad (3)$$

$$\sum_{i \in I} \omega_{ij} \leq U_j \quad (4)$$

$$\sum_{i=1}^{N} x_{ij} * D_{ik} * V_i \leq R, \forall j \quad (5)$$

$$1 \leq \sum_{i=1}^{n} x_i \leq N, x_i \in \{0,1\}, \forall i \in \{1,2,\ldots,n\} \quad (6)$$

$$S_i < B \quad (7)$$

Constraint (1) represents the safety distance of hydrogen refueling stations, constraint (2) indicates that the hydrogen provided by hydrogen must meet the demand of hydrogen refueling stations, constraint (3) represents the constraint of hydrogen transportation volume, constraint (4) is the constraint of hydrogen source capacity, constraint (5) is the constraint of maximum service coverage for customers, constraint (6) is the limitation of the number of hydrogen refueling stations, and constraint (7) is the constraint of government investment.

R_i represents the expected annual income;$C_{setup,i}$ represents the initial construction cost;$C_{oper,i}$ is the operating cost;S_i is the annual subsidy amount of the government;d is the discount rate, and T is the time span of the project. These parameters are known in a given optimization problem and do not change with the decision variable x_i.

4 CASE ANALYSIS

4.1 Algorithm Design

Step 1: Data collection and pre-processing collect relevant data, and carry out data cleaning and pre-processing, so as to facilitate the subsequent GBDT model analysis and the construction of hydrogen refueling station site selection model.

Step 2: Use the GBDT model to forecast sales

Step 3: Preliminary site selection. According to the prediction results of the GBDT model, the areas with high sales volume are preliminarily selected as candidate locations for hydrogen refueling stations. This model can handle nonlinear relationships and take into account the interaction between multiple variables.

Step 4: Establish a site selection model Combined with the constraints, a site selection model with the best economic benefits for hydrogen refueling stations is established.

Step 5: Combined with the energy supply and cost of the candidate site, the most suitable hydrogen production method and location are selected.

Step 6: The final decision is based on model analysis and site visits to determine the final hydrogen refueling station location.

4.2 Parameter Settings

In projects where private investment in hydrogen refueling stations is made, the information contained in the original and auxiliary datasets supports GBDT model prediction and site selection decisions. The following three tables are the components of the original dataset and the secondary dataset:

Table 1. Raw dataset for the sale of hydrogen-fueled vehicles

Region_ID	Sales	Geographical_Constraints	Spatical_Constraints	Hydrogen_Production_Method	Hydrogen_Location
1	1000	Near major road	Large area	Electrical water	Low energy cost
2	800	Far from existing stations	Small area	Natural gas reforming	Medium energy cost
3	1200	Near major road	Medium area	Steam reforming	High energy cost
4	900	Far from existing stations	Large area	Electrical water	Low energy cost
6	1100	Near major road	Small area	Natural gas reforming	Medium energy cost

Table 2. partially assists with dataset parameter settings

Region_ID	Land_Cost	Construction_Cost	Operation_Cost	Hydrogen_Production_Cost	Government_Subsidy
1	500000	2000000	100000	3.00	500000
2	600000	2500000	120000	3.50	400000
3	400000	1800000	90000	2.50	600000
4	700000	2200000	110000	3.25	450000
6	800000	2400000	130000	3.75	350000

Table 3. Optimal parameter value combinations

Parameter Name	The value is specified
n_estimators	200
learning_rate	0.20
subsample	0.9
max_depth	5

The government encourages companies to build hydrogen refueling stations by providing financial support or tax incentives, including subsidies for construction costs, incentives for providing land or buildings, etc. In this paper, for the 35Mpa hydrogen refueling station with a daily hydrogen refueling capacity of 500kg/d, the subsidy is 30% of the equipment investment of the hydrogen refueling station, with a maximum of 3 million yuan, and for the 70Mpa hydrogen refueling station with a hydrogen refueling capacity of 500kg/d or 35Mpa with a hydrogen refueling capacity of 500kg/d, the subsidy is 30% of the equipment investment of the hydrogen refueling station, with a maximum of 5 million yuan.

4.3 GBDT Model Prediction Results

A certain area of Midoriya City is randomly selected to forecast the sales of hydrogen fuel vehicles, and the forecast and actual sales of hydrogen fuel vehicles in this area are shown in the figure below.

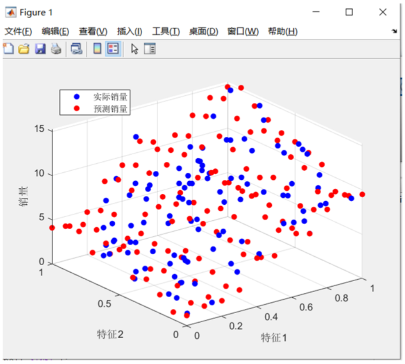

Fig. 1. Comparison of forecasts and actual sales of hydrogen-fueled vehicles

4.4 Optimal Hydrogen Refueling Station Decisions

According to the fuzzy comprehensive judgment method and calculation results, two types of hydrogen production sites were set up for comparison, namely off-site hydrogen source and on-site hydrogen production, and the impact of current transportation costs on the development of HFCV was analyzed. Specifically, it includes coal hydrogen production, natural gas hydrogen production, methanol hydrogen production in off-site hydrogen production, and natural gas hydrogen production, methanol hydrogen production, and water electrolysis hydrogen production in on-site hydrogen production, and the final scores obtained are shown in Table 4.

Table 4. Final score of fuzzy comprehensive evaluation method under different hydrogen production methods

Hydrogen source	Hydrogen production method	Final score
Off-site hydrogen production	Hydrogen production from coal	70.4424
	Hydrogen production from natural gas	77.9036
	Methanol to hydrogen	76.0909
Hydrogen production in the station	Hydrogen production from coal	75.1401
	Hydrogen production from natural gas	76.6203
	Methanol to hydrogen	74.5079

Therefore, this paper selects a high-evaluation natural gas hydrogen production method to optimize the layout of off-site hydrogen production.

Through the economic benefit optimization model, we identified the optimal locations for the establishment of three hydrogen refueling stations in the city center and key suburbs as numbered [5,13,17].Table 5 shows the parameters related to the net profit of the optimal hydrogen refueling station in the first year

Table 5. Parameters related to the net profit of the optimal hydrogen refueling station in the first year

	Position 5	Position 13	Position 17
Construction cost/RMB	1,000,000	1,200,000	1,500,000
Annual income/RMB	1,800,000	2,250,000	2,700,000
Operating costs/RMB	200,000	250,000	300,000
Cost of hydrogen production/kg	15	15	15
Government subsidy/RMB	20000	25000	22000
Customer service volume/kg	60000	75000	90000
Hydrogenation capacity/kg	200	300	500
Number of days of operation per year/day	300	300	300
Total cost/RMB	3,650,000	4,455,875	5,658,75
Hydrogen refueling service pricing/RMB	30	30	30
Net profit/RMB	-1,850,000	-2,205,875	-2,958,75

The analysis shows that although the annual service volume of sites 5, 13 and 17 is 60,000kg, 75,000kg and 90,000kg respectively, the net profit of these stations is -1,850,000 yuan, -2,205,875 yuan and -2,958,75 yuan respectively due to the difference in hydrogen production costs and operating costs. This result shows that even with the support of government subsidies, the profitability of hydrogen refueling stations still faces challenges, especially when the current hydrogen fuel vehicle market is not yet mature.

5 CONCLUSION

1. The GBDT model provides an effective method for predicting hydrogen vehicle sales and can help investors identify areas with high demand for hydrogen refueling stations.

2. Combined with the choice of hydrogen production method and location, our model is able to provide a comprehensive perspective to ensure that the selected site is not only in high market demand, but also technically and economically feasible.

3. Government subsidies play a key role in this process, reducing the risk of private investment, increasing the attractiveness of projects, and potentially accelerating the construction of hydrogen energy infrastructure.

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