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Research on the Siting of Shared Electric Bicycle Drop-Off Points Based on a Static Game

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Abstract: In this paper, we analyse the current situation of domestic and international research and the formation and development of game theory, and consider the interests of decision makers and select sites for shared bikes in a multi-dimensional space, and establish a site selection optimization model based on the objective of maximizing comprehensive benefits. This study can be used as a reference for sharing companies in selecting sites for sharing motorcycles in cities.

1. Introduction

Although in recent years, because of the advantages of easy operation, efficient use, low carbon and environmental protection, shared electric bicycle has been developed rapidly, the “last mile” travel problem has been well solved to meet the needs of users for short-distance travel, but in some sites there are still people “no bikes to rent”, a large number of other sites piled up, obstructing normal traffic driving and other undesirable phenomena caused by improper site selection, urban land resource constraints and poor management of enterprises[1].

To solve the above problems, Lin Yang[2]solved and analyzed the whole process of bike-sharing station location planning using the improved grey wolf algorithm, and verified the feasibility and validity of the location model with examples; Wenzheng Wang[3]established an expansion station location planning model considering rebalancing scheduling to determine the number of bicycles at the initial moment and the rebalancing scheduling scheme between regions; Yong Ye[4] constructed a robust optimal bike-sharing station location planning model considering uncertainty The model is based on the risk preference of decision makers and the actual application of the model. The model and clustering algorithm proposed by Yiming Li[5]provide new ideas for hub location optimization, a theoretical basis for operators to plan bicycle sharing systems, and decision support for government agencies to optimize urban transportation layout. This paper proposes a static game-based model for the siting of shared bikes.

2. Model Assumptions

2.1 Introduction to Game Theory

Game theory is an extremely important branch of operations research, also known as response theory. Game theory investigates issues such as the behavioural strategies of crowds of people interacting, the behavioural decisions of crowds of people in a state of direct mutual constraint or facilitation and whether the decisions are equilibrium.

The properties of game theory are: (1) The tendency of any person to think rationally, i.e. the desire of a group of people to maximize their own interests within the constraints available; (2) In the process of interaction and cooperation between people, conflicts are bound to arise, behaviour is influenced by each other to a certain extent, and the information available to both or more parties is generally not symmetrical.

Game theory is often used to study the development of rules that enable groups of people to voluntarily comply and implement efficient arrangements in a macro-market economy, thereby increasing the efficiency of a region or country. Game theory is divided into cooperative and non-cooperative games, with non-cooperative games being divided into static and dynamic games. Static games: where the players choose their strategies simultaneously, e.g. rock-paper-scissors, coin toss etc. The five main factors in static game theory are: player, gain/loss, strategy, outcome and Nash equilibrium. The basic analysis is solved by the strict lower-strategy iterative elimination method, the line drawing method, and the upper-strategy equilibrium with arrows method.

2.2 Model Assumptions

In this paper, we choose to use a discrete siting model after a comparative analysis, and therefore make the following assumptions.

(1) There are multiple shared-use motorcycle sites.

(2) There is no linkage between each shared motorcycle site.

(3) No consideration is given to the variation in investment size and revenue progression over the phase cycle.

2.3 Model Construction

(1) Constraints

Decision maker p selects a site for a shared motorcycle drop-off site at a location j with[6]:

$$\sum_{j\in N} x_j^p = 1, p = I, II \tag{1}$$

$$x_j^p = \begin{cases} 1, \text{Decision maker p selects the location j to establish a shared electric bicycle drop} - \text{off site} \\ 0, \text{Decision maker p does not select a location j to establish a shared motorcycle drop} - \text{off site} \end{cases}$$

$$, p = I, II, j \in N \tag{2}$$

Of which, x_j^p: Decision-making variables; N: Collection of Candidate E-Bike Drop-off Sites; I, II: Decision makers; l: Decision makers p choose the scale of construction of shared e-bike drop-off sites; Therefore:

$$\sum_{l\in S} y_l^p = 1, p = I, II \tag{3}$$

$$y_l^p = \begin{cases} 1, \text{The decision maker p chose to build a shared electric bicycle drop} - \text{off site at a scale of l} \\ 0, \text{Policy makers p choose to build shared electric bike drop} - \text{off sites at a scale not for l} \end{cases}$$

$$, p = I, II, l \in S \tag{4}$$

Of which, y_l^p: Decision-making variables; S: The scale of the choice to build a shared electric bike drop-off site.

(2) Objective function

The payoff function for decision maker 1:

$$v^I\left(x_j^I, y_l^I, x_j^{II}, y_l^{II}\right)=$$

$$c^I \sum_{j\in N}\sum_{k\in N}\sum_{j\in M} \frac{\exp\left(-\theta_1 d_{ij} + \theta_2 \sum_{l\epsilon S}\alpha_l \gamma_l^I\right)}{\exp\left(-\theta_1 d_{ij} + \theta_2 \sum_{l\epsilon S}\alpha_l \gamma_l^I\right) + \exp\left(-\theta_1 d_{ik} + \theta_2 \sum_{l\epsilon S}\alpha_l \gamma_l^{II}\right)} v_i x_j^I x_k^{II} - \sum_{l\epsilon S} f_l \gamma_l^I \quad (5)$$

Of which, v^I: Benefits to decision maker 1; $x_j^I, y_l^I, x_j^{II}, y_l^{II}$: Decision-making variables; c^I: Decision maker 1 unit of demand profit; k: Candidate sites for sharing electric bicycles; θ_1:Adjustment distance and efficiency factor; θ_2: Adjusting the size and effectiveness factor of shared motorcycle deployment sites; d_{ij}, d_{ik}: The distance between population aggregation site i and candidate shared-cycle drop-off sites j, k; α_l: Coefficient of attraction per unit of demand, $l \in S$; f_l: Unit investment costs.

The payoff function for decision maker 2:

$$v^{II}\left(x_j^I, y_l^I, x_j^{II}, y_l^{II}\right)=$$

$$c^{II} \sum_{j\in N}\sum_{k\in N}\sum_{j\in M} \frac{\exp\left(-\theta_1 d_{ij} + \theta_2 \sum_{l\epsilon S}\alpha_l \gamma_l^{II}\right)}{\exp\left(-\theta_1 d_{ij} + \theta_2 \sum_{l\epsilon S}\alpha_l \gamma_l^{II}\right) + \exp\left(-\theta_1 d_{ik} + \theta_2 \sum_{l\epsilon S}\alpha_l \gamma_l^{I}\right)} v_i x_j^I x_k^{I} - \sum_{l\epsilon S} f_l \gamma_l^{II} \quad (6)$$

Of which, v^{II}: The benefits accruing to decision maker 2; c^{II}: Decision maker 2 unit demand profit.

Therefore, when two decision makers are making decisions at the same time, and the outcome of one of the decision makers causes the other decision maker's benefit to be affected, then both decision makers have a static game relationship for their benefit.

3. Example Validation

Suppose that two decision makers plan to invest in a place to build a shared-cycle drop-off site, where there are two pending shared-cycle drop-off sites A and B, and six more populated locations a, b, c, d, e and f. The number of rides needed for the six locations are 1000, 900, 1150, 950, 1200 and 850, respectively, and N_m denotes the distance between the shared bicycle drop-off site N and the population gathering place a. Then$A_a = 5, A_b = 3, A_c = 4, A_d = 12, A_e = 10, A_f = 8; B_a = 3, B_b = 12, B_c = 6, B_d = 8, B_e = 3, B_f = 4$ .As shown in Figure 1. The sites to be shared motorcycles are divided into two sizes: large sites and small sites, where the number of shared motorcycles needed to ride at (0,3000] is a small site, and the demand at (3000,+∞] is a large site, with a unit demand of 0.5 yuan/kilometre for motorcycle users, $\theta_1 = 0.2, = 0.3$.

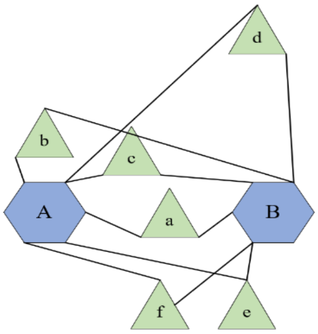

Fig.1 Map of the Location of the Bike-Sharing Stations and the Crowd Gathering

Assume that decision maker 1 will invest $400,000 for a large site and $120,000 for a small site;

decision maker 2 will invest $300,000 for a large site and $180,000 for a small site; the demand attraction factor for the user population is set to 1.5 for a large site and 0.8 for a small site. After the coefficients were set, matlab was used to program the maximum total revenue for decision maker 1 and decision maker 2, and then the total revenue for decision maker 1 and decision maker 2 was calculated based on the different costs of the two parties, and finally the actual total revenue for decision maker 1 and decision maker 2 was calculated by removing the investment costs from the total revenue calculation results and using the line drawing method. The results of the calculation are shown in Table 1, where “size” in brackets indicates the size of the shared bicycle station built, and the number in brackets indicates the investment return of the decision maker. The actual total benefits for the decision makers are shown in Table 1.

Table 1 Actual Total Benefits to Policy Makers

Investors		II			
		(A, Big)	(A, Small)	(B, Big)	(B, Small)
I	(A, Big)	(122.4,128.7)	(135,6,129.8)	(125.6,123.1)	(134.8,130.2)
	(A, Small)	(133.3,138.5)	(139.9,141.5)	(138.2,131.4)	(140.3,136.4)
	(B, Big)	(119.3,130.8)	(126.4,137.4)	(122.4,128.7)	(135,6,129.8)
	(B, Small)	(131.3,138.6)	(131.2,131.1)	(133.3,138.5)	(139.9,141.5)

Based on Table 1 and the basic principle of the static game can be known: absolutely can not choose the strictly suboptimal solution, so decision makers 1, 2 can both firstly exclude the possibility of building a large-scale shared motorcycle launch site; secondly compare the first component of each row in the column, and the second component of each column in the row, such as the actual total gain of the underlined sign in Table 1, that is: 133.3, 139.9, respectively 138.2, 140.3 versus 130.2, 131.5, 137.4, 141.5, so it is known that the maximum even pair for both decision makers is: (139.9,141.5), i.e. when decision makers 1, 2 both build small sites at location A, a Nash equilibrium can be reached, at which point the actual total benefit for decision maker 1 is $1.399 million and the actual total benefit for decision maker 2 is 1.415 million.

4. Concluding Remarks

After analysing the current situation of domestic and international research on shared bicycle drop-off sites and the formation and development of game theory, a siting optimisation model is established based on the objective of maximising the comprehensive benefits, using the theory of optimal solutions based on static games to analyse the solution to the problem, and using the line drawing method to solve the model. The model is solved by the line drawing method. The model used in this paper is based on certain assumptions to satisfy the solution of the problem. However, in real life, the selection of sites for shared bicycle deployment sites should be considered from the perspective of decision makers' interests and in a multi-dimensional space, and should also take into account the scale of investment and short-term, medium-term and long-term changes in revenue and profit, and include the influence of factors such as management, maintenance and operation. This will provide a direction of action for our subsequent research.

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