Locating stations in bike-sharing service: a special maximal covering location problem

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Summary

Bike sharing systems are increasingly prevalent in urban areas. One important issue of planning these systems is the location of bike stations. This problem is challenging because stations should satisfy riders' demands for bikes and docks, while these two demands are dynamic in space and time and interrelated. In this paper, we propose a maximal coverage problem for bike stations by incorporating bike and dock demands. We then present an approach for this problem, using the tabu search metaheuristic and agent-based modelling. A case study in Shanghai proves that this model can provide high-quality location solutions.

KEYWORDS: bike sharing, maximal coverage, location problem, spatial optimisation

1. Introduction

Bike sharing systems are widely deployed in urban areas across different countries, providing a convenient and environmentally-friendly means of transport for citizens. A user can pick up and drop off a bike at different stations in an urban area, usually in coordination with other transport modes. Therefore, there are demands for bikes and docks in bike sharing systems. These demands are unbalanced and dynamic in space and time, which leads to the issue of system imbalance; bikes become clustered in some geographic areas or stations while other areas (or stations) are left empty without bikes.

One of the key elements in the planning of these systems is the location of bike stations. If they are poorly located, customers would have difficulties securing bikes and docks, and the system imbalance would worsen, resulting in customer loss and increased operational costs. Usually, the main goal for locating the bike stations is to maximise the coverage of demands within a desired service distance using a fixed number of stations. This can be regarded as an optimisation problem that can be tackled by the location-allocation models, specifically the maximal coverage location problem (MCLP) (Church & ReVelle 1974; Murray 2016).

Many studies have attempted to optimise the location of stations via maximising the coverage of user demand (Frade & Ribeiro 2015), most of which are based on the MCLP with a single-type (bike or dock) and static demand (Rybarczyk & Wu 2010; García-Palomares et al. 2012; Park & Sohn 2017). In addition, some models locate the stations per traffic zone without giving the exact station location, which limits its accuracy and applicability (Frade & Ribeiro 2015). To address these issues, we develop a new model for locating the bike stations. The multi-type and time-variant demands for bikes and docks are modelled explicitly in conjunction with the fine-grained spatial components of demand and location sites.

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2. Problem description

Table 1 shows the description of the Bike Station MCLP (BS-MCLP). The objective is to maximise the proportion of covered user demand, and this is obtained by optimising the location of planned bike stations. It is assumed that station settings are determined, including the number, capacity, initial bike stock. The bike and dock demands in each location and each time step can be generated by different approaches, including using historical usage data and predictive analysis.

Table 1 Description of the BS-MCLP

Item	Content
Input	Set of demand location Set of potential station site Number of bike and dock demands in each location and time step Station settings: number, capacity, initial bike stock Maximal service distance
Constraint	Service distance constraint: a user can be served only by stations within the maximal service distance; Bike stock constraint: the bike stock of a station should be between 0 and its capacity
Output	Location of stations
Objective function	To maximise the proportion of covered user demand

3. Solution approach

The BS-MCLP formulation presents enormous computational challenges, which make it difficult to be solved optimally using a Mixed Integer Programming (MIP) solver. Therefore, an approach based on tabu search (TS) (Glover 1989) and agent-based modelling (ABM) (Epstein & Axtell 1996) was designed for this formulation. This approach is able to generate a set of high-quality solutions in a short time.

4. Case study

The BS-MCLP model is applied to locate sharing bike stations in the Huangpu District of Shanghai. Shanghai is the largest city by population and the economic centre in China, with an area of over 6300 km^2 and a population of 24 million. Huangpu District is part of old central area in Shanghai. By July 2017, Shanghai had 1.5 million dockless bikes, making it one of the largest bike-sharing market in the world.

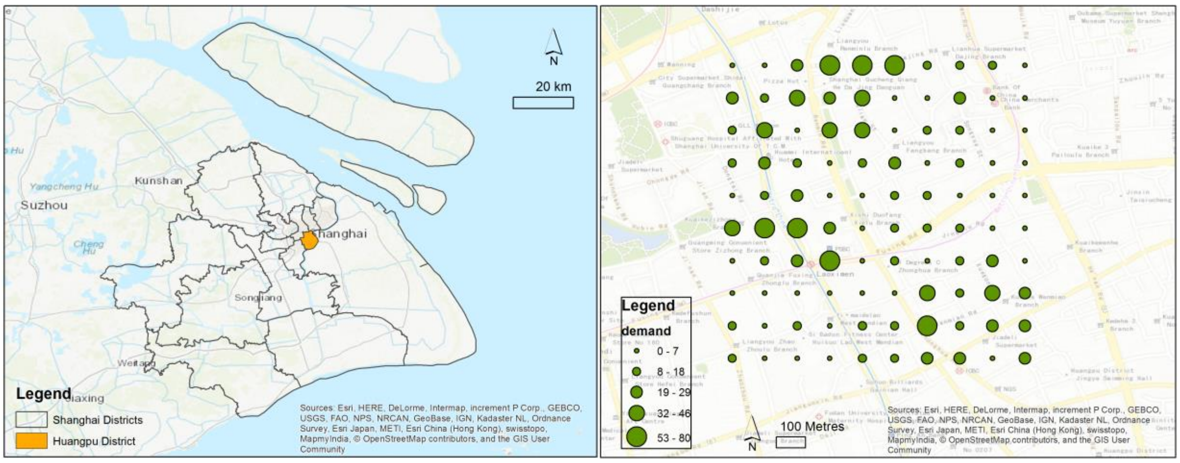

Figure 1 (a) A map of Shanghai, highlighting the Huangpu District; (b) The study area, consisting of 100 urban cells in Huangpu District

The dataset is provided by Mobike and contains over 1 million trip orders in August 2016. Each order contains user ID, bike ID, start time, end time, the geographic coordinates of the origin and destination, among other attributes. Due to privacy issues, the coordinates have been aggregated to a grid, each urban cell with 0.001° in latitude and 0.001° in longitude.

The first case study was conducted in a region consisting of 10*10 urban cells and 1-week bike usage within Shanghai, as shown in Figure 1(b). In this case, the objective is to maximise the demand coverage via optimally locating 10 bike stations with a capacity of 20 per station. We compare the solution of BS-MCLP with a classic MCLP formulation (Church & ReVelle 1974), in which the demand on each location is the sum of bike and dock demand. It is shown that the location solution of BS-MCLP covers 69.9% of the total demands, which significantly outperforms the coverage of 49.8% of the MCLP solution.

5. Conclusion

In this study, we address the location planning of stations in share bike service, via formulating a variant of the maximal covering location problem for sharing-bike stations. We also propose an approach for this specific problem by integrating the tabu search metaheuristic and ABM. This model is applied in a case study of Shanghai, which demonstrates the usability and efficiency of the model.

6. Acknowledgements

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References

Church, R. & ReVelle, C., 1974. The maximal covering location problem. *Papers of the Regional Science Association*, 32(1), pp.101–118.

Epstein, J. & Axtell, R., 1996. *Growing artificial societies: Social science from the bottom up* 1st ed., Washington, D.C.: Brookings Institution Press.

Frade, I. & Ribeiro, A., 2015. Bike-sharing stations: A maximal covering location approach. *Transportation Research Part A: Policy and Practice*, 82(December 2014), pp.216–227.

García-Palomares, J.C., Gutiérrez, J. & Latorre, M., 2012. Optimizing the location of stations in bike-sharing programs: A GIS approach. *Applied Geography*, 35(1–2), pp.235–246.

Glover, F., 1989. Tabu Search—Part I. *ORSA Journal on Computing*, 1(3), pp.190–206.

Murray, A.T., 2016. Maximal Coverage Location Problem: Impacts, Significance, and Evolution. *International Regional Science Review*, 39(1), pp.5–27.

Park, C. & Sohn, S.Y., 2017. An Optimization Approach for the Placement of Bicycle-sharing stations to Reduce Short Car Trips: An Application to the City of Seoul. *Transportation Research Part A: Policy and Practice*, 105(August), pp.154–166.

Rybarczyk, G. & Wu, C., 2010. Bicycle facility planning using GIS and multi-criteria decision analysis. *Applied Geography*, 30(2), pp.282–293.

Biographies

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