**Introduction**

\*Bikeshare system benefits, state of practice, etc\*

Bikeshare systems can be planned with a variety of objectives but are most often focused on improving accessibility to trip generators like jobs through coverage of potential user demand (Kabak et al, Wuerzer et al, Qian et al, Liu et al, Frade and Ribeiro, Garcia-Gutierrez et al, Mix et al, Conrow et al, Garcia-Palomares et al, Eren et al, Ghandehari et al, Celebi et al, Cetinkaya et al). Some municipalities and academics have identified other goals for bikeshare systems, such as improving access to recreational cycling (Eren et al) or minimizing transportation inequalities among population groups (Caggiani et al). Privately operated bikeshare systems may seek to maximize profit through both demand coverage and detailed operating cost minimization (Frade and Ribeiro). Other objectives mentioned in guidance literature such as the NACTO Bike Share Station Siting Guide and ITDP Bikeshare Planning Guide include connecting first/last mile to transit stops

Smaller/medium sized urban areas may face unique challenges with the planning and operation of bikeshare systems. Smaller municipalities or metropolitan planning organizations may not have resources for extensive data collection and analysis techniques for station siting. Due to the distribution of land uses and spatial concentration of dense development unique to smaller urban areas, there may be multiple objectives for a bikeshare system that may sometimes compete. For example, maximizing job accessibility may locate stations primarily in a downtown district while maximizing access to recreational opportunities may locate stations primarily near trailheads or parks in the less dense edges of town. Small communities may also struggle to maintain systems with limited resources and may benefit from public-private partnerships with local businesses, campuses, or business districts to assist operationally ([NLC website](https://www.nlc.org/article/2022/06/03/bikeshare-solutions-for-small-cities-towns/)).

This article presents an approach to bikeshare station siting catered to small/medium-sized urban areas considering 1) limited resources for data collection/analysis, planning, and operation of a BSS and 2) a combination of policy objectives, which can be made flexible to reflect the goals of the city. The approach uses a survey of transportation industry professionals and an Analytic Hierarchy Process (AHP) to determine weights of different criteria for different policy objectives, then uses GIS tools to determine a raster propensity (hotspot) analysis with a new spatial index assigned to each cell conveying its relative value, and finally takes raster cells as candidate station locations to optimize placement of bikeshare stations. Results for different criteria weighting reflecting different policy objectives (job accessibility, recreation/tourism accessibility, first/last mile connectivity to transit, improving transportation equity, and minimizing initial costs through site selection) will be compared to each other, and to the generic ITDP guidance given for station siting to show improved objective values.

**Literature Review**

There is much existing literature on bikeshare station siting guidance, propensity analysis, multi-criteria decision-making approaches, siting optimization methods, dimensioning optimization methods, and evaluation of transportation network and built environment factors that most affect bikeshare station activity in existing urban systems.

Propensity analyses were typically used to generate a hotspot map for potential valuable station locations, which can then be hand-picked by the system operator. Optimization methods typically required a predefined universe of candidate station locations or zones, with a subset selected that maximizes an objective value. The approach presented combines propensity analysis and siting optimization.

**General Guidance for Bikeshare Planning and Small/Medium-Sized Urban Areas Context**

Two bikeshare planning guides were referenced in the development of the approach presented in this paper: NACTO’s Station Siting Guide (2016) and ITDP’s Bikeshare Planning Guide (2018). Both recommend siting stations close to bicycle lanes, transit stations, and vaguely defined “demand generators”. ITDP provides two approaches (the grid approach and field approach) that help planners ensure desired density of bike stations.

In the specific context of small urban areas with lower population densities, the National League of Cities compiled case studies to recommend that stations be sited “near important destinations such as schools, parks, and business districts”, in both disadvantaged and well-off neighborhoods, and considering partnerships with local organizations such as Business Improvement Districts, local businesses, or campuses to reduce initial installation costs. Gilbert et al summarized recommendations for initiating bike share in small communities, including siting stations close to food and shopping destinations, in a variety of neighborhoods, near businesses with a high number of employees, close to public transportation, and seeking partnerships with local businesses. In both resources, less emphasis was placed on proximity to dedicated cycling infrastructure because it might be lacking in many small urban areas.

**Input Criteria to be Considered**

Proximity to a variety of geospatial inputs has been used in bikeshare activity analysis and station siting methods. Multiple researchers have studied the correlation between transportation network, user population, and built environment factors and existing bikeshare activity (Croci and Rossi, Duran-Rodas et al, Wang et al). Several papers have modeled proximity to specific input factors as trip attractions or generations for the purpose of predicting trip demand between stations in an optimization model (Celebi et al, Mix et al, Liu et al, Qian et al, Conrow et al). Propensity analysis papers use similar demand indicators to determine spatial index values to visualize hot spots for potential bikeshare stations/mobility hubs.

A full summary of past studies and input criteria used is available in Table 1.

**Table 1: Input Criteria Used in Existing Literature**

Table, calendar

Description automatically generated with medium confidence

The input criteria used in the proposed approach is comprehensive, and much of this data is regularly updated and publicly available or typically maintained by Metropolitan Planning Organizations.

Many station siting papers have used a multi-criteria decision-making approach to guide the input criteria weights, and most have used an analytic hierarchical process, or AHP (Eren et al, Kabak et al, Salih-Elamin and Al-Deek, Ghandehari et al). One used a fuzzy AHP process to account for uncertainty in decision making (Cetinkaya). A majority of these papers used AHP to determine a spatial index for all candidate locations, then used a ranking method, as opposed to an optimization approach, to indicate high-value station candidates. The approach proposed in this paper will use AHP to generate a spatial index to be used in the optimization objective function.

**Propensity (Hotspot) Analysis Methods**

A few academics and municipalities have used arbitrary weights for determining the value of candidate site locations (Wuerzer et al, Washington DC, Twin Cities) in a hotspot visualization.

In both the Capital Bikeshare Development Plan Update and Mobility Hubs Siting Methods and Analysis, a classification was made for the type of station/hub based on its outcome objective. In DC, three categories were considered: “Ridership” for regular use/commuting, “Revenue” for casual use/tourism, and “Public Welfare” for servicing disadvantaged communities. In the Twin Cities the categories were “Connect the Region” for hubs in proximity to demand generators, “Expand and Integrate Multimodal Travel Options” for hubs in proximity to the existing transportation network, and “Advance Equity” for hubs in proximity to disadvantaged communities. In DC it was determined that an allocation of half of new stations should be “Public Welfare”, while a fifth should be “Revenue” stations. In the Twin Cities, it was determined that a third of hubs selected should “Connect the Region”, a third should “Expand and Integrate Multimodal Travel Options”, and a third should “Advance Equity”.

This commonality in practice indicates that classifying stations for specific outcome objectives, which can be distributed proportionally according to policy goals, is valuable to transportation planners. The approach presented in this paper allows for this classification and distribution to be made. Only one other paper has classified multiple objectives like this (Eren et al), and the only objectives considered were transportation and recreational cycling.

**Station Siting Optimization**

Several papers reviewed used weighted input criteria from the AHP to evaluate candidate station locations and used a Multi-Criteria Decision-Making approach to output a ranked list of all stations instead of a subset of optimal stations. Two used a Technique for Order of Preference by Similarity (TOPSIS) ranking approach (Cetinkaya, Salih-Elamin and Al-Deek), one used a VIKOR method and Psychometric-VIKOR method (Eren et al), and another used a Multi-Objective Optimization by Ratio Analysis (MOORA) approach (Kabak et al).

Most optimization approaches using mathematical programming in literature optimized to maximal demand coverage, with demand either known or modeled/approximated from the input criteria discussed above.

Constraints typically involved a maximum budget with in-depth modeling of the bikeshare system costs (Wuerzer et al, Frade and Ribeiro, Caggiani et al, Garcia-Guitierrez et al) or a simple maximum number of stations (Ghandehari et al, Conrow et al, Qian et al, Liu et al, Mix et al, Celebi et al, Garcia-Palomares et al). Some approaches utilized a minimum total coverage (Caggiani et al) or minimum distance between stations (Ghandehari et al, Liu et al) constraint to ensure less dense station siting. Some approaches specified a maximum distance between stations to ensure a connected/useful density of stations (Conrow et al, Ghandehari et al). If the objective function attempted to reduce inequality in level of service between stations (Caggiani et al), a minimum average accessibility constraint was used to set a baseline standard of service.

Optimization approaches using known trip demands between zones or candidate locations (Frade and Ribeiro, Garcia-Palomares et al, Caggiani et al, Celebi et al) typically attempted to maximize the coverage of trips demanded. This typically required data from a travel survey or multimodal transportation demand model, which smaller municipalities or MPOs may not have access to.

Optimization approaches that modeled or approximated demand from the input criteria discussed above (Mix et al, Liu et al, Qian et al, Conrow et al) instead of using a known O/D matrix might be more feasible for smaller municipalities or MPOs. One approach (Conrow et al) simply approximated bike network segments as spatial coverage and population density in proximity to stations as demand coverage and used a bi-objective coverage optimization model considering both coverage problems with an arbitrary importance weight assigned to each objective. Three studies modeled the influence of demand indicators on existing urban bikeshare activity data (Mix et al, Liu et al, Qian et al), re-zoned the city, generated trip demand between zones using the model, and maximized demand coverage of the generated trips. In an environment without existing bikeshare, modeling the demand indicators’ effect on trip demand directly is impossible. However, using AHP methods with transportation professionals in the community to determine the importance of each input criteria to generating demand in that local context is a similar approximation.

Two optimization approaches aimed to minimize cost instead of just maximizing demand coverage. One (Garcia-Gutierrez et al) used bi-level optimization with the leader (planner) minimizing total multimodal transportation system costs and the follower (users) minimizing travel time, which required a lot of data about the existing transportation network. The other (Ghandehari et al) used a combinative model aiming to both maximize station utility and minimize cost given AHP-weighted input criteria. *(This approach would be very similar to mine if I added cost of installation, which I might)*

All approaches reviewed used a universe of predefined zones or candidate station locations hand-selected ahead of time. The approach presented in this paper removes this step by considering a continuous raster set of potential locations, so that selections are possible anywhere in the study area, similar to the propensity analysis approaches discussed. Considering the guidance that smaller urban areas partner with local businesses, campuses, or business districts to save on operational costs, a full set of potential locations is reasonable, as stations don’t need to be constrained to intersections or public parks.

A summary of all station siting optimization approaches reviewed is presented below in Table 2.

**Table 2: Optimization Approaches used in Existing Literature**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Paper** | **Candidate Locations** | **Input Criteria Considered** | **Weighting Method** | **Station Selection Method** | **Constraints** |
| **Ranking of Candidates** | | | | | |
| Cetinkaya (2017) | Candidate stations | Demand indicators with proximity | Fuzzy AHP | TOPSIS ranking | NA |
| Eren et al (2022) | Existing station locations | Demand indicators with fuzzy buffer | AHP for two categories: transportation and recreation | VIKOR method and new Psychometric-VIKOR method for ranking | NA |
| Kabak et al (2018) | Candidate locations | Demand indicators proximity | AHP | MOORA ranking | NA |
| Salih-Elamin and Al-Deek (2020) | Existing station locations | Closeness, Degree, Betweenness centrality metrics between station pairs in service distance | AHP for three measures | TOPSIS ranking | Maximum service distance for CC, DC, BC (multiple considered) |
| Wuerzer et al (2012) | Continuous service area considered | Demand indicators with buffer | Arbitrarily selected (Los Angeles’ method) | Hand-selected locations, optimized # of stations/bikes | Maximum budget |
| **Maximizing Demand Coverage (O/D Trip Demand Known)** | | | | | |
| Frade and Ribeiro (2015) | Zones | O/D demand between zones | NA | Maximize coverage of trips demanded | Maximum budget, revenue >= operating costs |
| Garcia-Palomares et al (2012) | Existing train stations, candidate locations within zones | O/D demand between zones, scaled to building level with population/job data | NA | Minimize impedance between stations  Maximize demand coverage | Maximum # stations (multiple considered) |
| Caggiani et al (2020) | Zones, candidate locations within zones | O/D demand between zones | NA | Minimize inequalities in bicycle-public transport mobility among population groups | Minimum average accessibility  Minimum total coverage  Maximum budget |
| Celebi et al (2018) | Candidate stations | O/D demand between stations from direct survey about demand points | NA | Minimize total unsatisfied demand | Maximum # stations  Maximum # bicycles |
| **Maximizing Demand Coverage (O/D Trip Demand Modeled/Approximated from Demand Indicators)** | | | | | |
| Mix et al (2022) | Equilateral triangle zones with station at center | O/D demand from existing system data modeled with demand indicators (Regression) | NA | Maximize generated trips for local generation, accessibility-based generation | Maximum # stations (multiple considered) |
| Liu et al (2015) | Voronoi Regions with stations at center | O/D demand from existing system data modeled with demand indicators (Neural Network) | NA | Maximize demand from chosen stations while minimizing unbalanced stations | Maximum # stations  Minimum distance apart |
| Qian et al (2022) | Candidate locations (randomly selected from set of intersections) | Trip demand generated from previous research on demand indicators | NA | Maximize accessibility  Maximize revenue  Pareto frontier comparison | Maximum # stations |
| Conrow et al (2018) | Continuous bike network considered | Census block population, bike network segments | Importance weight for bike network coverage vs population coverage | Biobjective coverage optimization model for bike network and population | Maximum # stations |
| **Minimize Cost** | | | | | |
| Garcia-Gutierrez et al (2014) | Zones, candidate locations within zones | Mobility survey O/D information used with utility (mode choice) model | NA | Bi-Level optimization (planner minimizes total transportation system cost, users minimize travel time) | Maximum budget |
| Ghandehari et al (2013) | Candidate locations | Demand indicator proximity | AHP with simple additive weighting | Combinative model minimizing deviation from goal (maximizing station utility, minimizing cost) | Minimum distance between stations  Maximum # stations |