Transportation Research Interdisciplinary Perspectives 4 (2020) 100101

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: https://www.journals.elsevier.com/transportation-research-interdisciplinary-perspectives

Optimal locations for bikeshare stations: A new GIS based spatial approach

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ARTICLE INFO

Article history:
Received 5 December 2019
Received in revised form 26 February 2020
Accepted 26 February 2020
Available online 6 March 2020

Keywords:
GPS
Bikeshare
Bike Station
Baltimore
Location allocation
Huff's gravity model

ABSTRACT

This study identifies three new bike station locations for Baltimore City's bikeshare program using a location allocation spatial analysis tool. Over 1.6 million Global Positioning System (GPS) coordinates of bikeshare trips over a period of four months were used to identify the routes most frequently used by bikers. It was hypothesized that potential new bike station locations have a relationship with proximity to transit, attractions and restaurants/pubs. A negative correlation was found between route usage intensity and proximity to attractions and restaurants/pubs, which means that the closer the proximity to attractions or restaurants/pubs, the higher the road usage intensity is. A new methodology was developed by modifying Huff's gravity model, replacing facility location size with a suitability score. The bike station suitability score is calculated with regard to proximity to transit, attractions, restaurants/pubs and existing bike stations. A location allocation model is developed to maximize market share, i.e., the potential bike station locations will be accessible to maximum population while also being within a 400-m (0.25-mile) radius of attractions, restaurants/pubs and at least 300 m from existing bike stations. The location of the proposed bike stations through location allocation is within a block of the planned bike stations by the City of Baltimore, which corroborates the findings of this study. This methodology will be useful to identify new facility locations in any metropolitan city where maximum exposure is a necessity.

1. Introduction

Climate change, a healthy lifestyle and global energy security have led people to think about a sustainable transportation system (Yan et al., 2017). Bikeshare or bicycle rental is one of the outcomes of these initiatives. In contemporary times, the focus of urban transport planners has shifted to policies that encourage the utilization of bicycles as a substitute to standard automobiles. Public bike sharing is not only an alternative mode of transportation, but also an innovative initiative to reduce environmental pollution, traffic congestion and encourage a healthy lifestyle. Bicycles have several advantages at the individual and societal level when viewed from the perspective of sustainable mobility (García-Palomares et al., 2012). Apart from being cost-effective and a healthy means to commute, cycling is quicker and more efficient than cars or public transport in congested areas of a city, as traffic hold-ups can be circumvented (Heinen et al., 2010).

Transportation planners have taken steps in promoting bicycle usage with the introduction of bike-sharing programs, which are known as "bicycle transit," "smart bikes," "public-use bicycles" (PUBs) or "rental bike" (Midgley, 2011). Bike sharing programs provide a low-cost, public use bicycle network, that is distributed across the city. According to the New York City Department of City Planning (Burden and Barth, 2009), such programs involve bicycle rental schemes on a short-term basis that enables bicycles to be picked up at a self-served bike sharing station and returned to another bike sharing station, thus enabling point-to-point travel. A prior study (Shaheen et al., 2010) points out that the basic principle of bike sharing is that, individuals can use bicycles on an as-needed basis while avoiding the responsibilities and costs associated with owning a bicycle.

The location of bike stations and its relation to trip demand are deciding factors for a bike-sharing program's success (Lin and Yang, 2011). To attain acceptability among bicycle users, the distance between stations and origin and destination of trips should not be long (Shu et al., 2010). For a successful bike sharing program, factors like topography, weather, quality of public transport, type of bicycle, dockings, hours of service, safety and security, maintenance, and bike station location play an important role (Curran, 2008). Efficient bicycle distribution, which also relates to the bike station location, is essential (García-Palomares et al., 2012). It is evident that the closer (regarding distance) the facilities are to the users, the better the service provided (Rahman and Smith, 2000). The optimal location for any facilities or services can also drive an increase in profit, efficiency and maximize accessibility (Revelle et al., 1970). So, selecting appropriate locations for bike stations is a significant contributor to the success of the system.

The city of Baltimore had introduced its bike share program in 2016 and was largest electric assist pedelec system in North America. At the time of study, there were only 21 bike stations and identifying new locations, would help promote bike share usage and increase accessibility. In this study, a methodology is developed to identify the most appropriate locations for three new bike stations in the City of Baltimore, based on multiple factors as identified through a spatial analysis of bikeshare GPS trajectories. The methodology used in this study will be highly beneficial to developing

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http://dx.doi.org/10.1016/j.trip.2020.100101

cities for identifying locations for new facilities where location suitability is more important than the size of the facility.

2. Literature review

2.1. Bike sharing

Bikeshare is counted as a sustainable system in the present world. Europe is the pioneer of the bikeshare program, present in >400 cities (Meddin and DeMaio, 2016). The first program was introduced in Amsterdam in 1965, which was called 'White Bike Plan.' These bikes were free for anyone to travel across the city. The second-generation bike-sharing started with the use of coins. This program first started in Copenhagen, Denmark, in 1995 and in the cities of Minneapolis and St. Paul in Minnesota in 1996. Both generations faced issues such as bike stealing. The third-generation bike-sharing has almost overcome these problems by using mobile apps, real-time bike inventories by bike station, computerized docking stations with automatic locking devices, and the ability to attach user information to the bikes to prevent theft, creating an incentive to bring the bikes back in a timely manner (Shaheen et al., 2011). In contemporary times, smart bike sharing has become a trend across the globe. There are approximately 375 programs currently in 30 countries and another 45 future programs are under consideration (Midgley, 2011; Shaheen et al., 2011). The city of Baltimore also introduced a bikeshare system in 2016 (Nickkar et al., 2019). At launch, Baltimore bikeshare was the largest Pedelec (electric-assist) system in North America. The ultimate objective of these bike sharing programs is to give excellent customer service along with profit gain. To fulfill this objective, the location of the bikeshare station plays an important role (Lin and Yang, 2011). Evidence of the increase in bicycle mode share post implementation of a bikeshare program is confounded by improvements in bicycling facilities implemented at the same time as the bike-sharing program (Pucher et al., 2010).

2.2. Location and distribution of bike-station

The location and distribution of bike stations are one of the central reasons for the success of bikeshare programs (Lin and Yang, 2011). Past studies only tend to give generalized recommendations about the implementation of bike stations. Network coverage is one such recommendation, which suggests that the distribution of bikeshare stations is dependent on the city's configuration and size. In the context of Spain, a methodological guide for bike-sharing makes a differentiation based on the density and size of the city (Ferrando et al., 2007). In the case of high-density cities with a population of >200,000, recommendations were given for automatic stations spread across the whole city.

Similarly, for low-density cities, coverage with automatic stations is recommended in high-density areas or city centers. The only program which covers the whole city, is that of Paris. On the other hand, some studies (Burden and Barth, 2009; Ferrando et al., 2007) have recommended the introduction of bike sharing stations in high-density areas like the city center and later extending them to the peripheral areas. After consideration of the bike station's coverage area, it should be adapted to meet the public bike program's objectives and aims related to demand that needs to be satisfied. At this point, it is essential to delineate among general bike sharing programs and rentals for recreational bicycling. Tourist or recreational programs generally have just a few locations such as major tourist areas, historical places or parks from where the bikes could be rented or returned. On the other hand, bike sharing programs target commuters. The stations are required to be located in the vicinity of one another and near major transit hubs. Moreover, to make bike sharing an ideal commuter transport system, they are required to be placed in both commercial and residential areas which might be the destination and origin of regular commuters (Midgley, 2011). Existing bike stations in the city of Baltimore already cover the major transit hubs and as such, were not considered as a factor in this study.

The manner in which the demand is met constitutes the success of bike sharing as a mode of public transport. Researchers (Rybarczyk and Wu, 2010; Schwartz et al., 1999; Turner et al., 1997) have developed several demand-based methods to predict non-motorized travel and applied them to the planning of bicycle mobility. A latent demand score model (LDS) was proposed by (Landis, 1996) to estimate travel demand based on bicycle trip attractors and generators like shopping centers, employment, schools, and parks. The New York City Department for City Planning (Burden and Barth, 2009) developed a report on bike sharing programs that proposed the introduction of a system in New York City. This report analyzed the distribution of potential demand by users by the integration of variables such as facility service, worker and population density, closeness to recreational or cultural places like theaters, concert halls, and museums and closeness to retail shopping options. Understanding the distribution of potential demand and delineating trip generator areas from trip attractor areas makes the anticipation of dynamic travel demand possible in most metropolitan cities. Also, the distance between the stations needs to be considered while selecting the location of bike stations. For instance, bike stations in Paris are located at a distance of every four blocks which amounts to 300 m, allowing easy access (DeMaio, 2009).

2.3. Location models based on GIS

The use of location science started in the early 17thcentury (Hale and Moberg, 2003) but the actual beginning of location theory did not start until the 19th century (Farahani and Hekmatfar, 2009). Over time, location theory has changed and been used for analyzing the location of fire stations (Badri et al., 1998; Liu et al., 2006), ambulances and hospitals (Goldberg et al., 1990; Sasaki et al., 2010), police patrol areas (Curtin et al., 2010; Sacks, 2000) and other emergency facilities. To identify a suitable location for a facility, Geographical Information System (GIS) based assessment methods has been widely popular (Forkuo and Quaye-Ballard, 2013; Isa et al., 2016; Murray, 2013). GIS provides real-time simulation of transportation networks as well as a high level of accuracy as it uses original travel

Table 1
Researches on service locations.

Authors Name	Year	Research Focus	Analysis Method
Liu et al.	2006	Location of fire station	GIS and ANT algorithm
Ferrando et al.	2007	Location of bike station based on covering area	Methodological guide
Burden and Barth	2009	Assessment of bike share models for NYC	Case study based report
Rybarczyk and Wu	2010	Bicycle facility planning	GIS and multi-criteria decision analysis (exploratory spatial data analysis)
Curtin et al.	2010	Location of police patrol area	Maximal covering formulation and an innovative backup covering formulation
Saski et al.	2010	Ambulance location	Genetic algorithm
Lin and Yang	2011	Number and location of bike station	O-D metrics, Sensitivity analysis
Larsen and El-Geneidy	2011	Urban cycling facilities	GIS
Forkuo and Quaye-Ballard	2013	Location of a fire emergency response system	GIS
Murray et al.	2013	Location of urban fire stations	GIS
Isa et al.	2016	Location of fire services	GIS
Tali et al.	2017	Location of fire stations	GIS
Khadem et al.	2019	Location of bike stations	GIS

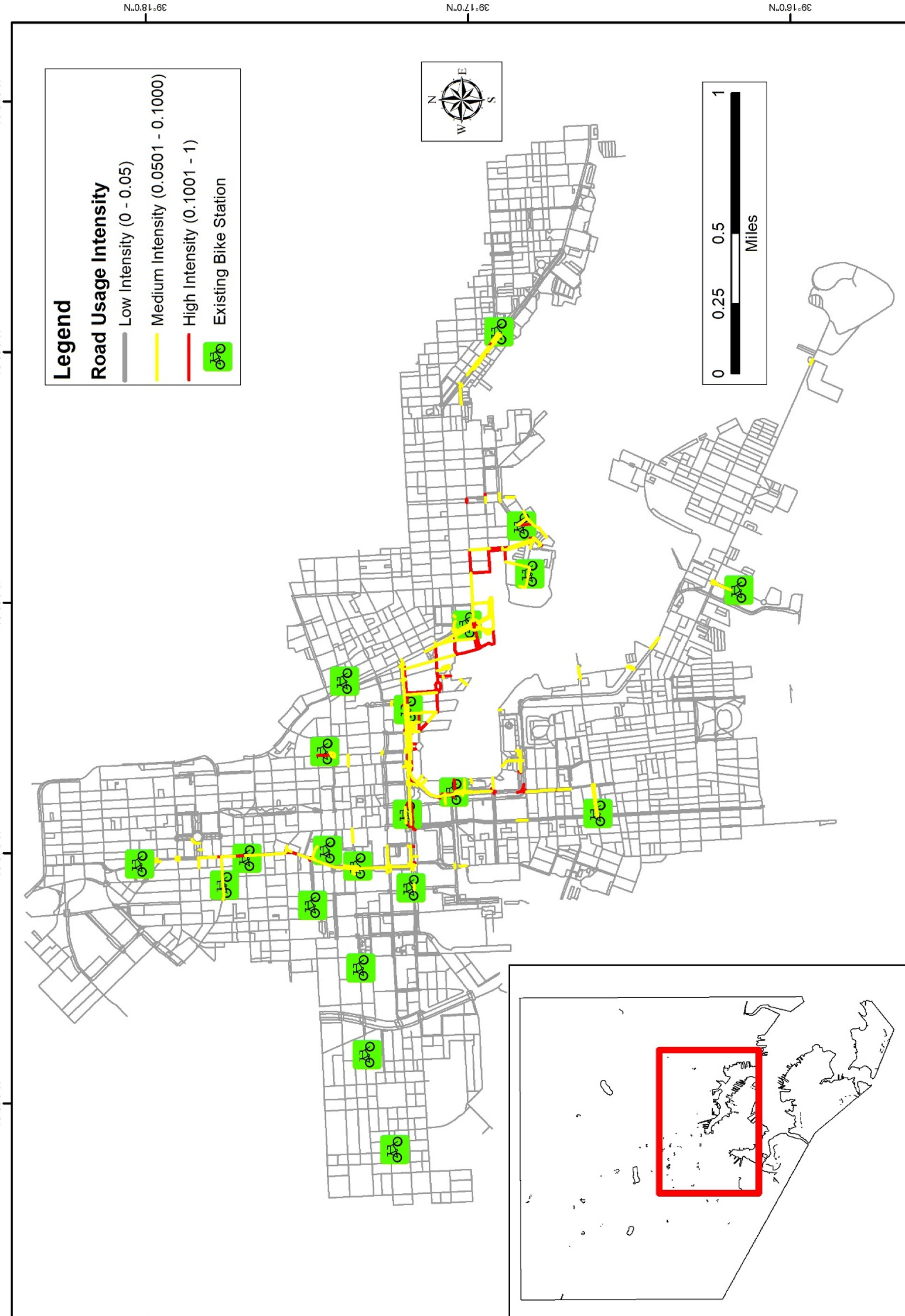

Fig. 1. Study area – City of Baltimore.

Table 2
Descriptive statistics.

Description		Statistics
Trips	No of trips	11,656
Usage	Membership	85%
	Go Pass	14%
	Students	1%
Gender	Male	82%
	Female	18%
Bike Type	Bike	57%
	Pedelec	43%
Biker Age Groups (Years)	18–25	9%
	26–35	59%
	36–45	18%
	46–55	9%
	>55	4%
Average Trip Duration (minutes)	0–5	14%
	5–10	38%
	10–15	22%
	15–30	17%
	>30	10%

distance, vehicle speed and delays time (Tali et al., 2017). Some important researches that have been reviewed for this study, are shown in Table 1.

Looking at the importance of the distribution of stations for bikeshare program operations, there is a need for models that aid in the optimization of location for such bike stations. GIS is a useful tool for developing methods for identifying optimum bike station locations (García-Palomares et al., 2012). Location-allocation selects the optimal location for facilities from a set of available locations (Drezner, 1995). A GIS based methodology aimed at getting an optimal location for upgrades, minor linkages, and new routes was proposed for a cycling network in Montreal (Larsen and El-Geneidy, 2011). The researchers suggested that this method can be utilized to identify locations for investment in public bicycle stations and bicycle parking spaces.

Location-allocation models or optimal location tools for services have been applied in a GIS environment, which might be an efficient way to locate bike stations with regard to potential demand distribution (Khadem et al., 2019). A location-allocation model identifies, where facilities of a specific kind could be located and establishes their capacity to meet predefined objectives along with satisfying demand from a defined number of centers (Ribeiro and Antunes, 2002). Since the initial studies were conducted on location-allocation models by several researchers (Cooper, 1963; Ghosh and Rushton, 1987; Hakimi, 1965; Rushton, 1979), various solutions for optimal location of services have been proposed, and their application has been carried out in numerous fields. A location model was developed, in which a minimum number of facility locations were to be found, which guaranteed a standard service of coverage or range in regard to central place theory (Toregas et al., 1971). Service provisions indicate the coverage of demand and a minimal set of facilities are required, so that demand points are serviced or responded to within a maximum travel distance/time.

When deciding whether to use a bike sharing program in their daily commute or not, residents of most large metropolis often consider traffic safety as the main factor that influences their decision. In a survey conducted by the Transportation Research and Education Center at Portland State University (TREC), nearly half of the residents of Chicago, Philadelphia, and Brooklyn, who were surveyed in this study, cited traffic safety as the major barrier for using bikes in their daily commute (Howland et al., 2017). In Baltimore too, the lack of safety associated with riding a bike was found to be the major barrier behind the widespread use of the bike sharing program in the city. 52% of bike share users in the city considered the lack of safety in Baltimore streets and sidewalks to be the main barrier against more widespread usage of the bike share program (Nickkar et al., 2018). Another study (Irani et al., 2019) reiterated the above results and found that 64% of would-be cyclists in Baltimore would prefer if bike lanes were separated by a physical barrier for road traffic. Consequently, in order to increase the usage of the bike share program in Baltimore, traffic safety must be taken into consideration when identifying the locations of the bike share stations. Placing bike share stations in perceived safe areas for biking, such as: in low traffic stress zones that includes dedicated bike lanes, will improve the safety of the bike users and, in return, improve its usage (Nickkar et al., 2018).

According to the National Association of City Transportation Officials (NACTO, 2016), the most visible component of the bike sharing system are the bike stations. Therefore, finalizing the location of a bike station is one of the most challenging aspects of the planning process for a bikeshare system. Appropriate placement of bike stations can attract riders, contribute to the holistic design of road safety, generate value for sponsors and add activity to the realm of pedestrians. Inappropriate placement of bike stations can make it difficult for riders to find or get bikes, reduction in ridership, disruption in pedestrian, cyclist or vehicular movements and may lead to complaints from the community (NACTO, 2016).With only 21 bike stations at the initial launch in Baltimore City and the increasing demand for bikes in the bikeshare program, there is a need to identify appropriate locations for new bike stations. This study adds to the existing literature by using the location allocation GIS based method, with a modified version of Huff's gravity model, to identify new bike stations in Baltimore City.

3. Study area

The city of Baltimore launched bikeshare in 2016 (Nickkar et al., 2019), introducing the largest Pedelec (electric-assist) system in North America. The system began with 21 stations and later expanded to 39 stations (Baltimore bikeshare, 2016). This study uses data from October 2016 to January 2017 (the initial three months of launch) when there were only 21 bike stations present. The most utilized stations are in the tourist areas, Harbor East and near popular tourist attractions the National Aquarium and Cross Street Market. The existing bikeshare stations are located on or near cycle tracks adjacent to major attractions and close to few parks as seen in Fig. 1. The descriptive statistics of the dataset is shown in Table 2.

As can be seen from Table 2, 85% of the bike share users are members, i.e. frequent users. Go Pass is usually used by tourists or non-frequent users, and as such is not very common among tourists compared to regular users. There is an uneven distribution of male and female bikers in the 3 months of data used in this study, with a high proportion of electric bike users. 59% of the bikers are in the 26–35 working group, mainly consisting of short trips.

4. Methodology & results

A location-allocation model is used to determine the location of any central facility, which is going to serve a dispersed population. In this study, the demand for new bike-stations are assumed to be represented by the population within a radius of 1000 m (3280.84 ft) of the proposed bikeshare station (candidate location). A 1000 m buffer is chosen based on prior researches (Braza et al., 2004; Colabianchi et al., 2007; Frank et al., 2006; Kerr et al., 2006; Timperio et al., 2006). Demand is measured as a point in the centroid of each block group; this represents the demand weight in the location-allocation model.The objective of this model is to locate three new bike stations based on a number of constraints. In this case, this model considers all possible candidate sites to select the best possible bike-station location.

4.1. Data collection and normalization

In this study, over 1.6 million Global Positioning System (GPS) data points were logged by bikeshare users in the city of Baltimore (Transportation If and Gauthier, 2013) over a period of four months from October 2016 to January 2017. These GPS coordinates were edited with respect to the road layer obtained from the open street map portal and joined

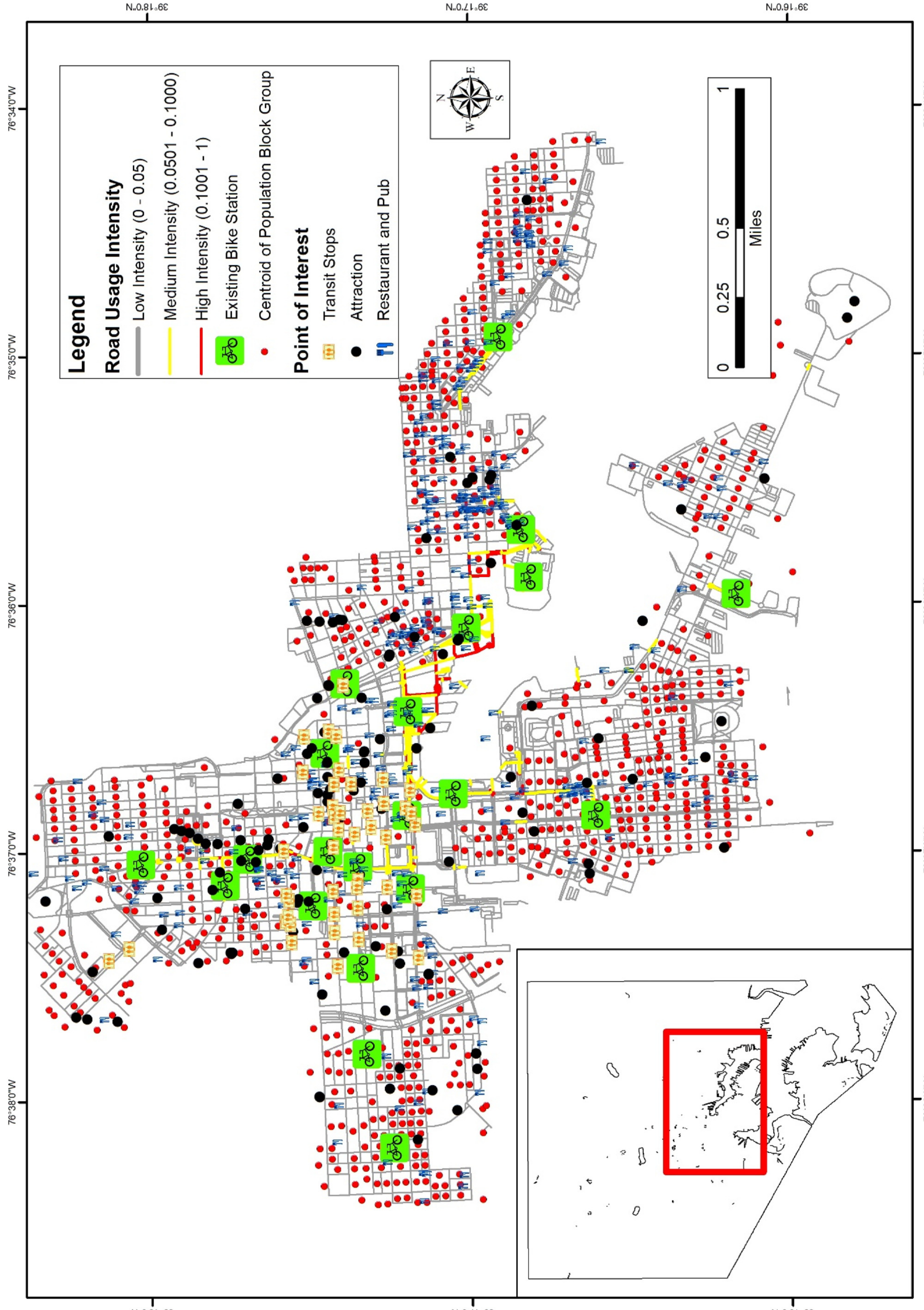

Fig. 2. Bikeshare road usage intensity and land use map – City of Baltimore.

Table 3
Road usage by class.

Class	High Intensity	Medium Intensity	Low Intensity
Cycleway/Footway	55%	44%	23%
Residential roads	8%	10%	18%
Primary roads	11%	15%	14%
Secondary roads	7%	10%	11%
Service Roads	10%	10%	26%
Other roads	9%	11%	8%

to the road layer using ESRI's ArcGIS. GPS points were snapped to the nearest road/cycleway/footway. The possibility of snapping points to a different road segment especially near intersections were minimal, as these GPS points were very few compared to the overall points. GPS points are logged every 5 s per bikeshare trip. As some GPS points were missing from the trip information, possibly due to weak signals, road usage intensity was considered. Road usage intensity is calculated by considering one GPS point per trip per road segment. This methodology was chosen to avoid biases where bikeshare users stay stationary at a point for extended periods of time. The number of GPS points per road segment is normalized to compute the road usage intensity score on a scale of 0 to 1, classified into three categories; low, medium and high intensity as shown in Fig. 1. The intensities were categorized based on the natural jenks classification, manually modified for better visualization.

The medium and high usage intensity roads consist of approximately 4% and 3% of all road segments respectively. It is widely known that land use and built environment impact travel behavior and mode choice. The medium and high intensity usage roads are primarily in the center of the study area-as shown in Fig. 2. Points of interest like the number of transit points, attractions (Library, Landmark, Museum, Recreation center), restaurants/pubs were identified within a 300 m buffer area, to identify the correlation between existing bike stations.

4.2. Route usage intensity

The class of the roads used by the bikers based on their usage is shown in Table 3.

From Table 3, it can be seen that the highest usage is in the presence of cycle tracks and footways. This possibly means that bikers feel safer using paths devoid of automobiles. This observation is later incorporated into the final identification of bike station locations. It was hypothesized that bikers would be more inclined to bike to nearby transit stops, attractions and restaurants/pubs as compared to commuting longer distances. The study area was divided into 300 sq. meter grids to test the hypothesis. The number of Points of interest (transit stops, attractions and restaurants/pubs) are calculated for each group and considered as an attraction score to be transferred to the centroid of the grids. The length of the medium and high intensity roads was calculated for determining intensity scored for each grid and finally transferred to the centroid of the population block group; those are considered as candidate locations. The transit stops, attraction sites, restaurants and pubs within the study area were used for analysis (the list is taken from City of Baltimore web page). The proximity of the potential bike station locations to the transit stops, attraction sites, restaurants and pubs were calculated and their correlation with the road usage intensity was tested using Pearson's correlation test. Pearson's correlation test showed that there is a moderate negative correlation between road usage intensity and proximity to attraction sites and restaurant/pubs as shown in Table 4. This means that, the closer the proximity to attractions or restaurants/pubs, the higher the road usage intensity. Since correlation of transit stops to intensity is weak, this variable was dropped from further computations.

Table 4
Pearson's correlation output.

	Intensity	Transit	Attractions	Restaurant/Pubs
Intensity	1			
Transit Stops	−0.012	1		
Attractions	−0.435	0.432	1	
Restaurant/Pubs	−0.375	0.411	0.298	1

This correlation was considered as the baseline land use and built environment model to identify new bike station locations, considering maximum population coverage.

4.3. Bike station suitability score

A distance of 300 m (0.19 miles) was considered to be an appropriate distance, one with which bikers would be comfortable walking from the bike station to reach their destination: transit stops, attraction sites and restaurants/pubs, in this case (Lee and Moudon, 2006; Smith et al., 2008; Yang and Diez-Roux, 2012). Eq. (1) was developed to calculate a bike station suitability score based on proximity to attraction sites and restaurants/pubs:

$$\mathrm{Sp/a} = (0.19 - d + 0.001)/0.19 \tag{1}$$

where,

$S_{p/a}$ = Numerical score for, attraction sites and restaurants/pubs
d = Distance to nearest attraction sites and restaurants/pubs

The 0.001 value was added to abstain from getting an error in case the distance to the nearest transit, attraction or restaurants and pubs was exactly 300-m (0.19 miles). These values were scaled and multiplied equally by 50% to get a suitability score between 0 and 1, as shown in Eq. (2).

$$\frac{\mathrm{SS} = \sum S_p - S_{p(\min)}}{\frac{S_{p(\max)} - S_{p(\min)} \times 0.5 + S_a - S_{a(\min)}}{S_{a(\max)} - S_{a(\min)} \times 0.5}} \tag{2}$$

where,

SS = Suitability score
S_p = Numerical score for restaurants/pubs
S_a = Numerical score for attraction

The closer a potential bike station location was to the nearest attraction sites and restaurants/pubs, the higher the suitability score it received, on a scale of 0 to 1. In a metropolitan area, the average distance between bike stations is around 300 m (Griffin and Sener, 2016; Transportation If and Gauthier, 2013). Keeping this in mind, candidate locations that fell within 300 m of an existing bike station were discarded. The remaining candidate locations are shown in Fig. 3.

4.4. Determining parameters for location-allocation modeling

For any location allocation model, the spatial distribution of demand, attractiveness and proximity to the location, are essential factors. In this study, the population of block groups are demand points and proximity to transit stops, attraction sites and restaurant/pubs are considered as attractiveness. Population (demand) block group data is obtained from the US census bureau, 2010. The relation between these parameters can be represented by Huff's gravity model, which was the first model to be introduced to location analysis for evaluating market share (Drezner, 1995). The model calculates the market share at each potential bike station location and, thus, finds the best location for a potential new bike station whose individual attractiveness (suitability score) is known. In this study, the Huff's gravity model was modified to include the suitability score instead of the size of the location. Suppose, there are k existing bike station facilities and n

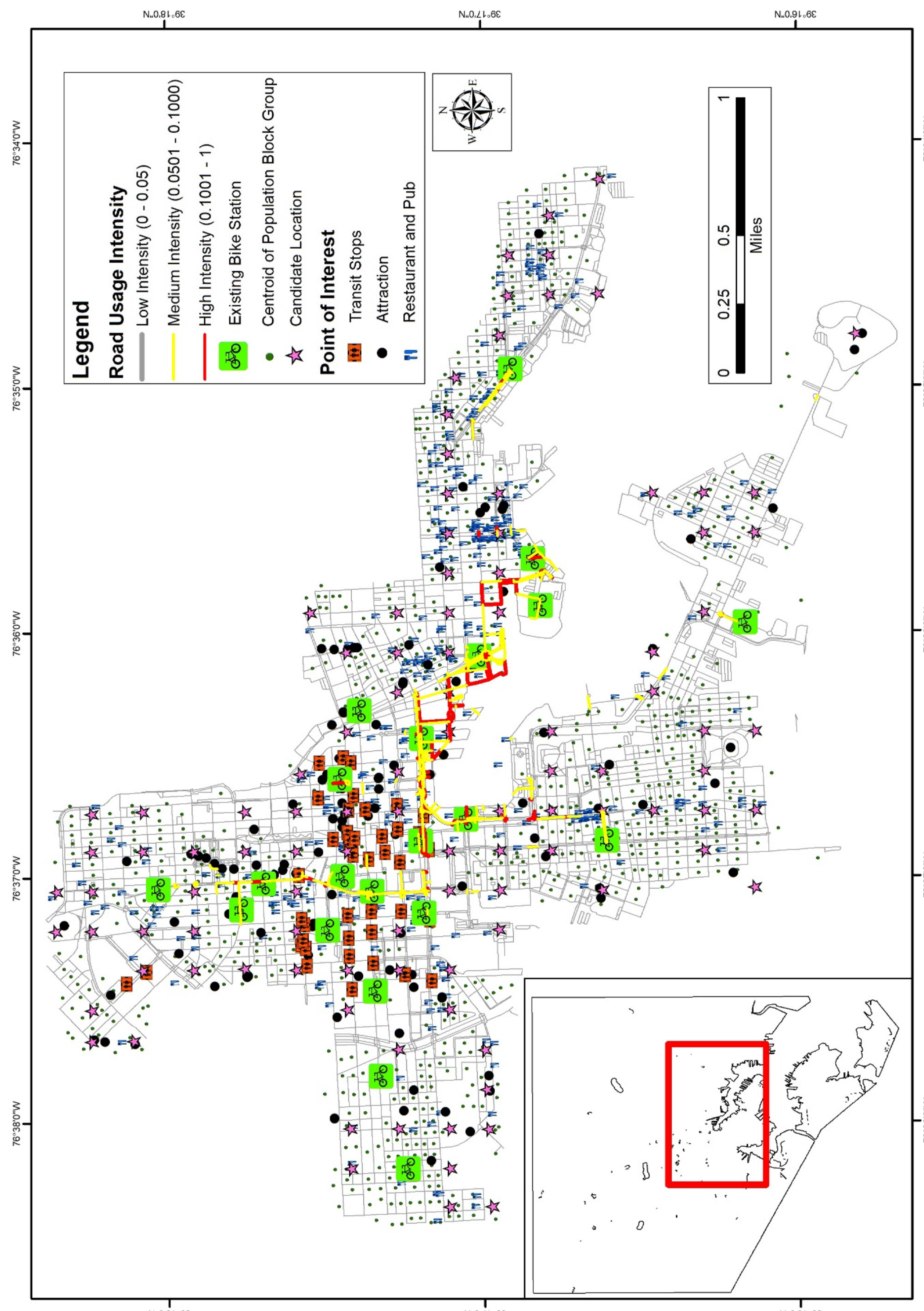

Fig. 3. New candidate bikes station locations.

Fig. 4. Three new bike station locations using location allocation modeling.

population demand points, the suitability score of facility j is SS_j for i = 1, …, k, and the distance between demand point i and facility j is d_{ij}. The accessibility at demand point i is b_i. Eq. (3) is given by:

$$M_j = \Sigma_{i=1}^{n} b_i \frac{SS_j / d_{ij}\lambda^k}{\Sigma_{j=1}} SS_j / d_{ij}\lambda \tag{3}$$

where,

M_j = Market share or population attracted to the bike station facility j
λ = power to which distances are raised

In any location-allocation model, potential new facilities are calculated using discrete data. In this study, they are candidate locations and population block groups or demand points. Eliminating the candidate locations within the 300 m of the existing bike stations, the final set of candidate locations were identified. The 'Maximize Market Share' location allocation model is used with the impedance cutoff set to 1000 m. This problem type will identify the best bike station locations taking into account competitor facilities (existing bike stations). The cutoff is assuming people would not want to walk to the bike station from their homes, beyond 1000 m. Once the model is run, three new bike stations are identified, based on the suitability score and maximum population reach. These are snapped to the nearest cycleway/footway/road. A correlation test was conducted for the proposed bike station locations, similar to the existing bike stations with road usage intensity. The outcomes are satisfying and show similarity to the initial correlation test. This supports the initial observations that high usage intensity is more concentrated on cycle tracks and footways, as well as the existing bikeshare stations being located on or near the cycle tracks. The locations identified as potential bike station facilities are shown in Fig. 4.

The order of the bike station locations in a 300-m (0.19-mile) proximity of attractions and restaurants/pubs are shown in Table 5.

Potential bike station locations are selected on the basis of the location being accessible to the maximum number of people as well as a high suitability score, as shown in Table 5. Although location 2 i.e. East Fall Street has connectivity overlaps with many block groups, it is located in one of the highest demand/use zones in the inner harbor area.

5. Conclusion & discussion

This study used bikeshare GPS points to calculate the intensity of usage of road segments into three categories; low, medium and high. Only 1 GPS point per road segment per trip was used to avoid biases related to extended periods of stationary time at the same location. A moderate negative correlation was found between road usage intensity and proximity to attraction sites and restaurant/pubs. This means that, the lesser the distance to the attraction sites and restaurants/pubs, the higher is the road usage intensity. Using this correlation, a location allocation model using a modified version of Huff's gravity model was used to identify the top three locations for bike station placements. These locations were snapped to the nearest cycle track or footway based on the findings that higher bikeshare route usage and location of existing bikeshare stations are on or near cycle tracks or footways. As there are already existing bike stations near most points of interests, the location allocation model identifies three of the proposed bike stations in the middle of the city, expanding in both east and west direction. This distribution of existing and proposed bike stations caters to both tourists as well as residents living close to the downtown and Inner Harbor areas.

The data used in this study covers bikeshare usage from October 2016 – January 2017 during the launch of the bikeshare program in Baltimore, when there were only 21 bike stations. Since then, the program has added another 17 bike stations across the city and an additional 10 bike stations have been planned by the city as shown in Fig. 5. Two of the three proposed bike stations through the location allocation model are within a block of either a planned bike station or an already established bike station, post January 2017. This means that the methodology used in this study is in line with that of the professionals from the city of Baltimore, who use '*n*' number of constraints to identify a new bike station location.

Some of the limitations of this study included missing datapoints (missing latitude/longitude), which is one of the main reasons we had to compute road usage intensity, since we could not identify some of the roads used on the trip. Another limitation is the lack of policy recommendations, since the model developed in this study is based on observed demand. To make policy recommendations, the observed demand should be validated by evidence-based information (land-use, surveys etc.), which is not available. Information on traffic and bike accidents in the city, dedicated bike lanes, certain biker demographics like car ownership, accessibility to nearest bike stations, reason for using bikeshare could be used to further enhance the model, once such data is available.

The majority of the high intensity usage roads already have existing bike stations on or near them. As there were only 21 bike stations at the time of this study, there is a lot of scope for future bike stations as there is a lot of cities to cover. With the construction of new bike stations, there would possibly be an increased demand at the newer locations and a higher number of bikeshare users. Even though the road usage intensity near the newer bike stations might be low, it is possibly due to the absence of bike stations in the immediate vicinity. This methodology will be highly beneficial to developing cities for identifying locations for new facilities where location suitability is more important than the size of the facility. This will possibly prompt an increase in bikeshare usage with the advent of new facilities, in close proximity to attractions and restaurants/pubs. Another aspect that might help in improving the model developed in this study is to include safety while identifying the locations for the bike share stations. A number of research studies aimed at developing models that select such locations which maximize the users' safety (Askari and Bashiri, 2017); thus, incorporating safety in our developed model might lead to an increase in the usage of such bikeshare programs.

Credit authorship contribution statement

Snehanshu Banerjee: Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Md. Muhib Kabir:** Methodology, Visualization, Writing - review & editing. **Nashid K. Khadem:** Methodology, Writing - review & editing. **Celeste Chavis:** Supervision, Writing - review & editing.

Table 5
Optimal Bike station locations.

Order	Bike Station Locations	Suitability Score	Population Reached	Block Groups
1	East Lombard Street (77)	1	7142	105
2	East Falls Street (100)	0.987	5406	103
3	Lancaster Street (127)	0.940	8091	137

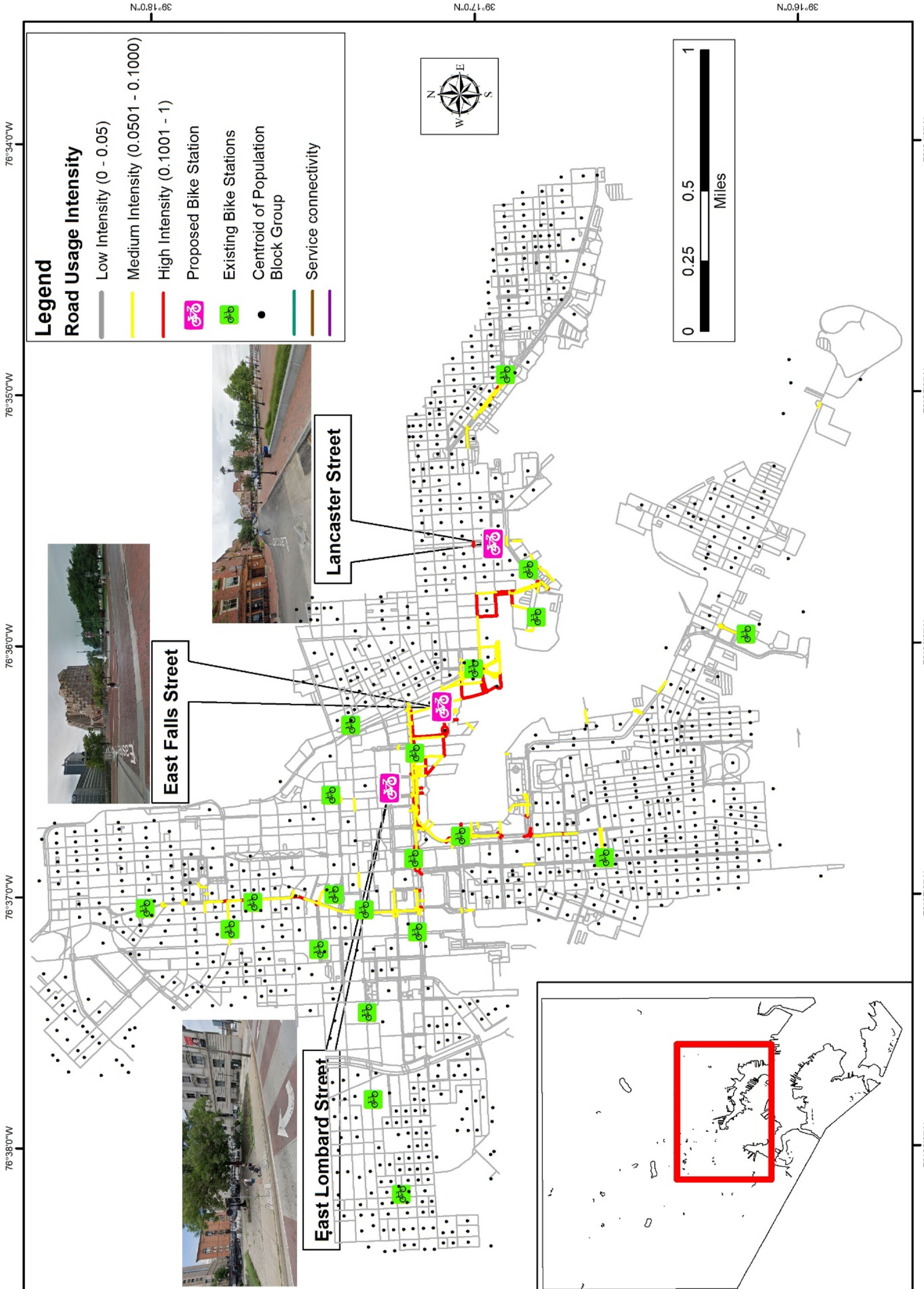

Fig. 5. New bike stations.

Acknowledgment

The authors would like to thank Baltimore bikeshare for providing GPS data used in this study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

None.

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