



Suitable Bus Stop Locations for a Proposed Bus Rapid Transit Corridor in a Developing Country City: An Analytical Hierarchy Process Approach

Md Musfiqur Rahman Bhuiya¹ · Rezwana Rafiq² · Khandaker Nabid Md Morshed³ · M. Imtiaz Rahman⁴

Received: 3 November 2021 / Accepted: 27 January 2023 / Published online: 14 March 2023
© Springer Nature Switzerland AG 2023

Abstract

Bangladesh is one of the world's most densely populated developing countries, and so is its capital Dhaka, where ever-growing travel demand is causing congestion and numerous other transportation problems. To improve the situation, the "Strategic Transport Plan for Dhaka (STP)" was conceptualized in 2005 with the plan of developing mass transit systems (buses and rail), which was revised in 2016. The revised STP proposes two BRT bus routes for Dhaka city: BRT Line 3 and 7. Bus stops on the proposed routes are the ultimate point locations where people at large will access these BRT services. Therefore, determining the locations of bus stops is crucial for these proposed routes' overall efficiency and accessibility. In this study, we proposed a bus stop selection technique for the BRT Line 3 in Dhaka, which considers multi-variate influencing factors, including travel demand, population density, land use, accessibility of pedestrians, and accessibility of rickshaws. We collected data on these factors through a field survey for 77 intersections along the study route. After that, a composite score is assigned for each study intersection based on the five factors' relative value and priority weights obtained via the Analytical Hierarchical Process technique. Finally, based on the composite score and selection criteria, we suggested 25–40 intersections for suitable bus stop locations along the study route. The methodology used in this study to select suitable bus stop locations will provide citizens with better utilization and transit experience as envisioned by the BRT routes.

Keywords Bus Rapid Transit · Bus stop locations · Suitability score · Dhaka city · Analytical Hierarchy Process

Introduction

Dhaka is the capital of Bangladesh and the sixth megacity in the world with a 21 million population, where more than 23,000 persons live per sq. km [1]. Dhaka city, being the hub of administration, commerce, trade, education, and economic activities, attracts many people from different parts of the city. The population of this city is predicted to rise to 25 million in 2025 [2]. The ever-increasing population induces an increasing number of trips at an unprecedented rate. However, the transportation system is not developed in commensuration with the necessity of this growing population. Besides, inefficient road use, inadequate traffic management, and poor quality of public transportation facilities worsen the traffic situation day by day. The deteriorating traffic conditions cause significant delays in everyday life and thus adversely affect the quality of life.

The "Strategic Transport Plan (STP) for Dhaka" conceptualized a plan in 2005 for developing mass transit systems (buses and rail) to improve the situation, which was

✉ Md Musfiqur Rahman Bhuiya
mrbhuiya@ucdavis.edu

Rezwana Rafiq
rrafiq@uci.edu

Khandaker Nabid Md Morshed
nabidmorshed@yahoo.com

M. Imtiaz Rahman
mr00060@mix.wvu.edu

¹ Institute of Transportation Studies, University of California Davis, Davis, USA

² Institute of Transportation Studies, University of California Irvine, Irvine, USA

³ Baseline Mobility, Cary, NC, USA

⁴ Department of Civil and Environmental Engineering, West Virginia University, Morgantown, USA

revised in 2016 and named RSTP [3, 4]. Bus Rapid Transit (BRT) is one of such mass transit projects that introduces a road-based mass transport system connecting the farthest city points in Dhaka by these end-to-end bus routes. BRT buses will operate as an initiative to improve and replace Dhaka city's current public bus service [3]. BRT is considered one of the most cost-effective public transportation systems compared to the expensive urban rail investments [5, 6]. This service can deliver a rapid and high-quality service with its route flexibility, better passenger carrying capacity, and cost-effectiveness [7].

In Dhaka, where the service quality of buses is extremely poor, BRT should aim to provide more efficient service to the customers than existing bus services [3, 4]. Service quality of any transport mode is linked with ensuring a comfortable trip by a mode and other factors necessary to avail the service [7]. One such factor is allocating bus stops, contact points between buses and passengers, in a suitable place to avail this service. Studies reveal that when a bus stop is located in a suitable place with due consideration of travel demand, accessibility, and other factors, it can play a vital role in improving urban mobility. Therefore, appropriate locations of bus stops can increase service quality as well as users' satisfaction. Because of this reason, it is of paramount importance to allocate bus stops in suitable locations [8–11].

The feasibility study report for BRT recommended locating bus stops along these routes based on a single trip generation criterion, passenger travel demand [2, 12]. In that, the locations that generate a higher volume of travel demand are considered more suitable as candidates for bus stops. We argue that travel demand is indeed an important factor but should not be the only decider. Instead, a combination of a handful of attributes with social, spatial, and trip generation parameters needs to be considered, all of which contribute, albeit with different degrees of impact on bus stops' selection and integrated under a framework to determine bus stop location. For this, it is necessary to follow a multi-criteria-based approach to allocate bus stops. As Analytical Hierarchy Process (AHP) is a multi-criteria approach to determining the significance of diverse factors influencing a phenomenon and unifying the factors into a single framework with due consideration of trade-offs between them for the decision-making process, AHP might be an ideal approach to determining bus stop location [12]. AHP has been used in several studies to make important transport planning decisions, such as the assessment of alternate corridors to find a feasible route [12], prioritizing public transportation projects [13], and solution of logistic transportation problems [14]. But it has not been applied to unify various criteria in a single framework for determining suitable bus stop locations. This study aims to fill that gap in the literature.

To this end, this study proposes a bus stop selection technique that considers four more factors besides passenger

travel demand. Among these five factors, there is one current trip generation factor: travel demand, two trip generation potential factors: land use and population density, and two spatial accessibility factors: accessibility for pedestrians and accessibility for rickshaws. Arguably, not all factors contribute equally to the selection; some factors may weigh higher or less than others. The degree to which each factor affects the bus stop selection is subject to the expert's opinions. We accommodate that by taking opinions from experts and determining the relative importance value of these five factors via the AHP technique. We then propose a bus stop selection technique based on these five factors weighted by the expert suggested values and apply it to BRT Line 3 as a case study route.

Study Area Profile

The Revised Strategic Transport Plan (RSTP) for Dhaka was prepared considering a 20-year (2016–2035) urban transport policy. It prioritized the improvement of mass transit systems by proposing two major corridors for Bus Rapid Transit (BRT) and three routes for Mass Rapid Transit (MRT) (e.g., commuter rail) [3, 4, 15]. We selected “BRT Line 3” for this study among the two proposed BRT corridors (as shown in Fig. 1). BRT Line 3 ranges from Gazipur to Jhilmil. In this study, we have only considered the Airport to Jhilmil section as the study route due to the time, financial, and human resource constraints. This study route is selected based on the following criteria: (i) it serves the central corridor of Dhaka City Corporation and runs between the new city area (e.g., the International Airport) and the old city part (termed as Old Dhaka), (ii) the government of Bangladesh provides top priority for this route, and (iii) the feasibility and detailed design study for BRT has already been conducted for a portion of this route by Dhaka Transport Coordination Authority [15]. The route is 22.4 km long. The number of lanes varies between three to four on each side of the corridor.

With regard to the land use distribution of the Dhaka City Corporation (DCC) area, where most of the corridor under study belongs, the total land area comprises 44% of residential areas, 4% of commercial, 4% of mixed-use, and 7% of public facilities (e.g., medical centers, universities) [2]. Some of the significant planned residential areas are located close to the proposed BRT Line 3 corridor, for example, Gulshan and Banani residential areas. Higher-income groups typically occupy these areas. One of the significant industrial areas (Tejgaon) is located in the middle of the corridor, where many industries, including a large number of garment factories, are located. The major commercial activities are primarily located on the southern side of the corridor. In addition, the Bangladesh Railway system has four rail stations near the BRT corridor. Other

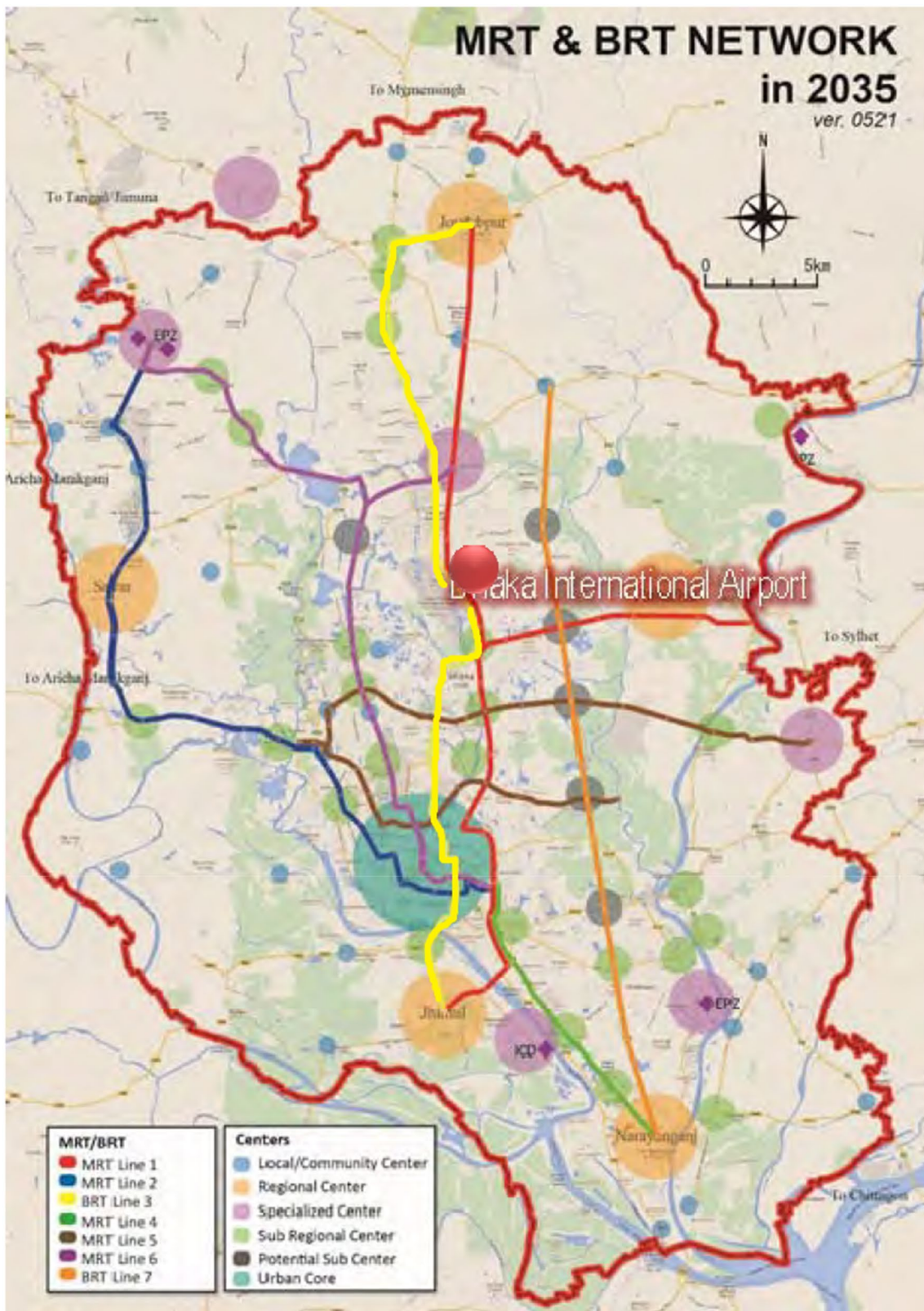


Fig. 1 Proposed BRT Line 3 (Airport to Jhilmil) route in Dhaka (yellow-marked line) (colour figure online)

transport infrastructures, such as International Airport, the larger inter-district bus terminal (Tejgaon), and the river terminal in (Sadarghat) are also located close to the corridor. This BRT corridor also includes major public facilities, parks, and playgrounds in the DCC area [2].

Literature Review

This section considers relevant studies on Bus Rapid Transit (BRT) and bus stop allocations. The rapid global expansion of the BRT system has generated a tantamount of literature on different aspects of the BRT system in developed and developing countries. Studies have been conducted on the service performance of China, India, Indonesia, USA, Turkey [5]; Columbia [7]; challenges of planning and implementing BRT in the USA, Brazil, China, UK, France, India, Columbia, Vietnam, Singapore [16]; socio-economic and environmental impact of BRT in Mexico, Turkey, Columbia, and South Africa [17]. Several studies focused on the design [15], feasibility [18], and environmental benefits of BRT [8] for Dhaka. However, no study has been conducted yet on systemically allocating BRT bus stops for Dhaka.

Previous studies were also reviewed to explore the influence of relevant factors in allocating bus stops or optimizing the number of bus stops along a route. APTA study suggests that the location of major trip origin and destination points on corridor, population density, and land use characteristics should be the significant deterrents of allocating bus stops [9]. Another APTA research published a detailed study providing guidelines to allocate bus stops in an accessible location [10]. The TCRP report provided guidelines on allocating bus stops based on the street side and curbside factors [19]. Several studies also investigated the impacts of factors including travel demand, accessibility, and land use on bus stop locations. Jahani et al. determined suitable locations for the bus stop in Tehran, maximizing demand coverage and minimizing access time [20]. Ahsan identified the optimum location of bus stops based on pedestrian accessibility for Dhaka city [11]. Islam et al. studied allocating bus stops along Kaptai Road, Chittagong, Bangladesh, based on four factors: public transportation demand, slope, land use, and available setback from the road using the overlay method in GIS [21]. Furth and Rahbee used a combination of ridership data and GIS data to determine the optimal number and location of bus stops using a dynamic programming model in Massachusetts [22]. George suggested that bus stops should be allocated adjacent to land uses with high trip generation potential [23]. Cooper proposed a methodology to consolidate bus stop stops based on transit ridership, transfer points, and existing bus stop locations for Route-1 California, USA [24]. Xuebin's

study focused on optimizing bus stop numbers by trading off between walking accessibility and travel demand [25]. Gauncha and Mejia's research determined the number of BRT stations needs to be provided to minimize downtimes and operation costs by considering waiting time and using a multi-objective function [26]. Behal et al. studied the impact of accessibility of paratransit on bus stop allocation in New Delhi, India [27]. Table 1 shows a brief overview of the factors considered for allocation of bus stops.

The above-mentioned literature primarily focuses on sorting out factors influencing bus stop allocation, the impact of a particular factor(s) on bus stop allocation, or optimizing bus stop allocation by the trade-off among a limited number of factors. There is rarely any defined methodology or framework to allocate bus stops combining multiple factors with diversified characteristics.

Methodology and Data

To make an effective and high-quality bus transit system, bus stops should be allocated in suitable locations by considering relevant factors [7, 24]. The detailed methodology and data collection process are discussed in this section.

Identification of Factors Influencing Bus Stop Locations

In prior studies, population density is considered one of the critical factors in determining the locations of stops [7, 28, 29]. While allocating bus stops, priority should be given to providing stops near high-density residential areas as these areas tend to generate more potential transit trips than low-density neighborhoods. Passenger travel demand is also recognized as an influential determinant of bus stop location choice [3, 15, 24]. In detail, bus stops should be located near the major activity centers where passenger demand for buses is higher. It will enable a large portion of current bus riders to access buses easily and attract new riders [30, 31]. Since non-residential land uses, such as commercial, recreational, shopping, educational, and healthcare facilities act as potential generators and attractors of traffic [32], bus stops should be allocated considering these land-use distributions along the BRT corridor [33, 34].

Moreover, accessibility to pedestrians is a key element for an urban transit system since walking is typically considered the primary access or egress mode for urban stations [35]. Therefore, bus stops should be located in a place where pedestrians have a better degree of access [36, 37]. Intermodal connectivity with BRT, particularly a better connection with non-motorized transport at stations, is also crucial for a successful BRT system. In Bogotá, Curitiba, and Guangzhou cities, bicycles are effectively integrated with the

Table 1 A brief overview of the literature on factors influencing bus stop allocation

Literature	Factors influencing bus stop allocation
APTA [9]	Location of major origin and destination (places with higher travel demand), population density, land use
APTA [10]	Accessibility to potential bus stop locations
TCRP [19]	Street side factors: stop spacing, types of bus stops, location of traffic signal and stop sign, safety, availability of space Curb-side factors: pedestrian accessibility, connectivity with nearest residential and commercial development, accessibility for people with disability to potential bus stop location, availability of amenities like benches, lighting, trash receptacles, bicycle storage facilities
Jahani et al. [20]	Maximizing coverage of travel demand and minimizing travel time to bus stops
Ahsan [11]	Pedestrian accessibility
Islam et al. [21]	Public transportation demand, slope, land use, and available setback from the road
Furth and Rahabee [22]	Allocating minimum number of bus while meeting maximum travel demand
George [23]	Land uses with high trip generation potential
Cooper [24]	Transit ridership and location of transfer points
Xuebin [25]	Pedestrian accessibility and travel demand
Gauncha and Mejia [26]	Minimizing downtimes and operation costs by considering waiting time
Bahl et al. [27]	Accessibility of paratransit

BRT system to provide better access to transit stops [38, 39]. In the context of Dhaka, a rickshaw, a three-wheeler non-motorized transport, covers 38.7% of all trips [20]. People usually prefer rickshaws (a three-wheeled non-motorized mode) over other modes for short-distance travel [32]. Also, the rickshaw provides better modal integration between bus stops and trip origins and/or destinations. Besides, this mode is highly accessible and provides a convenient option for older and disabled people who cannot walk to transit stops [21]. The Strategic Transport Plan for Dhaka (2016–2035) suggested an integration of rickshaws with BRT to ensure an accessible BRT system [15].

Based on a comprehensive literature review, five factors: passenger travel demand, population density, land use, accessibility for pedestrians, and accessibility for rickshaws, which can be quantified directly, were selected to determine BRT bus stop locations. We did not consider median width as a factor since DTCA already chose BRT Line 3, evaluating the adequacy of median width. Topography and weather conditions were also not included as a factor as they were not quantifiable directly. In addition, as the route of BRT Line 3 is on flat land [15], we did not consider slope as the determining factor of bus stop location choice.

Collecting Data on the Identified Factors

We considered 77 intersections along the BRT Line 3 route for this study. After identifying the five factors, we collected data on each factor for each intersection from both field

surveys and secondary sources in 2013. The detailed data collection process is discussed in this section.

Population Density

To collect data on population density, we first demarcated a circular buffer area surrounding each intersection to identify potential residential areas that can generate trips. We demarcated a buffer area of 1.5 km (~ 1 mile¹) surrounding each intersection. There is a particular rationale behind this choice. We assumed that travelers would primarily access or egress from BRT stations either by walking or rickshaw riding. We then explored the convenient access or egress distances for walking or rickshaw riding. Since the Strategic Transport Plan for Dhaka (2005) suggested a maximum of 0.5 km for walking and a maximum of 1.5 km for rickshaw riding as convenient access/egress distances [3], we considered the largest one (1.5 km) as the radius of a buffer so that a buffer can include possible pedestrians and rickshaw riders living in residential areas adjacent to intersections.

We then intersected the buffer layer with the land-use map to extract a layer of residential land uses within the demarcated buffer area. The land-use map of the study area was collected from a GIS database developed by RAJUK (i.e., the Capital Development Authority of the Government

¹ In planning studies, walkable distance is considered ranges from 1/8 mile to a mile (Layton, 2017).

of Bangladesh) for the Detailed Area Plan (DAP) of Dhaka Metropolitan Development Plan (DMDP) 1995–2015 [40]. After demarcating the residential land uses, a household survey is conducted in each household to collect the number of people residing in those designated catchment areas. Finally, the total number of people was divided by the entire residential ground coverage area to compute population density (i.e., the number of people living per square km). This process was repeated for each of the 77 intersections.

Passenger Travel Demand

Since no secondary data was available on passenger travel demand of buses for BRT Line 3, the field survey method has been applied. We considered the peak hour passenger demand for buses as a representative measurement unit of passenger travel demand at intersections with the assumption that current bus users will shift to BRT after the implementation of the BRT project [41]. The data collection process is similar to the intersection volume survey, but instead of counting the number of vehicles at intersections, we counted the total number of passengers boarded on buses during the morning (6 am–10 am) and evening (4 pm–8 pm) peak hours. For each intersection, data is collected for one single weekday. While scheduling the weekdays, we avoided days of bad weather conditions and unusual events for the survey. We then calculated the average number of passengers over the eight peak hours for each of the 77 intersections. In this way, we only considered the number of current bus riders as possible BRT riders. There are certain limitations to this selection. For example, there could be modal shifts from other modes as well, for example, private cars, rickshaws, and other para-transits. In addition, there could be an increase in the number of bus riders when the BRT is implemented. But, due to time and resource constraints, this study is only limited to the current bus riders as a representation of passenger travel demand. Our major goal was to prioritize those intersections as bus stop locations where the composite scores are higher considering all the five selected factors. We believe that the relative scores of the factors among the bus stop locations (intersections) play a more significant role than the absolute scores of the factors at an intersection.

Non-residential Land Use

Trip generation can be treated as a function of residential and non-residential land use [41]. Thus, it can be anticipated that a higher concentration of different land uses will generate a higher number of BRT trips. Since trip generation rate is proportional to the total floor area of various land uses [42], we considered the total floor area of non-residential

land uses (residential uses are measured in population density) as a representative unit of potential trip generators.

Similar to the process of collecting population data with the assumption of people who come to a bus stop by rickshaw, a 1.5 km circular buffer was at first drawn surrounding each intersection and the buffer layer was then intersected with the land-use map to extract a layer of non-residential land-uses within the designated buffer area. After demarcating various non-residential land uses, such as manufacturing and processing activities, offices, banks, shopping centers, educational institutions, health care, and recreational activity centers, a field survey was conducted to collect data on the number of floors for each non-residential building (building height) within the target zone. The number of floors was then multiplied by the gross floor area of the building (available in the DAP GIS database [40]) to calculate the total floor areas of the building. Note that the gross floor area of the buildings represents the floor area enclosed by the outer walls of the buildings and excludes the setback and the roof [31, 32]. The exact process was applied to each intersection.

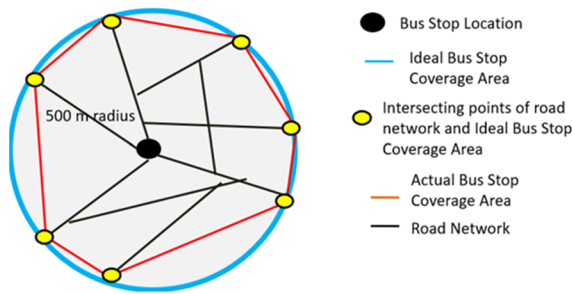
Accessibility of Pedestrians

In the context of Dhaka, accessibility of pedestrians is an important consideration in the bus stop location choice as the majority of BRT riders are anticipated to access or egress from stations by walk [2]. To measure the degree of accessibility for an intersection, we applied a technique called Stop Coverage Ratio Index (SCRI) measure [35]. According to this technique, SCRI for an intersection is determined by dividing the actual coverage area by the ideal coverage area of the pedestrian networks. The advantages of this technique are that it determines pedestrian accessibility to a bus stop based on the geometry of the road network, does not overestimate accessibility, and allows comparison among bus stop locations based on the same denominator [35]. A higher value of SCRI denotes greater pedestrian accessibility. SCRI can be expressed with the following equation:

$$\text{Stop coverage ratio index (SCRI)} = \frac{\text{Actual coverage area}}{\text{Ideal coverage area}}$$

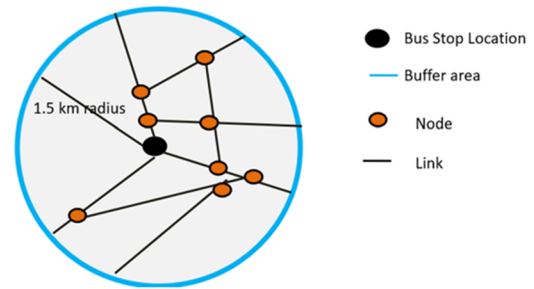
In detail, at first, we demarcated a 500-m (~ 1/3 mile) circular buffer surrounding an intersection and recognized the area as the ‘ideal coverage area’ for pedestrians. We consider a 500-m buffer area for an intersection as a pedestrian catchment area based on the suggestion provided by STP [3] for Dhaka. The road network map is collected from the DAP GIS database [40]. On the other hand, to calculate the actual coverage area for an intersection, we digitized a polygon by connecting each point where road networks intersect

$$\text{Stop coverage ratio index (SCRI)} = \frac{\text{Actual coverage area}}{\text{Ideal coverage area}}$$



(a)

$$\text{Links to Node Ratio (LNR)} = \frac{\text{Total number of links connected to nodes in a network}}{\text{Total number of nodes in a network}}$$



(b)

Fig. 2 a Actual and ideal bus stop coverage within a 500-m buffer and b links to node ratio within the 1500-m buffer area

the radius of the ideal coverage area and then consider the area of that polygon as an actual coverage area. Figure 2a shows an example of an actual and ideal coverage area for an intersection. Finally, the actual coverage area was divided by the ideal coverage area to compute the stop coverage ratio index, which determines the degree of pedestrian accessibility for an intersection. The exact process is repeated for all 77 intersections.

Accessibility of Rickshaws

The accessibility of rickshaws is measured by using a technique suggested by Handy et al. [43] and Tal and Handy [44], who applied the technique to measure bicycle accessibility. Here, accessibility is considered a function of road network connectivity. A route connected with a higher number of links at a node or intersection implies greater access to different points [44]. An indicator called Link to Node Ratio (LNR) is used in this study to measure the accessibility of rickshaws for an intersection. LNR can be expressed by the following equation. A higher value of LNR denotes greater connectivity and accessibility of non-motorized vehicles with the intersections (bus stop locations) and vice versa.

$$\text{LinkstoNodeRatio(LNR)} = \frac{\text{Totalnumberoflinksconnectedtonodesinanetwork}}{\text{Totalnumberofnodesinanetwork}}$$

The road network map required for this calculation is collected from the DAP GIS database [40]. To compute the link-to-node ratio, at first, we determined the number of links connected to each node. Since the collected road network map had separate shapefiles for nodes and links, we spatially joined them to identify the connected links with each node. Then, both node and spatially joined link shapefiles are

clipped with a 1500-m buffer area (suggested by STP [3]) as a catchment area of rickshaws to access/egress public transit stops) surrounding an intersection (Fig. 2b). The number of links and nodes in the clipped area was then computed by using the statistical tools of ArcGIS. A similar process is applied to all the intersections.

Normalization of Factor Values

Since each factor is in a different unit, we normalized them to bring them to a single scale of 0–1 by using the min–max normalization method. This method is one of the most common ways to normalize data. For every feature, the minimum value of that feature gets transformed into a 0, the maximum value transforms into a 1, and every other value transform into a decimal between 0 and 1. The min–max normalization equation is provided below:

$$NF_{ij} = \frac{F_{ij} - F_{j(min)}}{F_{j(max)} - F_{j(min)}}$$

where, NF_{ij} = normalized value for factor j at intersection i . F_{ij} = original value of factor j at intersection i . $F_{j(max)}$ = the maximum value of factor j among all intersections. $F_{j(min)}$ = the minimum value of factor j among all intersections.

Assigning Priority Weight to Each Factor by AHP

Each identified factor has different levels of significance in allocating locations for a BRT bus stop. To prioritize the factors based on their degree of importance, we applied Analytical Hierarchy Process (AHP) proposed by Saaty [45]. The most significant advantage of incorporating AHP in this methodology is that it can be used to determine bus stop locations by combining any number of factors with diversified characteristics [45]. This technique is usually

applied to situations where ideas, feelings, and emotions affecting the decision process need to be quantified to provide a numerical scale for prioritizing the alternatives. AHP can effectively quantify both subjective and objective judgments in a logical way [46]. The detailed methodology of the AHP process used in this study is discussed below.

Determination of weights for Factors from Expert Judgement

At first, a reciprocal matrix of pair-wise comparison between the factors needs to be developed to determine the relative importance of one factor with respect to others. For each pair of criteria, the decision-maker is required to respond to a question of “How important is factor 1 relative to factor 2?” Suppose a decision problem considers “n” numbers of factors at a certain level of hierarchy for a given decision problem, then a “n × n” comparison matrix “A” is required to be developed. Comparison matrix “A” quantifies the decision maker’s judgment of the relative importance of different factors. The pair-wise comparison is made such that factors in rows “i” ($i = 1, 2, 3, \dots, n$) are ranked relative to every other factor. Letting a_{ij} define the element (i, j) of “A”, AHP uses a numeric scale from 1 to 9 in which $a_{ij} = 1$ denotes that i and j are of equal importance whereas $a_{ij} = 5$ implies that i is strongly more important than j, and $a_{ij} = 9$ indicates that i is extremely more important than j. Other intermediate values between 1 and 9 are interpreted correspondingly. Consistency in judgment means that if $a_{ij} = k$, then $a_{ji} = 1/k$. Also, all the diagonal elements a_{ii} of “A” equal 1, because these elements rank each criterion against itself. The value of weights ranges from 9 to 1/9 [46]. Table 2 shows a sample pairwise comparison matrix with corresponding priority weights given to the five factors by one of the experts and their calculated normalized scores. Here, for example, non-residential land uses are weighted two times more important than population density in allocating bus stops, and consequently population density is weighted 0.5 (1/2) times less essential than non-residential land use. In our study, the value of weights ranges from 4 to 1/4, which indicates that the maximum weight given to a factor by the experts is 4. However, the range of weights varies among the experts. For example, Table 2 shows the priority weights of the expert who weighted the factors in the range of 3 to 1/3. After getting the priority weights, we calculated the normalized scores, and priority vector and checked the consistency of the overall comparison matrix as shown in Table 2. The detailed calculation process is discussed in the following sections.

With regard to the number of experts required to carry out AHP appropriately, Saaty did not suggest any specific number of experts to be included [45]. Hamurcu and Eren

Table 2 Correlation between all pairs of five factors

	Population density (in log)	Passenger travel demand	Non-residential land uses	Accessibility of pedestrians	Accessibility of rickshaws
Population density (in log)	1				
Passenger travel demand	0.245	1			
Non-residential land uses	0.373	0.451	1		
Accessibility of pedestrians	0.267	0.312	0.220	1	
Accessibility of rickshaws	- 0.156	- 0.481	- 0.165	- 0.150	1

conducted a study on prioritizing public transportation development projects where the factors were weighted by six experts from the relevant government agencies and academia with more than 15 years of experience working in the public transportation sector [13]. In our study, ten recognized experts in the transportation field assigned priority weights in the pair-wise comparison matrix (which consisted of five factors). We selected these experts from a combination of professionals: transportation engineers, transportation planners from Dhaka Transportation Coordination Authority (DTCA), Roads and Highway Department, Capital Development Authority of Bangladesh, and academicians from the Department of Urban and Regional Planning of various public universities with experience of at least 15 years of work or research across multiple transportation issues of Dhaka.

Computing Normalized Matrix and Priority Vector

We now have ten pair-wise comparison matrices assigned by ten experts. A normalized matrix is produced for each comparison matrix by dividing all the entries in a comparison matrix by the respective column total or column vector. We also computed a row average of weights, which is also called a priority vector. Any entry in the normalized matrix, $a_{Lij} = \frac{a_{ij}}{\text{Column total}}$ and the Row average of weight, $w_{Rij} = \frac{\sum a_{Rij}}{N}$ [46].

Consistency Check of Comparison Matrix

A consistency check is necessary to identify the actual inconsistency in the judgment. The degree of inconsistency is determined to measure the logical inconsistency in the experts' judgment. More compactly, given that "w" is the column vector of relative weights w_i , where $i = 1, 2, 3, \dots, n$,

comparison matrix "A" would be consistent if $Aw = nw$. If a comparison matrix "A" is not consistent, then the relative weight w_i is approximated by the average of the "n" elements of the row "i" in the normalized matrix. If the computed average vector is \bar{w} , then $A\bar{w} = n_{max}\bar{w}$, where $n_{max} \geq n$. The closer n_{max} is to n , more consistent is the comparison matrix "A". Based on this observation, the consistency ratio is measured, $CR = CI/RI$, where CI = Consistency index of $A = \frac{n_{max}-n}{n-1}$ and RI = Random consistency of $A = 1.08 \times \frac{n-2}{n}$. If $CR \leq 0.1$, the level of inconsistency is acceptable and tolerable [35]. In our study, we checked the consistency in an above-mentioned way for all the experts' judgments, which all appeared consistent. A sample calculation of a consistency check is provided in the results section.

Determining Overall Priority of the Factors

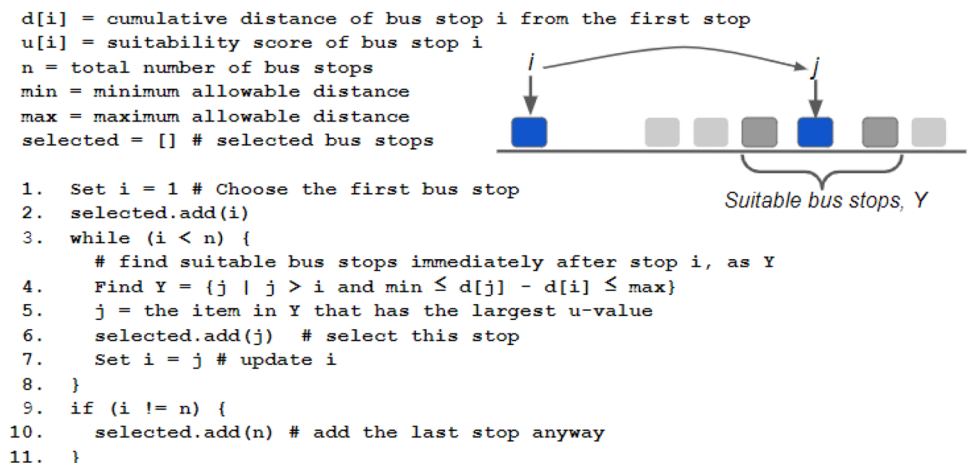
After the consistency check, we determined the overall priority of each factor. For each factor, we calculated a geometric mean of all the corresponding values of the priority vectors (calculated from ten experts' weights).

Computing Suitability Score for Each Intersection

We computed a suitability score for each intersection. A suitability score is defined as the weighted sum of factor (five) values. The reason behind multiplying factor values with respective weight is to prioritize each factor. As discussed, each factor's weight is determined using the AHP technique. Required data for this technique were collected from expert opinion surveys. The following equation defines the suitability score used in this study.

$$u_i = \sum_{j=1}^5 w_j \times v_{ij}$$

Fig. 3 Algorithm for identifying suitable bus stop locations



where, u_i = suitability score at the intersection i w_j = priority weight calculated from experts' opinion for factor j v_{ij} = normalized value for factor j at intersection i

Identification of Suitable BRT Stop Locations

Figure 3 shows the algorithm for identifying suitable bus stop locations (intersections). The algorithm works as follows. It first arranges all intersections in their ascending order of cumulative distance from the first stop. The process then iterates over the intersections one by one (indexed by i) and selects the best suitable intersections as a solution. The process starts with selecting the first intersection ($i = 1$) [line 1 in Fig. 3]. For each last selected intersection (index i), the process finds a set of "suitable" intersections that immediately follow the last selected intersection and those that are within a distance of min and max as specified by the configuration [line 4]. Let this set be Y . If more than one intersection becomes suitable (that is, Y contains more than one element), the intersection with the largest u -value (suitability score) is selected and added to the solution [lines 5–6]. The last selected intersection index is then updated to this selection, and the process continues until all intersections are considered. Suppose the very last intersection of the route is not selected so far. In that case, the last intersection is unconditionally added to the solution [lines 9–10] because the last intersection needs to be selected as a bus stop location.

Most BRT stops are located 500–600 m apart in built-up urban areas. On the other hand, in comparatively lower population density countries, for example, in the US and Australia, the average spacing is considerably longer (1.5 km) [5]. IDTP [47] reports that the spacing ends up between 450 and 500 m (quarter mile) in most contexts. Beyond this, more time is required for bus riders to walk to stations than is saved by higher bus speeds. Below this distance, bus speeds will be reduced by more than the amount of time saved by shorter walking distances. Thus, in keeping reasonably consistent with optimal station spacing, ITDP has suggested average distance between stations should be between 300 and 800 m [48].

In this study, we run the iteration process to select suitable locations of bus stops by specifying different configurations described by the minimum distance between two successive bus stops and the maximum allowable distance between two stops. If bus stops are allocated too close, stops will be underserved, and the operating speed of BRT buses will be negatively affected. On the other hand, if bus stops are allocated too far, there will be access problems for people to reach the stops. We wanted to explore how the selection of bus stops varies as we change the configuration. For example, (300, 800) meter configuration implies that no bus stop should be selected less than 300-m distance from

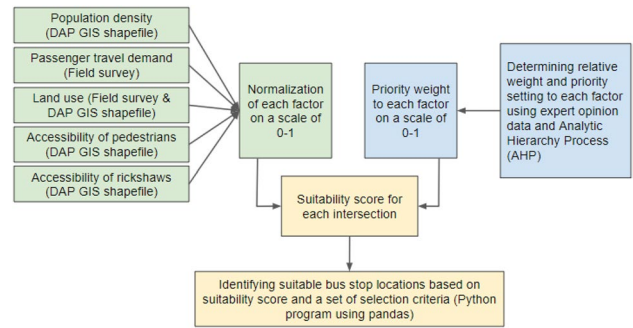


Fig. 4 Conceptual framework to identify suitable bus stop locations for BRT

the immediate prior bus stop. Also, the distance should not exceed more than 800 m. We tried several other configurations as well to select the bus stops, such as (300, 1200), (300, 1500), (400, 1200), and (400, 1500) meters. The complete conceptual framework used in this study to identify suitable locations for bus stops is shown in Fig. 4.

Determining Journey Speed of the BRT

According to DTCA, it will require 42 min = 2520 s for a BRT bus to travel between two terminal points of BRT Line 3, excluding dwelling time on bus stops [15]. DTCA has considered 20 s of dwelling time for each bus stop; if total "n" bus stops are provided along the route, total dwelling time will be 20n seconds. BRT buses will not stop for any other reasons.

Total journey time $TT = 2520 + 20n$ seconds = $\frac{2520+20n}{3600}$ hours.

As BRT Line 3 is 22.4 km long, journey speed = $\frac{22.4}{TT}$ = $\frac{22.4}{\frac{2520+20n}{3600}}$ km/hr.

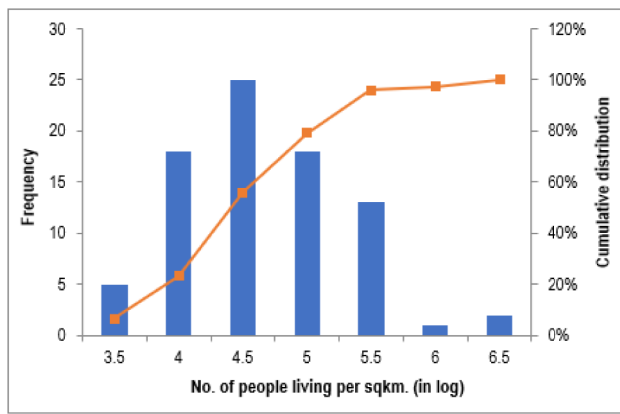
DTCA mentioned that BRT bus stops will be allocated to maintain at least a journey speed of 23 km/h, considering total dwelling time [15].

Results and Discussion

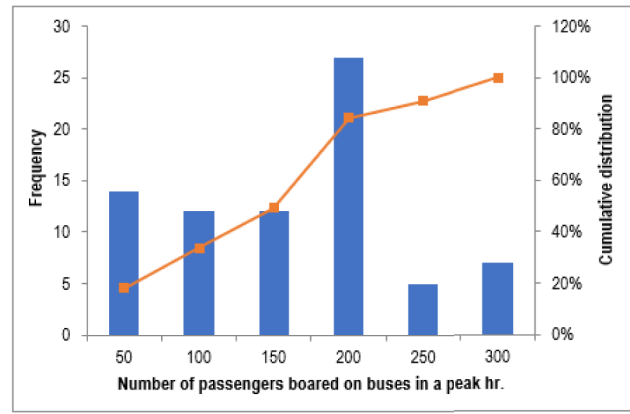
This section discusses the field survey data, priority scores from the expert survey, and a discussion on the suitable location of bus stops.

Data on Five Identified Factors

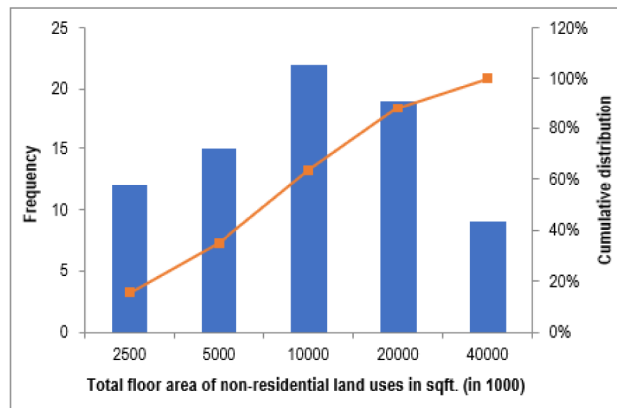
Figure 5 shows the histogram and cumulative distribution function (CDF) of the five factors for all 77 intersections. One common observation is that all five factors have unimodal distributions (one peak in their histogram). Figure 5a shows the histogram of population density measured in the



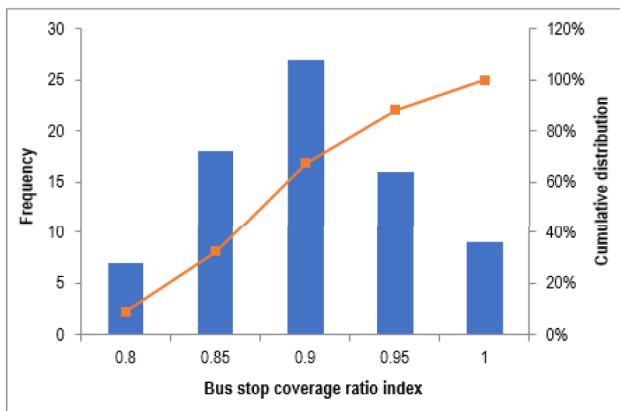
(a) Population density



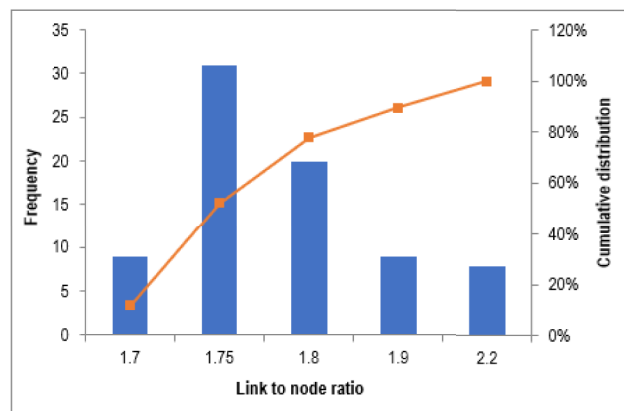
(b) Passenger travel demand



(c) Non-residential land uses



(e) Accessibility of pedestrians



(d) Accessibility of rickshaws

Fig. 5 Histogram for five identified factors

logarithm of population density (number of people per square kilometer). Since population density varies in a wide range (some values are way higher than the rest of the values), we took a logarithm to offset the large variation. This is natural to observe in the context of a crowded city like Dhaka that some intersection points may be way more crowded than others, as the population is not uniformly distributed but rather skewed in the areas. We observe that around 20% of

intersections serve less than 10,000 (10^4) people per square kilometer, whereas 95% of intersections serve less than 10^6 (1 million people) per square kilometer. Exactly three intersections serve more than 1 million people per square kilometer.

Figure 5b plots the distribution of the number of passengers boarded on buses during peak hours across the intersections, and we note that the median value is 140. We observe that 25 intersections are located in a location

where nearly 200 people ride on buses during peak hours, whereas 80% of intersections have this value less than or equal to 200. Furthermore, the total floor area of non-residential land use varies from 2500 thousand to 40,000 thousand square kilometers (Fig. 5c), and the overall distribution appears to be quite normal-like bell-shaped across the intersections. Figure 5d and Fig. 5e display the degree of accessibility of pedestrians and rickshaws, respectively that the candidate intersection locations offer. This accessibility is measured in the bus stop to coverage ratio and link of node ratio, respectively. The median accessibility indices are 0.855 and 1.74, respectively. We notice that around 70 percent of intersections have a bus stop to a coverage ratio of less than 0.9, whereas 80 percent of intersections have a link to node ratio of less than 1.8. All intersections have pedestrian accessibility equal to or higher than 0.8, and no intersections are observed to have a rickshaw accessibility index less than 1.7.

Table 2 shows the correlation between all pairs of these five factors. We observe that all pairs of factors have positive correlations except the rickshaw accessibility index, which has negative correlations with the other factors. Population density is positively correlated with land use, whereas higher land use leads to higher travel demand. It indicates that more bus trips are generated in areas where more people reside. Highly dense areas have fewer road networks for non-motorized vehicles, so rickshaw accessibility decreases with a higher density of population (correlation -0.156). Again, the areas with higher rickshaw accessibility generate less travel demand by buses (correlation is negative). This is because there can be other modes of transportation available (private cars or others) in those areas, so fewer people make bus trips. Similarly, in the locations where rickshaw accessibility is low, more people tend to travel by bus because there are no other better options.

Priority Weight Value for Each Factor

After collecting data on five factors, we normalized the factor values. Then we prioritized the factors based on their degree of importance by applying the Analytical Hierarchy Process (AHP). According to AHP, pairwise comparison matrices between factors are developed based on ten experts' judgments (step 1). A normalized matrix is then produced for each of the comparison matrices by dividing all the entries in a comparison matrix by the respective column total (step 2). After that, we calculated the priority vector by dividing the row total by the number of factors (step 3). We also checked the degree of inconsistency in the judgments and found all the inconsistencies within an acceptable limit (step 4). Finally,

we calculated the *priority weight* of each factor (step 5). The detailed step by step process of this calculation is discussed in the methodology section (Sections “[Determination of weights for Factors from Expert Judgement](#)”, “[Computing Normalized Matrix and Priority Vector](#)”, “[Consistency Check of Comparison Matrix](#)”, “[Determining Overall Priority of the Factors](#)”).

Table 3 shows a detailed calculation of all steps for one of the experts as a sample. The first 5×5 matrix represents the pairwise priority weights given to the five factors by the sample expert. The second 5×5 matrix shows the normalized score of each of the cells of the first matrix. As mentioned, the normalized score of each of cell in the second matrix was calculated by dividing the value of each cell of the first matrix by the respective column total of that matrix. For example, in the second matrix's first cell, the value 0.25 was calculated by dividing 1 (first cell of the first matrix) by 4 (first column total of the first matrix). The column titled “row total” was computed by summing up the values of each corresponding row of the second matrix. For instance, the first cell of the “row total” column 1.26 was the summation of 0.25, 0.30, 0.33, 0.11, and 0.27. The priority vector was then calculated by dividing the values of the row totals by the number of factors (e.g., the first cell of this vector is: $1.26/5 = 0.25$). We then checked the degree of inconsistency in the judgments. For example, the consistency measure for the factor population density was calculated in the following way:

$$\text{Consistency Measure for Population Density} = \frac{(1 \times 0.25 + 1 \times 0.29 + 2 \times 0.19 + 2 \times 0.14 + 1 \times 0.12)}{0.252} = 5.268$$

$$n_{max} = \frac{5.268 + 5.303 + 5.322 + 5.285 + 5.218}{5} = 5.27$$

$$CI = \frac{5.27 - 5}{5 - 1} = 0.069$$

$$Forn = 5, RI = 1.12$$

$$CR = \frac{0.069}{1.12} = 0.062$$

As $CR < 0.1$, pairwise matrix is consistent.

The consistency measures were calculated for other factors as well in the same way (shown in Table 2). The step-by-step calculation was repeated for all ten experts. The calculated priority vectors of all the experts are shown in Table 4. Last, we calculated the final priority weight of each factor by taking the average of the priority weight values of the ten experts. For example, the final priority weight of population density is:

$$\frac{0.25+0.28+0.30+0.22+0.18+0.25+0.25+0.22+0.27+0.25}{10} = 0.2447$$

Table 3 Sample calculation of priority vector based on one of the expert’s pairwise comparison matrix

Factors	Pairwise weightage		Normalized score						Row total	Priority vector (Row total/ no. of factors)	Consistency measure		
	Population density	Passenger travel demand	Non-residential land uses	Accessibility of pedestrians	Accessibility of rickshaws	Population density	Passenger travel demand	Non-residential land use				Accessibility of pedestrians	Accessibility of rickshaws
Population density	1	1	2	1	2	0.25	0.30	0.33	0.11	0.27	1.26	0.25	5.268
Passenger travel demand	1	1	2	3	2	0.25	0.30	0.33	0.33	0.27	1.48	0.30	5.303
Non-residential land uses	0.5	0.5	1	2	2	0.13	0.15	0.17	0.22	0.27	0.93	0.19	5.322
Accessibility of pedestrians	1	0.33	0.5	1	0.5	0.25	0.10	0.08	0.11	0.07	0.61	0.12	5.285
Accessibility of rickshaws	0.5	0.5	0.5	2	1	0.13	0.15	0.08	0.22	0.13	0.71	0.14	5.210
Column total	4	3.33	6	9	7.5								

Table 4 Priority weight (mean) of each factor based on experts’ opinion

Factors	Priority vector calculated from ten experts’ opinion										Geometric mean
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	
Population density	0.25	0.28	0.30	0.22	0.18	0.25	0.25	0.22	0.27	0.25	0.2447
Passenger travel demand	0.30	0.18	0.31	0.27	0.34	0.25	0.25	0.24	0.27	0.23	0.2598
Non-residential land uses	0.19	0.21	0.17	0.24	0.24	0.17	0.19	0.17	0.18	0.13	0.1852
Accessibility of pedestrians	0.12	0.23	0.10	0.19	0.14	0.18	0.20	0.20	0.15	0.28	0.1715
Accessibility of rickshaws	0.14	0.10	0.13	0.09	0.10	0.16	0.12	0.17	0.12	0.10	0.1204

Suitable Locations of BRT Bus Stops

Next, we computed the suitability score for each intersection. Then, we ran the program to identify suitable locations for BRT bus stops. We ran the iteration process to select suitable locations of bus stops by specifying different configurations (detailed discussion in the methodology section. The output of the program for different configurations is shown in Table 5.

According to Table 5, the average distance between two stops and operation speed is the lowest (560 m and 24.78 km/h) in the (300, 800) meter configuration, and the number of bus stops is the highest among other configurations. On the other hand, the lowest number of bus stops and operating speed is found for the (300, 1200) configuration while the average distance is highest for it. Constraints should be fixed in such a way so that a balance can be established between the choice of the number of stops (related to the economic constraints) and the average spacing between stops. The possible feasible configurations of distances for BRT Line 3 to maintain a journey speed of 23 km/h (recommended by DTCA) while not exceeding the average distance between bus stops of 800 m (recommended by ITDP) are configuration ID 1–9. Configuration ID 10–16 reveals possible configurations of bus stop distances where the average distance is above 800 m and does not align with ITDP’s recommendation. But, configuration ID 16 will provide a higher speed. A sample illustration of BRT bus stop locations at (300, 1200) configuration is shown in Fig. 6.

Comparison of Proposed Bus Stop Allocation Method that of Concerned Authority

This section compares the methods of identifying bus stop locations between the concerned authority and this study. In this study, we identified suitable bus stop locations based on the composite value determined through AHP by combining the five factors while maintaining a balance between operating speed and accessibility. On the contrary, DTCA, the concerned authority for designing and implementing BRT in Dhaka, prioritized travel demand to allocate bus stops. DTCA showed a preference for intersections along with land use features with high trip generation potentials such as stadiums and airports to allocate bus stops [15]. They did not consider the trip generation potential of other surrounding land uses in allocating bus stops. Our study considers trip generation potential for all surrounding land uses. DTCA has emphasized accessibility for pedestrians but in terms of installing new overpass, underpass, and foot over-bridge after choosing bus stop locations [15]. They did not consider the existing road network, which ensures better accessibility at a lower expenditure. They also ignored accessibility for rickshaws as a factor in determining BRT bus stop locations.

Table 5 Number of stops and the average distance between stops at different constraints

ID	Distance between intersections (maxi- num, minimum)	Number of bus stops	Average distance (meter)	Speed (km/hr.)
1	(300, 800)	40	560	24.28
2	(300, 900)	34	658	24.73
3	(300, 1000)	35	640	25.04
4	(300, 1100)	32	700	25.51
5	(300, 1200)	28	799	26.18
6	(400, 800)	35	658	24.8
7	(400, 900)	32	622	24.8
8	(400, 1000)	30	746	25.4
9	(400, 1100)	31	722	25.68
10	(300, 1300)	27	829	26.35
11	(300, 1400)	27	829	26.35
12	(300, 1500)	24	933	26.87
13	(400, 1200)	27	829	26.35
14	(400, 1300)	26	861	26.52
15	(400, 1400)	25	895	26.7
16	(400, 1500)	23	973	27.06

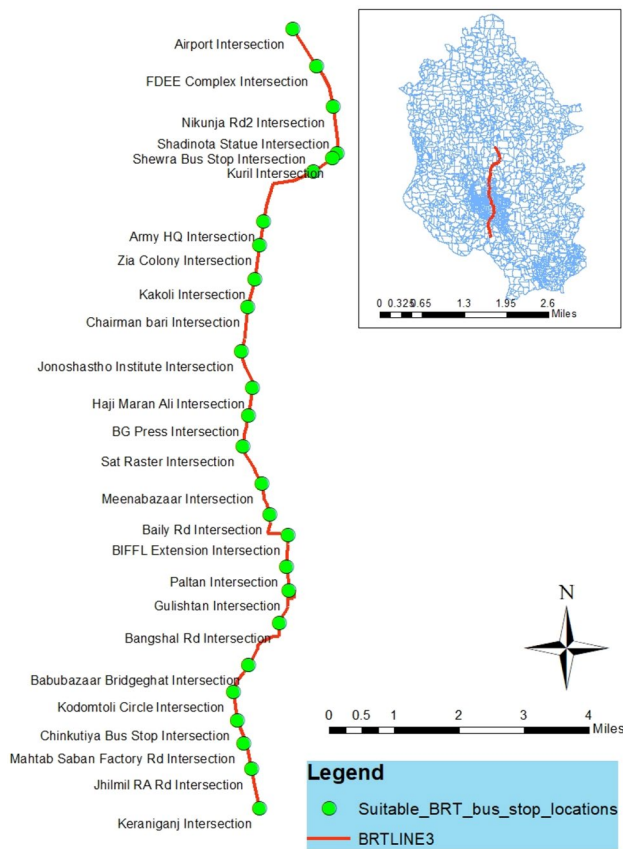


Fig. 6 Suitable BRT stop locations at (300, 1200) meters constraints

DTCA has suggested 16 bus stops maintaining an average distance of 1500 m among two consecutive bus stops, which is very high in the context of a highly dense urban area like Dhaka. Besides, when the average distance between bus stops is high, it will reduce accessibility for pedestrians. We suggest feasible solutions for maintaining the average distance between bus stops below 800 m. We propose different numbers of bus stops that can be provided while maintaining a balance between accessibility and speed. Based on the availability of funding, a decision can be taken on how many bus stops are to be provided (Table 6).

Conclusions

This paper proposed a bus stop selection technique based on multi-factor analysis. We identified that five determinant factors, including population density, passenger travel demand, land use, accessibility of pedestrians, and accessibility of rickshaws affect the choice of the possible locations of bus stops for a mass rapid transit route. While these five factors influence the suitability of a candidate intersection to be chosen as a bus stop, their contribution to the choice is not uniform; instead,

they have varying contributions. We conducted an opinion survey on experts and derived the relative weights of these factors by applying the Analytical Hierarchical Process (AHP). With that, we compose a suitability score for each intersection point and choose the locations that have the largest sum of these scores subject to the inter-bus stop spacing constraint. We applied the technique to 77 intersections of a proposed BRT route in Dhaka city (BRT Line 3 proposed in STP, 2005) and identified 25–40 suitable locations as bus stops.

Although this study considered five factors for determining bus stop location, it can be expanded to any number of relevant factors. The methodology followed in this study can also be applied to allocate bus stops on new bus routes and relocate bus stops in suitable locations on future bus routes for Dhaka as well as any other city in the world. As the study is not focused on design aspects of bus stops, physical and operational features are not included as factors. According to the layout plan of BRT stops, the issue of availability of pedestrian crossing and traffic signals, visibility, and safety will be addressed by installing the required amenities. For this, they were not considered as a factor influencing the bus stop locations of BRT Line 3. Separate studies can be conducted incorporating the perception of people living in the surroundings of BRT Line 3 regarding the visibility and safety of the intersections. As there are no designated rickshaw stops in Dhaka city, the location of rickshaw stops could not be considered a factor in allocating bus stops. Future studies can be conducted considering the travel time of bus riders to reach bus stops and network-based accessibility features in determining BRT bus stop locations. The study was focused on developing an efficient methodology to allocate bus stops. For this, issues such as transport equity was not taken into consideration while comparing methods followed by DTCA and this study. Research can also be conducted to allocate bus stops from the perspective of transportation equity, the potential of transit-oriented development, and the integration of non-BRT services in the context of Dhaka.

Due to time and resource constraints, this study is only limited to the current bus riders as a representation of passenger travel demand. However, we believe that the relative scores of the factors among the bus stop locations (intersections) play a more significant role than the absolute scores of the factors at an intersection. In addition, since this study involved extensive field survey in collecting data on five factors along the 77 intersections, due to the financial and human resource constraints, we could not collect data for the whole route of BRT Line 3 (Gazipur to Jhilmil) and thus, ended up considering only the Airport to Jhilmil section of BRT Line 3 as the study route. We believe that bus stops can be allocated in the rest of the section of BRT Line 3 by following the methodology discussed in this study. It can be concluded that the proposed way of selecting bus

Table 6 Comparison of methods followed by DTCA and this study in allocating bus stops for BRT Line 3

Aspects	DTCA [15]	Proposed methodology
Defined framework followed	No	Yes
Factors	Travel demand	Travel demand, population density, land use characteristics, accessibility for pedestrians and rickshaws
Trip generation potential of land uses	Priority is given to allocating bus stops close to major trip generators. The trip generation potential of residential and other land uses has not been taken into consideration	The trip generation potential of surrounding land uses (residential and others) has been considered thoroughly
Accessibility	Accessibility to BRT stops will be improved through infrastructure development. Accessibility of road networks has not been considered	Network-based accessibility of pedestrians and rickshaws has been integrated
A balance between pedestrian accessibility and speed	Cannot be maintained	Proposes several configurations to maintain a balance between pedestrian accessibility and speed

stops provides better efficiency and transit experiences to city dwellers compared to DTCA's method, particularly in terms of maintaining a balance between speed and accessibility. It will also help transit authorities and government agencies to allocate bus stops systematically.

Acknowledgements We would like to thank Mr. ABM Sertajur Rahman, Executive Engineer at Roads and Highways Department, Bangladesh for providing his valuable suggestions and supplementary materials. We also acknowledge Mr. Md Takmil Sakir, Engineer at Bangladesh Power Development Board for his help in developing the python code.

Data availability Data is collected with the assistance of Bangladesh of University of Engineering and Technology. We regretfully inform you that it is not possible to share the data.

References

- World Population Review. Dhaka Population. Available from: <https://worldpopulationreview.com/world-cities/dhaka-population>. Accessed Jan 2021
- GDSUTP (2021) Greater Dhaka Sustainable Urban Transport Project Volume-2 (BRT Gazipur to Airport). Advanced Logistics Group, BETS Consulting Services Ltd. and Transport Metropolitan de Barcelona, S.A. funded by Asian Development Bank
- STP (2005) The Strategic Transport Plan (STP) for Dhaka—Final Report. Dhaka Transport Coordination Authority (DTCA), Government of the People's Republic of Bangladesh
- RSTP (2016) The Revised Strategic Transport Plan (STP) for Dhaka—Final Report. Dhaka Transport Coordination Authority (DTCA), Government of the People's Republic of Bangladesh
- Cervero R (2013) Bus rapid transit: an efficient and competitive mode of public transport. Institute of Urban and Regional Development, University California Berkeley, Berkeley
- Wright L, Hook W (2007) Bus rapid transit planning guide. Institute for Transportation and Development Policy, New York
- Transport for London (2006) Accessible bus stop design guidance. Bus Priority Team technical advice note BP1/06, Bus Priority Team Transport for London, Victoria Street, London, UK
- Rahman MS, P Timms, F Montgomery (2012) Integrating BRT Systems with Rickshaws in Developing Cities to Promote Energy Efficient Travel. Presented at Euro Working Group on Transportation International Science Conference, Paris, France
- APTA (2010) Bus Rapid Transit Service Design. Bus Rapid Transit Working Group, APTA standards development program, American Public Transportation Association (APTA), Washington, USA
- APTA (2012) Design of On-street transit stops and access from surrounding areas. American Public Transportation Association (APTA), Washington, p 2012
- Ahsan N (2014) Evaluation of Bus Stop Accessibility and Determination of Optimal Locations for Bus Stops-A GIS Based Approach, Unpublished Master's Thesis, Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
- Banai R (2006) Public transportation decision-making: a case analysis of the Memphis light rail corridor and route selection with analytic hierarchy process. *J Public Transp* 9(2):1–24
- Hamurcu M, Eren T (2020) Strategic planning based on sustainability for urban transportation: an application to decision-making. *Sustainability*. <https://doi.org/10.3390/su12093589>
- Giachomini C, Lonro G, Lunardi A, Padoano E (2016) Applications and theory of analytic hierarchy process—decision making for strategic decisions. InTech Open, London
- DTCA (2013) BRT and Corridor Restructuring Implementation Study and Preliminary Design work for the Uttara – Mohakhali – Ramna – Sadar Ghat Corridor in Dhaka, report on final preliminary design, Clean Air and Sustainable Environment Project. World Bank and Dhaka Transport Coordination Authority (DTCA), Government of the People's Republic of Bangladesh
- Lindau LA, Hidalgo DH, Lobo ADA (2014) Barriers to planning and implementing bus rapid transit systems. *Res Transp Econ* 48:9–15
- Carrigan A, King R, Velasquez JM, Raifman M, Duduta N (2017) Social, environmental and economic benefits of BRT systems: bus rapid transit case studies around the world. World Resources Institute, Washington
- Guha R (2011) Pre-Feasibility of Bus Rapid Transit (BRT) and Metro Rail in Old Dhaka. Unpublished B.Sc. Thesis, Department of Civil Engineering, Bangladesh University Engineering and Technology
- Transit Cooperative Research Program (1996) Guidelines for the Location and Design of Bus Stops. TCRP Report 19.

- Transportation Research Board, National Research Council, USA
20. Jahani M, Hashemi SM, Ghatee M, Jahanshahi M (2013) A novel model for bus stop location appropriate for public transit network design: the case of central business districts (CBD) of Tehran. *Int J Smart Electr Eng* 2:133–141
 21. Islam MR, T Rahman, S Das, S Sanain, MR Islam (2014) Determining Suitable Bus Stop Location Using Geographic Information System in Kaptai Road, Chittagong. Proceedings of the 2nd International Conference on Civil Engineering for Sustainable Development (ICESD-2014), Khulna, Bangladesh
 22. Furth P, Rahbee A (2000) Optimal bus stop spacing through dynamic programming and geographic modeling. *Transp Res Rec* 1731:15–22
 23. George KA (1999) Transportation compatible land uses and bus-stop location. *Trans Built Environ* 41:459–469
 24. Cooper EM (2011) Planning for Stop Spacing under the San Francisco. Municipal Transportation Agency Bus Stop Consolidation Proposal. Unpublished Master's Thesis, California Polytechnique State University, USA
 25. Xiuben W (2010) Optimizing bus stop locations in Wuhan, China. Unpublished Masters Thesis, International Institute of Geo-information Science and Observation, Netherlands
 26. Gauncha DAG, Mejia JAS, Mejia SA (2016) Appropriate frequency allocation for a BRT system through a multi-objective model. *Revista EIA* 13(26):141–152
 27. Behal D, Kuman S, Tiwari G (2017) Determination and analysis of informal public transport stops. *IATSS Res* 44(1):36–54
 28. Johnson A (2003) Bus transit and land use: illuminating the interaction. *J Public Transp* 6(4):21–39
 29. Saghapour T, Moridpour S, Thompson RG (2016) Public transport accessibility in metropolitan areas: a new approach incorporating population density. *J Transp Geogr* 54:273–285
 30. Lyu Y, Chow YC, Lee VCS, Ng JKY, Li Y, Zang J (2019) CB-planner: a bus line planning framework for customized bus systems. *Transp Res Part C* 101:233–253
 31. Ahmed T, Mitra SK, Rafiq R, Islam S (2020) Trip generation rates of land uses in a developing country city. *Transp Res Rec* 2674(9):412–425
 32. VRT (2016) Bus stop location and transit amenities development guidelines. Valley Regional Transit, Idaho
 33. Vergel-Towel CE, Rodriguez DA (2018) The ridership performance of the built environment for BRT systems: evidence from Latin America. *J Transp Geogr* 73:172–184
 34. Hsiao S, Lu J, Sterling J, Weatherford M (1997) Use of geographic information system for analysis of transit pedestrian access. *Transp Res Rec* 1604(1):50–59
 35. Foda MA, Osman AO (2010) Using GIS for measuring transit stop accessibility considering actual pedestrian road network. *J Public Transp* 13(4):23–40
 36. Mohiuddin H (2021) Planning for the first and last mile: a review of practices at selected transit agencies in the United States. *Sustainability* 13(4):1–20
 37. Fjellstrom K, Duan X (2009) Bus Rapid Transit in the People's Republic of China. Asian Development Bank, Metro Manila
 38. Duarte F, Rojas F (2012) Intermodal connectivity to BRT: a comparative analysis of Bogotá and Curitiba. *J Public Transp* 15(2):1–18
 39. DHUTS (2010) Preparatory Survey Report on Dhaka Urban Transport Network Study (DHUTS), Final Report. Japan International Co-operation Strategy (JICA)
 40. RAJUK (2010) dhaka metropolitan development plan (1995–2015): detailed area plan (DAP). Rajdhani Unnayan Karttripakkha (RAJUK), Dhaka
 41. Ewing R, DeAnna M, Li SC (1996) Land use impacts on trip generation rates. *Transp Res Rec* 1518(1):1–6
 42. Limapornwanitch K, Montalbo CM Jr, Hokao K, Fukuda A (2005) The implementation of traffic impact assessment in Southeast Asian cities: case studies of Thailand and the Philippines. *J East Asia Soc Transp Stud* 6:4208–4223
 43. Handy S, Butler K, Paterson RG (2003) Planning for street connectivity—getting from here to there. American Planning Association, Chicago
 44. Tal G, Handy S (2011) Measuring non-motorized accessibility and connectivity in a robust pedestrian network. University of California Davis, Institute of Transportation Studies, Davis
 45. Saaty TL (2008) Decision making with the analytic hierarchy process. *Int J Serv Sci* 1(1):83–98
 46. Taha HA (2017) Operations research: an introduction, vol 790. Pearson/Prentice Hall, New Jersey
 47. ITDP. *The BRT Standards*. Institute for Transportation and Development Policy (ITDP). 2013. <https://brtguide.itdp.org/branch/master/guide/service-planning/deciding-on-stop-elimination-and-express-services#station-spacing-and-station-elimination>. Accessed 1 July 2020
 48. ITDP. About the BRT Standard: The Score card. 2020. <https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/the-scorecard/>. Accessed 1 July 2020

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.