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Locating Bus Rapid Transit Stops Using GIS And AHP: The Vo Van Kiet - Mai Chi Tho Route In Ho Chi Minh City

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Abstract

Bus Rapid Transit (BRT) is one of public vehicle systems in modern cities to provide transportation services fast, confortable, and cost saving. However, effectiveness of one BRT route depends on the locations of its stops. This study focuses on determining optimal locations to build the stops of a BRT route. Firstly, criteria having influences on effective operation of a BRT stop are explorered, consisting of i) traveling demands, e.g. buildings, offices, industrial parks, hopitals, etc; ii) public transportations, e.g. metro stations, bus stops, etc; and iii) roads, e.g. crossroads, parking lots, etc. Secondly, each criterion is assigned a weighted factor representative for its influence, determined by the AHP method. Finally, the progress of data processing in GIS environment is established to create a weighted overlay map from all criteria. Subsequently, locations having high values are reasonable to build BRT stops. This progress has been applied to locate BRT stops of the Vo Van Kiet – Mai Chi Tho route in Ho Chi Minh City. The result indicates 40 BRT stops along this route, and it is considered as a scientific reference to help the city government in decision making.

Keywords: GIS; AHP; BRT; Bus stop; Ho cChi Minh City

1. Introduction

Ho Chi Minh City (HCMC) is the important socio-economic center and also have the most densely population of Vietnam. Following to the city government’s statistics (UCCI, 2015), the population was about 8 million people in 2014 and will increase more than 10 million people in 2020. The population growth makes the city to face risks and challenges, in which particularly urban transportation is considered a primary challenge. At present, more than 80% of the HCMC citizen use motobikes as main. UCCI (2015) also indicated that HCMC had over 6 millions of motorbikes and approximately 586 thoudsands of cars in 2014. These cause serious problems in urban, e.g. environmental pollution, traffic jam, or traffic accident, affecting the citizen’s health and safety. To improve the quality of transportation systems, HCMC has focused on building the metro system, replanning current bus network, and developing the rapid bus system.

Bus Rapid Transit (BRT) is one of public vehicle systems in modern cities to provide transportation services fast, confortable, and cost saving. It is operated on separate lines. To establish a BRT system, determining bus routes and optimal BRT stops need to be studied. Subsequently, locating a BRT stop plays an important role. If BRT stops are at appropriate locations, they will attract a large number of passengers using the BRT system. This is expected to reduce traffic jams, traffic accidents, or environmental pollution (HCMPC, 2010).

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Choosing locations to set up BRT stops is dependent on many different criteria, such as traveling demands, urban transportation, culture, socio-economy, ect. The Analytic Hierarchy Process (AHP) method is useful to determine weights of the criteria. Additionally, Geographic Information Systems (GIS) provides geospatial analysis tools to overlay input data to choose optimal locations. Therefore, this paper focuses on using GIS and AHP to locate BRT stops, in case study of the Vo Van Kiet - Mai Chi Tho route in HCMC.

2. Factors affecting on a BRT stop

Choosing a BRT stop is affected by natural, socio-economic, and traffic infrastructure factors. Natural factors include topography, geomorphology, hydrology, etc For example, terrain surface is critical to place BRT stops, i.e. it is not too steep, not too low and not obstructed to ensure safety for passengers. Socio-economic factors consist of residential and traditional buildings, cultural, religious educational and healthy regions, industrial parks, amusements and sports. These are locations with a lot of travelling demands. Traffic infrastructure factors involve metro stations, current bus stops, water transport stations, overpasses, pedestrian bridges, intersections, and parkings. There are a lot of transiting demands between public vehicles. However, according to the AHP method, these factors have to be quantified into specific criteria (Hook, 2012).

3. The progress of choosing BRT stops

The progress of choosing BRT stops consists of six basic steps as following:

1) Identifying the target, collecting relevant data in case study. Data should be collected include i) the documents and statistic tables, e.g. travelling demand, socio-economy and transportation, and ii) geospatial data, e.g. digital layers, paper maps, etc preresentative for objects which affect the locating of BRT stations.

2) *Preparing input data.* Using GIS tools to manipulate the collected data, e.g. coordinate system conversion, format conversion, geometric correction, filling attribute, etc to creat an input dataset.

3) Defining criteria for BRT stops. Based on the factors affecting a BRT stop, the criteria are defined, dependent on characteristics of each study area. For example, for a BRT system built in flat terrain regions, topographic factors can be ignored. The criteria are quantified from the factors. For example, distances of 0-200 m, 200-400 m, 400-500 m, and over 500 m, corresponding passenger-walking distances from a residential area to a BRT stop are assigned values of 3, 2, 1, and 0, respectively. Based on the criteria, appropriate GIS data layers are created.

4) Grouping criteria, establishing comparision matrices and computing weights of the criteria. The weight of each criterion is computed using the AHP method (Saaty, 2008). Usually a set of criteria will be grouped into few common criteria, corresponding to major aspects, and each common criterion consists of some specific criteria, as considered minor aspects. Comparison matrices or priority matrices are established based on experts' experience and knowledge in urban transportation and planning. The critical levels between the criteria are refereced following to Saaty' relative importance classification. Weights for the criteria are determined by the following steps: i) weight of each common criterion, ii) weight of each specific criteria belonging to each common criterion, and iii) weigh of each criterion.

5) Using GIS tools to analyze the input data. Two main tools are buffer and overlay (union) analysis (ESRI, 2013). The buffer tool supports to create a new layer from a input layer following to the defined distances. Accordingly, the values of priority levels are assigned to bufferred distances (see Step 3). For example, bufferred distances {0-200, 200-400, 400-500, 500-1000} m, representative for passenger-walking capabilities to a BRT stop from a residential area. Meanwhile, the union tool is applied to superimpose two or more layers to create a new layer containing all the attributes of all input layers. For example, a location can be identified based on conditional distances of 250 meters from a residential area and of 50 meters from a road intersection. In addition, ArcGIS Model Builder supports to automatically perform this process.

6) Locating BRT stops. After superimposing together all the layers with the weights, the output layer indicates optimal values to select BRT stops.

4. Determining BRT stops on the Vo Van Kiet – Mai Chi Tho route

4.1. The Vo Van Kiet – Mai Chi Tho route

The Vo Van Kiet – Mai Chi Tho avenues in HCMC, aslo called the East-West Highway, has a total length of 24.92 km, from the intersection of the Hanoi highway (District 2) and 1A Highway (District Binh Chanh). This route passes through 1, 2, 5, 6, 8, Binh Tan and Binh Chanh districts, as described in Fig. 1. The Vo Van Kiet - Mai Chi Tho avenues has just been renovated ad extended. At present, this route connects the northeast and the southwest of HCMC. It contributes to improve the HCMC urban traffic system.

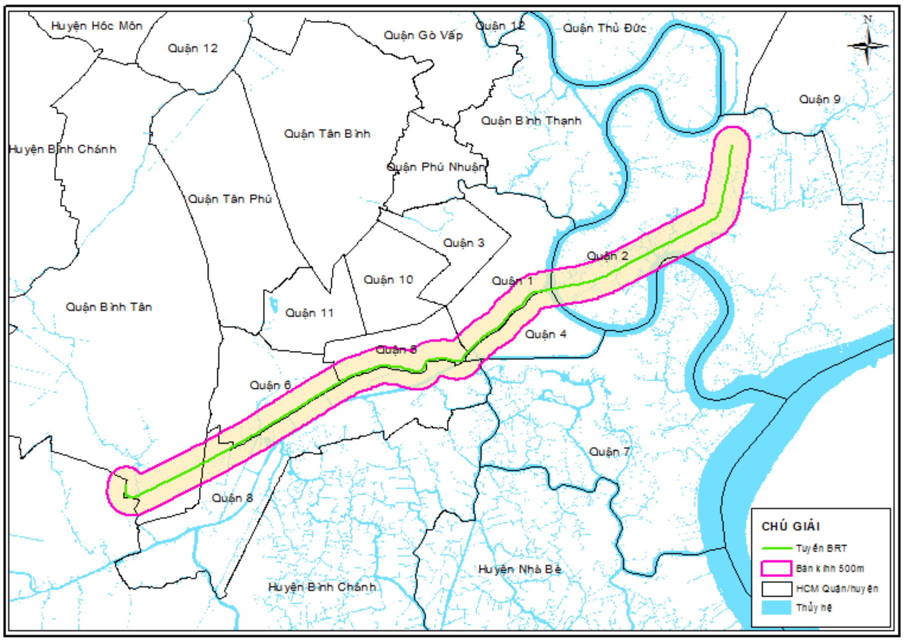

Fig. 1. The BRT route on the Vo Van Kiet – Mai Chi Tho avenues

4.2. Criteria to choose the BRT stops

Based on charasteristics of the Vo Van Kiet – Mai Chi Tho avenues, we suggest three common criteria as following.

- Travelling demand: this criterion is the most important to choose BRT stops. It plays an important rule to the BRT route's effective operation.
- Public transportation: they are public vehicles serving a large number of passengers, including metro stations, bus stops, and piers.
- Road system: here are locations where many passengers can transit from a public vehicle to another, such as pedestrian bridges, intersections, and parkings.

Subsequently, criteria to choose BRT stops on the Vo Van Kiet – Mai Chi Tho route are described in Table 1.

Table 1. The criteria to choose BRT stops on the Vo Van Kiet – Mai Chi Tho route

Common criteria	Specific criteria	Passenger-walking distance to a BRT stop
I. Travelling demand	I.1. Residential buildings	Maximum 500 m (Hook, 2013)
	I.2. Official and traditional buildings	
	I.3. Cultural and educational regions	
	I.4. Hopitals and healthy centers	
	I.5. Religious constructions	
	I.6. Parks and sports	
II. Public transportation	II.1. Metro station	Maximum 500 m (Hook, 2013)
	II.2. Bus stop	
	II.3. Pier	
III. Road system	III.1. intersection with overpass bridges	Maximum 500 m (Hook, 2013)
	III.2. Intersection with pedestrian bridges	
	III.3. Intersection	
	III.4. Parking	

4.3. Comparision matrices and weights

The critical levels between the criterian are determined using experts' experience and knowledge in regional development planning, urban planning, construction management, and transportation infrastructure management. Results surveying from nine experts indicated that most of their opinions was similar and gave the level values following to Saaty's rules, as shown in Table 2.

Table 2. Comparison matrices of a) common criteria, b) specific criteria of the travelling demand, c) specific criteria of the public transportations, and d) specific criteria of the road system

a)

	I	II	III
I	1	3	5
II	1/3	1	3
III	1/5	1/3	1

c)

	II.1	II.2	II.3
II.1	1	4	6
II.2	1/4	1	3
II.3	1/6	1/3	1

b)

	I.1	I.2	I.3	I.4	I.5	I.6
I.1	1	1	3	3	7	5
I.2	1	1	3	3	7	5
I.3	1/3	1/3	1	1	5	3
I.4	1/3	1/3	1	1	5	3
I.5	1/7	1/7	1/5	1/5	1	1/3
I.6	1/5	1/5	1/3	1/3	3	1

d)

	III.1	III.2	III.3	III.4
III.1	1	1/4	1/3	1/5
III.2	4	1	1/2	1/3
III.3	3	2	1	1/2
III.4	5	3	2	1

As a result, the weight of each criterion is computed by mean of C = A*B, as shown in Table 3. Here, column C is the weight of each criterion to choose a BRT stop, column A is the weight of the common criteria and column B is the weight of the specific crriteria. Consistency ratios of comparision matices of a) common criteria, b) specific criteria of the travelling demand, c) specific criteria of the public transportations, and d) specific criteria of the road system (see Table 2) are also calculated and the results of $CR_A = 0.037$; $CR_{B\_I} = 0.025$, $CR_{B\_II} = 0052$, and $CR_{B\_III} = 0.045$, respectively, indicate that comparison matices are reasonable.

Table 3. The weight of the criteria to choose a BRT stop

Common criteria	A	Specific criteria	B	C
I	0.633	I.1	0.318	0.201
		I.2	0.318	0.201
		I.3	0.135	0.085
		I.4	0.135	0.085
		I.5	0.033	0.021
		I.6	0.063	0.040
II	0.261	II.1	0.685	0.179
		II.2	0.221	0.058
		II.3	0.093	0.024
III	0.106	III.1	0.076	0.008
		III.2	0.191	0.020
		III.3	0.264	0.028
		III.4	0.470	0.050

4.4. Input data

Following to the criteria in Table 1, we collected and created input data, including six basic layers, e.g. administrations, streets, bridges, rivers, metro routes and study area boundary, and thirdteen thematic layers, corresponding to the criteria. These layers were built from the landuse planning map (Department of Planning – Architect of HCMC), the metro map (Management Aurthority for Urban Railway of HCMC) and the Lidar dataset (Center for Applied GIS of HCMC), Google Map and field trips. They are stored in the GIS shapefile format.

4.5. Data processing

The progress of data prcessing to compute values to locate BRT stops consists of steps as following.

- Input data: preparing thirdteen thematic layers in point vector format.

- Bufferred areas: using the Multi Ring Buffer tool to create a new thematic layers in polygon vector format in which areas are bufferred by distances of 200, 400, and 500 m, and then they are assigned by values of 0, 1, 2, and 3 as attribute values, corresponding to passenger-walking distances to a BRT stop of more than 500, 500 – 400, 400 – 200, and 200 – 0 m, respectively.
- Spatial correction: using the Clip, Erase, and Merge tools to process data to unify the thematic layers in the study area boundary.
- Overlaying: using the Model Builder extension (ESRI, 2013) to design the process of computing ranking values of all positions in the study area. The process consists of the vector to raster conversion and the weighted overlay. Here, each gridcell size is 4x4 m and its value is computed following to formula (1). The result of overlaying the thematic layers is shown in Fig. 2, where dark red gridcells have higher ranking values while light red gridcells have lower ranking values.

$$v_{ij} = \sum_{k=1}^{13} r_{k*} a_{ijk} \qquad (1)$$

Here, v_{ij} is the ranking value at gridcell (i, j), a_{ijk} is the point value of 0, 1, 2, or 3 of the k^{th} criterion at gridcell (i, j), and r_k is the k^{th} weight of the k criterion.

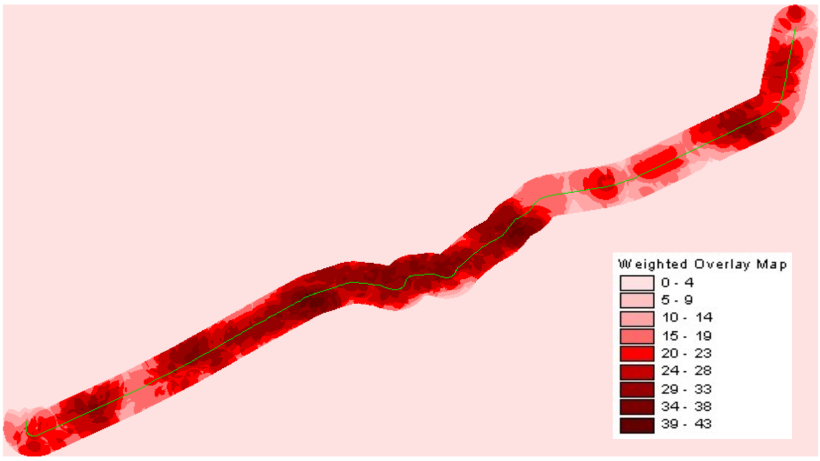

Fig. 2. The ranking values derived from the weighted overlay

- BRT stop: locating BRT stops follows the three conditions, consisting of priority locations having higher ranking values v_{ij} along the route, a distance between two consecutive BRT stops in the domain of 300 and 800 m, and a distance from a intersction of at least 40 m (Hook, 2013).
- Result: locations of 40 BRT stops along the Vo Van Kiet – Mai Chi Tho route are determined, as illustrated in Fig. 3.

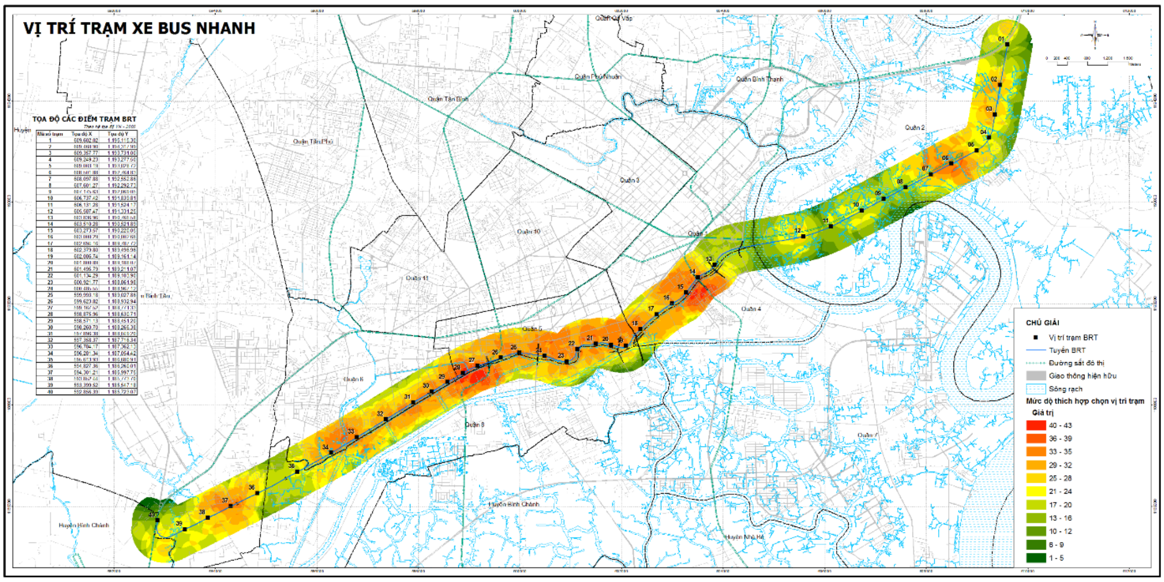

Fig. 3. The BRT stop map on the Vo Van Kiet – Mai Chi Tho route

5. Conclusion

GIS and AHP are the effective tools to choose the locations of BRT stops. GIS supports the process of spatial data analysis quickly and accurately while AHP is applied to compute weights of the criteria. AHP helps to reduce subjectivity and to use many experts' knowledge and experience. The result demonstrates the extensive GIS and AHP progress to select the location of BRT stops. Subsequently, the application of this progress indicates 40 BRT stops along the Vo Van Kiet - Mai Chi Tho route in HCMC. The result is expected as a scientific reference to help the city government in decision making in urban transportation planning.

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