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ANALYSIS OF FACTORS INFLUENCING BRT PERFORMANCE AND PROPOSAL OF APPROPRIATE OPTIONS FOR THE BRT SYSTEM IN HO CHI MINH CITY

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Abstract. The success of BRT systems in cities such as Curitiba (Brazil), Bogotá (Colombia), Jakarta (Indonesia), Guangzhou, Beijing, Kunming (China), and Seoul (South Korea) has inspired the widespread adoption of the BRT model. However, popularize BRT systems worldwide has not always yielded successful outcomes, as evidenced by the dismantling of BRT systems in New Delhi (India), Bangkok (Thailand), and Kuala Lumpur (Malaysia) due to operational inefficiencies. This highlights the necessity of customizing BRT systems to suit the unique conditions of each city. This paper presents an analysis of the urban context of Ho Chi Minh City, addressing factors such as population distribution, land use, travel behavior, and the current state of transport infrastructure, to propose a BRT model optimized for the city's specific conditions. The proposed result is a small-capacity BRT system with dedicated lanes shared with regular buses and open stations serving each direction is the most appropriate solution for the city. These research findings can be applied in the design of future BRT routes in Ho Chi Minh City.

Keywords: BRT, population distribution, travel behavior, transport infrastructure, operational capacity

1. INTRODUCTION

Bus Rapid Transit (BRT) represents a form of high-capacity public transport that offers lower investment costs, greater flexibility, and easier operation compared to Mass Rapid Transit (MRT). Due to these benefits, BRT has become a popular transport option in many cities, particularly in developing countries with limited resources [1], [2], [3].

A BRT system is defined as a bus service operating in dedicated lanes with specific enhancements designed to provide faster, more reliable service than conventional regular bus systems. According to the Institute for Transportation and Development Policy (ITDP) [4], a system can be classified as BRT if it meets the following minimum criteria:

- A route length of at least 3 km (1.9 miles);
- At least 4 points for dedicated bus lanes;
- At least 4 points for the location of dedicated lanes;
- A minimum score of 20/38 for key BRT components.

The core elements of a BRT system are scored as follows [4]:

- Dedicated bus lanes: 8 points;
- Location of lanes: 8 points;
- Intersection priority: 7 points;
- Fare collection at stations: 8 points;
- Level boarding (alignment of bus and platform): 7 points.

Thus, within a scoring range of 4-8 for each element, the Bus Rapid Transit (BRT) system offers various options depending on the technical infrastructure, executive capacity, and traffic management conditions. These technical improvements are primarily aimed at enhancing service quality, ensuring that bus passenger experience faster, more reliable, and more convenient transportation compared to regular bus services.

In addition to these technical enhancements, selecting appropriate features for the BRT system must be aligned with the level of travel demand generation, travel behavior, and passenger flow characteristics to achieve high operational efficiency. Depending on the degree of technical enhancement, each BRT system will have a different capacity. "Full BRT" systems, with maximum enhancements for all elements, can carry between 100,000 and 500,000 passengers a day, making them effective for corridors with high passenger density and concentrated demand [1], [5]. Conversely, in corridors with lower travel demand, this capacity would be underutilized, resulting in inefficiency. In such cases, “lite BRT” systems with a capacity of 35,000-50,000 passengers a day would be a more suitable option, ensuring resource efficiency without creating excess capacity [3], [5].

In essence, high technical standards do not guarantee the success of a BRT system. The efficiency of such a system hinges on its compatibility with local conditions. Hence, the choice of type and technical standards when designing and constructing BRT systems in urban areas must be based on careful analysis of trip generation, passenger flow characteristics, infrastructure conditions, and the operational capacity of the local transportation system. This paper presents such an analysis for Ho Chi Minh City.

Ho Chi Minh City stands as one of the largest and most dynamic urban centers in Vietnam, with a population exceeding 10 million and a daily demand for over 25 million trips. Presently, the city's public transportation system is including roundly 100 bus routes and satisfies only about 5% of the travel demand of residents. According to the urban transportation development plan to 2030, the construction of 06 MRT lines and 06 BRT lines is anticipated to fulfil 25% of the travel demand. Consequently, it is necessary to conduct studies that offer recommendations for the design and implementation of BRT lines in Ho Chi Minh City, ensuring they align with the city's unique conditions. This approach is required to avoid the fallibility encountered by the Hanoi BRT system, which has notably reduced the operational effectiveness of BRT Line 1 in Hanoi [5].

2. IDENTIFYING FACTORS INFLUENCING BRT PERFORMANCE

2.1. Trip generation and passenger flow characteristics

The BRT system, as a high-capacity public transportation mode, relies primarily on the level of trip generation and passenger flow for its operational efficiency. With technical improvements, BRT buses significantly enhance their carrying capacity and speed compared to regular buses. Therefore, BRT systems will be most effective in corridors with high and concentrated travel demand. High-density travel demand is crucial for maximizing vehicle capacity, reducing headways, and minimizing accessibility time, thereby increasing the attractiveness of the transportation service and increasing the passenger volume on BRT routes.

Travel demand is closely tied to population distribution and land use regulations in urban areas [6], [7], [8]. Different urban development patterns, such as "compact city" versus urban sprawl, specialized versus mixed land use, and circumscribed versus increased land use intensity, lead to varying outcomes in terms of trip generation [9].

Cities with a sprawling development model, characterized by functionally specialized land use and low-intensity development, tend to generate an increased number and length of trips [7]. However, these trips are often dispersed over a wide area, making shared transportation modes less practical. As a result, these cities tend to rely heavily on private vehicles, with public transportation struggling to achieve efficiency. Traditional urban development concepts in such cities aim primarily to make private vehicles circulate smoothly, minimizing traffic congestion. Indicators of transportation system success in these cities often focus on road infrastructure metrics, such as road network density, the number and length of road segments, and the number and area of parking lots. This model is more suitable for low population density cities, where private vehicles are the dominant form of transportation, rendering public transportation including “full BRT” systems largely ineffective.

The city becomes big city and densely populated when a it is population exceeds 1 million. At that time, expanding transportation infrastructure often lags behind the growth in private vehicle, making traffic congestion inevitable. In response, many megacities and densely populated cities are transitioning to the "compact city" model, characterized by urban development by height in limited areas, mixed land use, and higher land use intensity [10], [11]. This minimizes travel demand generation and concentrates demand at major attraction points, facilitating the use of shared transport modes. In compact cities, residents’ travel demand tends to concentrate around MRT or BRT stations, with mass-public transport modes serving the majority of travel demand. Transportation systems in these cities prioritize meeting passenger demand, shifting the focus from addressing vehicle traffic issues to improving passenger services. This urban development method, known as transit-oriented development (TOD), integrates transportation and urban development. High-standard BRT systems, with their large carrying capacities, are particularly effective in these urban areas [12].

Each city should base its decisions on its unique characteristics of population distribution and land use, selecting the appropriate service capacity and technical standards for the BRT system to avoid scenarios where high-capacity routes are built but serve low passenger volumes or vice versa [13].

2.2. Dedicated bus lanes

The primary distinction between rapid buses and regular buses lies in the speed and reliability of the transportation service. Dedicated lanes and signal prioritization at intersections are crucial for ensuring that buses move quickly and adhere to schedules. Thus, dedicated lanes are a fundamental requirement for establishing a BRT system [4]. To create these lanes, street widths must be sufficient typically at least three lanes in each direction. Additionally, various options exist regarding the location and usage rights of dedicated lanes.

Placing dedicated lanes in the center of a roadway offers the most operational benefits for BRT systems, as it ensures higher bus speeds and minimizes conflicts with other traffic. However, accessing stations becomes more difficult for passengers compared to lanes adjacent to sidewalks. Therefore, when determining the location of dedicated BRT lanes, both infrastructure conditions and traffic flow characteristics must be considered. For purely automobile traffic flows, the arrangement of BRT lanes close to the roadside will be more convenient than for mixed traffic flows with two-wheeled vehicles dominating, as in most Asian cities.

a) Dedicated lanes close to the roadside b) Dedicated lanes in the center

Figure 1. Dedicated lanes for BRT [4].

The usage rights of dedicated lanes also influence BRT system performance. If regular buses are not allowed to share the dedicated lane with BRT vehicles, the BRT’s operational speed and carrying capacity will be higher. However, allowing regular buses to share the dedicated lane can improve passenger access to the BRT corridor, as regular buses can collect passengers and feed them into the BRT system efficiently. Therefore, in corridors with high passenger volumes where speed and capacity are the priority, exclusive use of the lane by BRT buses is optimal. In contrast, in corridors with lower passenger volumes where increasing ridership is a priority, allowing regular buses to share the dedicated lane is advisable.

2.3. Traffic signal priority for buses at intersections

Enhancing bus speed in dedicated lanes becomes futile if buses experience congestion at intersections, particularly in urban networks with numerous at-grade crossings. Therefore, investment in centralized traffic signal control systems that prioritize buses at intersections while costly is essential to improving operational speeds and enhancing the overall efficiency of BRT systems.

The level of priority given to buses should correlate with their load factor: buses with higher occupancy rates should receive greater signal priority. Conversely, during off-peak hours or for buses with lower occupancy, priority can be reduced to minimize disruption to general traffic flow. Such decisions depend largely on overall urban traffic management capabilities rather than on the BRT system alone.

2.4. Automated fare collection system

To enhance the speed and accuracy of services, BRT systems typically utilize automated fare collection (AFC) systems. As payment methods become increasingly diverse and convenient, the AFC process becomes more efficient. However, the location of the payment systems whether at the station or on the vehicle has a significant impact on the operational efficiency of the BRT system. Placing the AFC system on the bus reduces both investment and operational costs. However, with high passenger volumes, this setup may slow down the boarding and alighting process, thereby reducing the operational speed of the buses. On the other hand, installing the fare collection system at the station allows for faster boarding and alighting, reducing the dwell time of the BRT vehicle at the station, which improves time efficiency. This approach, however, incurs additional costs for the installation and operation of fare collection systems at the stations, including substantial expenses for staffing and security to manage these systems.

a) AFC system on the bus   b) AFC system at the station

Figure 2. AFC systems for BRT [4].

2.5. BRT station

Location and structure of the BRT station plays a crucial role in influencing the operation of the BRT system. Key factors such as whether the station is positioned at the median or side curb, whether it is close or open station, and whether the platform is high or low are critical for ensuring smooth and efficient BRT system functioning. High-capacity BRT systems generally require enclosed station models integrated with fare control systems at the stations to ensure safety and convenience for the large number of passengers boarding and alighting whenever a vehicle stops. However, these enclosed station are most suitable when located at the central median, allowing them to serve both directions with buses that have doors on the left side though such buses tend to be more expensive than standard ones. Additionally, issues like ventilation, air condition, and sanitation in enclosed station can pose challenges and incur high costs. Such expenses are only justified if the passenger volume on the route is sufficiently high; otherwise, they become unnecessary and wasteful.

Open station usually located at the side curb have lower capacity and service potential but are easier and less expensive to operate, making them more suitable for lower capacity BRT systems.

a) BRT enclosed station   b) BRT open station

Figure 3. Types BRT station [4].

It is recommended that BRT systems employ platforms at the same height as the bus floor, facilitating faster and safer boarding and alighting. However, the platform height depends on the type of station. Open station should avoid high platforms due to safety concerns for passengers. On the other hand, low platforms require low-floor buses, which are typically more expensive and more sensitive to road surface conditions compared to standard buses. Therefore, a balance must be struck between saving on construction and operational costs for the station and the higher costs associated with low-floor buses when determining the platform height.

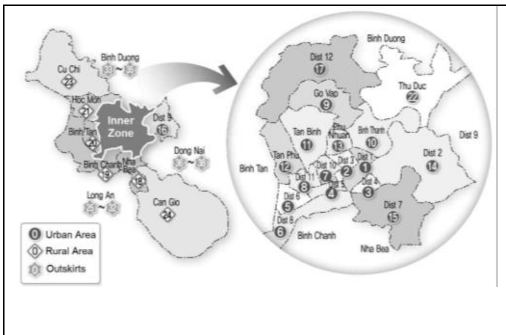
High platform on the left-side of bus   Low platform in the right -side

Figure 4. Platform in the BRT station [4], [6].

3. PROPOSAL OF APPROPRIATE OPTIONS FOR THE BRT SYSTEM IN HO CHI MINH CITY

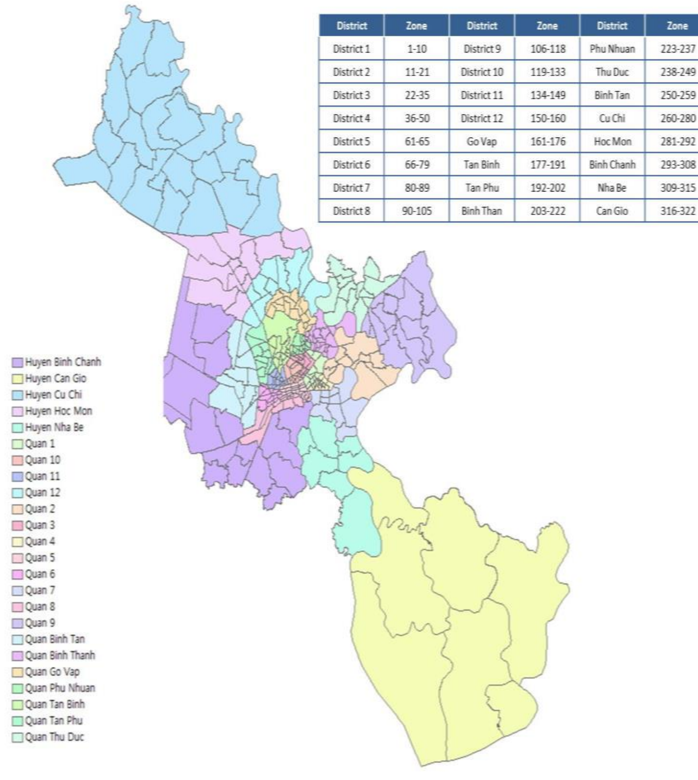
3.1. Capacity of the BRT system

Ho Chi Minh City, formerly known as Saigon, began developing around the 1700s with an initial area of approximately 1 km². By 1772, after nearly 100 years, Saigon had expanded to 5 km². In 1931, following several administrative changes, the city's area increased to 51 km², though urban development was mainly concentrated in a 3 km² area in the center (now District 1), while the rest remained underdeveloped. By 1976, the city covered 142.7 km² across 12 inner districts, with an additional 1,152.8 km² in suburban areas. At that time, the city had a population of about 4 million. Today, Ho Chi Minh City has evolved into a vast metropolitan area covering 2,095 km² with over 10 million permanent residents and serves as Vietnam's economic, financial, commercial, and service hub. However, due to prolonged urbanization and a sprawling development approach, the city has formed as a low-rise, high-density urban area with restricted building heights. The city's land-use planning is still divided by specialized functions, and the majority of residents live in individual houses along small, narrow alleys.



Master plan of HCMC

Travel demand



District	Zone	District	Zone	District	Zone
District 1	1-10	District 9	106-118	Phu Nhuan	223-237
District 2	11-21	District 10	119-133	Thu Duc	238-249
District 3	22-35	District 11	134-149	Binh Tan	250-259
District 4	36-50	District 12	150-160	Cu Chi	260-280
District 5	61-65	Go Vap	161-176	Hoc Mon	281-292
District 6	66-79	Tan Binh	177-191	Binh Chanh	293-308
District 7	80-89	Tan Phu	192-202	Nha Be	309-315
District 8	90-105	Binh Than	203-222	Can Gio	316-322

Figure 5. Urban development and land-use in HCMC.

Given these urban development and land-use characteristics, the city's daily travel demand is immense, with an estimated 25 million trips. Despite this high demand, it is dispersed over a wide area, leading residents to primarily rely on private vehicles, particularly motorbikes, due to the long walking distances between homes and main streets serviced by public transport. The city's dispersed urban structure further hinders public transportation development, as the travel demand is decentralized, making it difficult to concentrate passengers. Currently, public transport only serves 5% of travel demand and faces significant challenges in development. In the future, these issues are expected to improve as the city's development plan for 2021–2030, with a vision toward 2050, includes a focus on transit-oriented development (TOD) [14], [15].

However, until 2030, urban transportation will continue to rely heavily on private vehicles, especially motorbikes. Given these conditions, constructing high-capacity BRT systems (full BRT) in Ho Chi Minh City is not feasible. Instead, BRT routes with a capacity of 35,000–50,000 passengers a day would be more suitable. Even with this lower capacity, significant efforts will still be required to attract passengers to the BRT corridors to ensure operational efficiency. Correspondingly, technical enhancements for the BRT system should be scaled down appropriately to reduce investment and operational costs and avoid underutilization of vehicle capacity.

3.2. Dedicated bus lanes

In the context of mixed traffic, where motorbikes dominate [14] the establishment of dedicated BRT lanes is crucial and will significantly affect the success of the BRT system. Motorbikes are highly flexible, easily shifting between lanes and weaving between vehicles. The management of motorbikes in Ho Chi Minh City remains limited, especially regarding vehicle identification and remote fines, given the large number of motorbikes and a shortage of equipment and personnel for enforcement. As such, without completely segregated BRT lanes using physical curbs, BRT buses will face disruptions, impeding their ability to maintain the committed speed and reliability for passengers.

Typical traffic flow in HCMC. Source: https://tuoitre.vn/

BRT in the mixed traffic flow Ha Noi. Source: https://vtcnews.vn/

Figure 6. Traffic flow characteristics in Vietnam.

Dedicated bus lanes (BRT lanes) should not be positioned adjacent to roadsides in Ho Chi Minh City, as residents frequently use sidewalks for daily activities and commercial purposes, causing motorbikes to frequently enter and exit. Additionally, the city's narrow streets and numerous intersections would make curbside bus lanes obstruct right-turning motorbikes, exacerbating traffic congestion. The most suitable position for BRT lanes is in the center of roads with at least three lanes in each direction, allowing for complete segregation from motorbikes and ensuring stable BRT operations. Hard curbs should be installed to physically separate BRT lanes from other vehicles.

Shared use of these dedicated lanes with regular buses is recommended. Since the BRT system's capacity is not high, there is significant headway sizable, allowing regular buses to operate without disrupting BRT services. This approach not only optimizes the use of dedicated lanes but also allows regular buses to collect passengers from side streets and transfer them directly to BRT stations for easy and safe connections.

3.3. BRT stations

Traditional "full BRT" systems typically feature enclosed stations located on central medians, shared by buses in both directions. This layout ensures bus passenger safety and convenience but requires considerable space and high costs and necessitates buses with left-side doors. For lower-capacity BRT routes, costs can be reduced by using open stations, serving individual directions, and located on side medians [18], [19]. These stations allow regular buses with right-side doors to operate in shared lanes, an arrangement not feasible with central median enclosed stations. Though open stations increase bus dwell times and reduce passenger boarding/alighting speed, this is acceptable given moderate passenger volumes, making this design suitable for Ho Chi Minh City's BRT routes.

Open stations, which do not require ventilation and air conditioning, are well-suited to the city's hot climate, enabling reduced operational costs. Station heights should be similar to regular bus stops, facilitating easy boarding and alighting, especially with low-floor buses and a single step for mid-floor buses.

3.4. Traffic signal priority for buses at intersections

Ho Chi Minh City's traffic conditions are both necessary and possible to implementing bus signal priority at intersections. First, the city has a relatively dense network of intersections, most of which are at one grade. Without signal priority, the speed gains achieved by BRT in dedicated lanes would be undermined. Second, the city already has traffic signals at most intersections, managed by the centralized Urban Traffic Management Center. Thus, investment in signal priority systems should be prioritized in the development of BRT projects.

3.5. Automated fare collection system

For open stations without on-site staff, equipment installation at stations should be minimized. Therefore, for open stations in Ho Chi Minh City, fare collection and ticketing systems should be installed on the buses. Given the moderate passenger volume, bus drivers can manage ticket control, making it easier to protect equipment.

4. CONCLUSION

For a densely populated city with high travel demand like Ho Chi Minh City, the development of mass rapid transit systems such as MRT and BRT is inevitable rather than optional. However, these systems will only be efficient and attract passengers if designed according to the city's specific characteristics. Based on the analysis of Ho Chi Minh City's urban development and transportation conditions, a small-capacity BRT system with dedicated lanes shared with regular buses and open stations serving each direction, as proposed in this paper, is the most appropriate solution for the city. These research findings can be applied in the design of future BRT routes in Ho Chi Minh City.

However, while technical factors can be effectively managed through appropriate options, the decisive issue influencing the operational efficiency of the BRT system is the awareness and support of the citizen. Therefore, it is imperative to undertake research and develop strategies to enhance citizen responsibility of transportation and understanding about public transport, particularly regarding the BRT. These issues are not yet addressed in this article. This limitation highlights a key area for further investigation by the author.

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