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PERFORMANCE EVALUATION OF BUS STOPS ON ARTERIAL ROADS IN HANOI CITY

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Abstract. The operations of critical bus stops on arterial roads substantially influence the facility bus capacity and the bus quality of service in terms of schedule reliability. The aim of this article is to employ the methodology in the Transit Capacity Quality of Service Manual (TCQSM) to better understand the performance of key bus stops on arterial roads in Hanoi city. The obtained results shown that the capacities of most examined bus stops (Bus Stops 02, 03, and 04) are considerably lower than the actual demands of buses on the considered roads, and increasing the number of loading areas at bus stops is one of the feasible solutions to effectively improve the capacity of bus stops in Hanoi city. The results achieved provide urban transport management agencies and public transport practitioners in Vietnam with a valuable tool for bus stop capacity measurement and additional information for bus quality of service improvement.

Keywords: Bus stop, Bus capacity, Public transport, Bus travel demand, Quality of service

1. INTRODUCTION

The city of Hanoi, the capital of Vietnam, is one of the largest urban areas in Vietnam where the mode share of bus transit takes only 14%, compared with around 80% mode share of private motor vehicles in 2022 [1]. Additionally, the transit network in Hanoi relies mainly on the bus mode, with a light railway route (No 02), one bus rapid transit route (BRT 01), and 123 other normal bus routes, providing bus services for most of the urban areas. According to the Government's transport development orientation, public transport (PT) has been prioritized for investment and development in recent years. In large cities, such as Hanoi and Ho Chi Minh City, besides building more modern public transport systems such as BRT and light railways, the existing bus systems are being invested to improve the quality of services (QOS) and better serve the increasing demands of citizens. To effectively improve the QOS and capacity of the bus systems in large cities of Vietnam, improving the operation and capacity of bus stops on arterial roads plays a critical role. However, the planning and design of bus stops have not been implemented properly and synchronously. Furthermore, the operations of bus stops on arterial roads have not been sufficiently measured to identify the design/ operation issues, and then to be improved properly. This makes the bus stops often overloaded during the peak periods, and causes congestion for buses and other vehicles on road segments before bus stops.

This article thus aims to understand the performance of bus stops on several arterial roads in Hanoi city by using the method in The Transit Capacity Quality of Service Manual (TCQSM) [2] to estimate the design capacity of these bus stops. This helps to provide urban transport managers and planners in Vietnam with another useful tool to evaluate and improve the operations of bus stops on urban roads. Additionally, the findings also clarify the design and operation issues of bus stops on arterial roads in Hanoi city and propose the appropriate solutions to effectively improve the capacity and operation of these stops as well as bus routes.

The article is structured as follows: Section 2 presents the review of the literature. Section 3 presents the proposed methodology, followed by the details on the dataset used for empirical analysis in section 4 and discussion on the results and recommendations in section 5. Finally, the paper is concluded in section 6.

2. LITERATURE REVIEW

Numerous authors have focussed on the capacity and quality of service (QOS) of BRT [3-7]. Sharma & Swami [3] provided performance analysis of at-grade intersections under various bus priority configurations, with mixed traffic condition in Delhi and Jaipur, India. This study found that availability of bus lanes to other traffic for a reasonable distance before intersection considerably reduces the average queue length, maximum queue length, average delay time per vehicle, and emission per vehicle. This leads to the increase in vehicle throughput and average speed of all the vehicles. Babalik and Cengiz [7] reported that Istanbul's BRT system has attracted mixed opinions regarding its performance, with BRT failing to provide necessary capacity to meet its high demands, and with other design and planning-related issues such as a lack of passing lanes at stations and poor system integration. Reilly & Aros-Vera [4] estimated the capacity of various stop configurations in high volume bus services in Bogota, Colombia, using the failure rate of bus vehicles accessing the boarding berth of a bus stop.

Widana Pathiranage et al. [8] used a microscopic simulation model to estimate the BRT station bus capacity, considering a proportion of non-stopping buses. Widana Pathiranage et al. [9] continuously conducted microscopic simulation to examine the operation of the BRT station regarding the bus capacity, degree of saturation and queuing. Dodero et al. [10] examined the improvement of the level of service (*remaining passengers, travel time,* and *headway*) and operation of the BRT line 1 in Mexico by improving the infrastruction and technology and adjusting the system operation. The results shown that the overall services are able to be improved, but fairly limited.

The Transit Capacity and Quality of Service Manual 3rd Edition [2] contains methodologies to determine bus design capacity and quality of service (QOS) on the basis of operation of the critical stop. The TCQSM critical stop capacity methodology includes a failure rate approach. Bunker [11] used a fundamental microscopic simulation modelling approach to examine the high volume critical bus stop operations in the case study of Brisbane, Australia. This study quantified both the acceptable capacity and QOS of bus stops, considering the upstream average waiting time of buses as the most important measure of bus stop capacity and QOS performance. Hisham et al. [12] examined the performance of an on-street, mid-block, off-line bus stop by relating bus stop capacity to adjacent lane traffic volume under saturated conditions. The bus stop capacity method of TCQSM 2013 is considered as the most comprehensive and appropriate approach for estimating the capacity of bus stops on urban streets with mixed traffic flow. Furthermore, this method allows one to evaluate the capacity of bus stops for a variety of facility types, considering most sources of bus delay (bus stop position and facilities, traffic signal timing, traffic volume, dwell time, etc.). Thus, this study would apply the approach of TCQSM for bus stop capacity estimation in the case study of Hanoi, Vietnam.

3. METHODOLOGY

The method for estimation of a bus stop capacity in TCQSM 2013 is as follows:

Step 1: Set a design bus stop failure rate

The failure rate shows how often a bus should arrive at a stop only to find all loading areas occupied. If the stop failure rate increases, the bus stop capacity will be better, but the operational problems will be more serious. Thus, the design failure rate should be appropriately selected accounting for the trade-off between capacity and operational expectation. The recommended values are as follows:

- In downtown areas, the design failure rates vary from 7.5 to 15%;
- Outside downtown areas, the design failure rates vary from 2.5% to 7.5%.

Step 2: Determine standard normal variable (Z) corresponding to a desired failure rate

Z can be determined by following equation:

$$Z = \frac{t_{om}}{s} = \frac{t_i - t_d}{s} \tag{1}$$

Where:

s: standard deviation of dwell times

t_{om}: operating margin (s)

t_d: average dwell times (s)

t_i: dwell time value that will not be exceeded more often than the desired failure rate (s)

Operating margin t_{om} (s) required to achieve a particular design failure rate, when a bus stop operates close to its capacity:

$$t_{om} = sZ = c_v t_d Z \tag{2}$$

Where: c_v is the coefficient of variation of dwell times t_d

Step 3: Determine loading area capacity B_l

The bus capacity of a loading area depends on operating margin, dwell time, clearance time, and traffic signal timing. When the loading area is located at a traffic signal, buses may not be able to leave the loading area immediately after serving passengers (at near-side stops), or enter it immediately (at far-side stops).

The loading area capacity is expressed as:

$$B_l = \frac{3600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3600(g/C)}{t_c + t_d(g/C) + Zc_v t_d} \quad (3)$$

Where:

B_l: loading area bus capacity (bus/h)

g/C: green time ratio (the ratio of effective green time to total traffic signal cycle length, equals 1.0 for unsignalized streets and bus facilities)

t_c: clearance time (s), $t_c = t_{su} + t_{re}$, normally from 9s to 20s

t_{su}: minimum time for a bus to start up, travel its own length, and the next bus to pull into the loading area (s) (default of 10s)

t_{re}: reentry delay (s)

t_d: average (mean) dwell time (s)

t_{om}: operating margin (s)

c_v: coefficient of variation of dwell times t_d

Determine the reentry delay t_{re} (s)

For off-line stops, a potential added amount of time spent waiting for a gap to pull back into traffic, known as reentry delay t_{re} *(s)*. For on-line stops, $t_{re} = 0$.

Reentry delay t_{re} *(s)* can be measured in the field, estimated from simulation, or estimated using the method given below, which is based on procedures given in the Highway Capacity Manual [13, 14]. The evaluation of reentry delay depends on the location of bus stop relative to traffic signals that can influence traffic patterns in the lane adjacent to the bus stop. There are three cases for application: (1) Bus stop away from the influence of traffic signals; (2) Bus stop at a traffic signal; (3) and Bus stop downstream of a traffic signal.

Case 1: Reentry Delay Away from Traffic Signal Influence

$$d_{re,1} = \frac{3600}{c_{re}} + 900\left[\frac{N_{la}}{c_{re}} - 1 + \sqrt{\left(\frac{N_{la}}{c_{re}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{re}}\right)\left(\frac{N_{la}}{c_{re}}\right)}{450}}\right] - 3.3 \quad (4)$$

with:

$$c_{re} = v\frac{e^{-vt_{ch}/3600}}{1 - e^{-vt_f/3600}} \quad (5)$$

where:

$d_{re,1}$: average reentry delay for Case 1 (s)

c_{re}: capacity of the reentry movement (pcu/h)

N_{la}: number of loading areas at the stop

v: demand flow rate in the curb (rightmost) travel lane (pcu/h)

t_{ch}: critical headway for the reentry movement (default =7s)

t_f: follow-up time for the reentry movement (s) (default =3.3s)

e: exponential function.

Case 2: Reentry Delay at Traffic Signals

In Case 2, reentry delay is calculated from (a) the average time to clear the queue of vehicles in the adjacent lane and (b) the average delay waiting for a suitable gap in traffic the remainder of the time.

Determine queue service delay, d_{qs} (s) = min (g_s, g)

The time g_s required to service a queue of vehicles that has been stopped for a red light at a traffic signal:

$$g_s = \frac{Q_r}{(s_f/3600) - q_g} \quad (6)$$

With:

$$Q_r = q_r r \quad (7)$$

$$q_r = (1 - p_v)qC/r \quad (8)$$

Where:

g_s: queue service time for the adjacent lane (s)
Q_r: queue size at the end of the effective red time (pcu)
s_f: saturation flow rate (pcu/s)
q_g: arrival flow rate during the effective green time (pcu/s) = p_v/qCg
q_r: arrival flow rate during the effective red time (pcu/s)
p_v: proportion of vehicles arriving during the green indication (%) = g/C
r: effective red time (s) = $C - g$
C: traffic signal cycle length (s)
g: effective green time (s)
q: arrival flow rate (pcu/s) = $v/3600$
v: demand flow rate in the curb (rightmost) travel lane (pcu/h)

Gap-in-traffic delay, d_{gt} (s)

When a platoon is not present, the situation is similar to Case 1, in that the bus must wait for a suitable gap in traffic. The average delay, in seconds, waiting for a gap in traffic d_{gt} is estimated similarly to reentry delay in Case 1, except that the platooned vehicles over the course of an hour are not included as part of the adjacent lane traffic. An adjusted traffic volume, v_{adj} (pcu/h), is substituted for v in Equation 4.

$$v_{adj} = v\left(\frac{g}{C}\right) \quad (9)$$

For near-side stops, buses (and traffic in the adjacent lane) can only depart when the signal is green. In this case, reentry delay is the sum of average queue service delay d_{qs} and average gap-in-traffic delay d_{gt}, not to exceed the length of the effective green interval:

$$d_{re,2ns} = min\,(d_{qs} + d_{gt}, g) \quad (10)$$

At far-side stops, buses can depart at any time traffic in the adjacent lane permits. Reentry delay is the average of queue service delay d_{qs} and gap-in-traffic delay d_{gt}, weighted by the proportion of time each condition occurs.

$$d_{re,2fs} = d_{qs}\frac{d_{qs}}{C} + d_{gt}\frac{(C - d_{qs})}{C} \quad (11)$$

Case 3: Reentry Delay Downstream from Traffic Signals

In Case 3, bus stops are located within 400 m of an upstream signal. Traffic patterns are partially influenced by the upstream signal. In this case, reentry delay is calculated from both the Case 1 reentry delay and the Case 2 far-side reentry delay, giving greater weight to the Case 2 delay the closer the bus stop is to the traffic signal.

$$d_{re,3} = d_{re,2fs} - \frac{D_{bs}(d_{re,2fs} - d_{re,1})}{D_{max}} \tag{12}$$

Where:

$d_{re,3}$: reentry delay for Case 3 (s)
$d_{re,2fs}$: reentry delay for Case 2, far-side stop (s)
$d_{re,1}$: reentry delay for Case 1 (s)
d_{bs}: bus stop distance from the nearest upstream traffic signal (m)
D_{max}: maximum distance for Case 3 (equal to 400 m)

Step 4: Determine bus stop capacity B_s

Bus stop capacity is the capacity of a single loading area multiplied by the number of effective loading areas and the traffic blockage adjustment factor:

$$B_s = N_{el} B_l f_{tb} = N_{el} f_{tb} \frac{3600(g/C)}{t_c + t_d(g/C) + Z c_v t_d} \tag{13}$$

Where:

B_s: bus stop capacity (bus/h)
N_{el}: the number of effective loading areas at the bus stop
f_{tb}: the traffic blockage adjustment factor at traffic signals

$$f_{tb} = 1 - f_l \frac{v_{cl}}{c_{cl}} \tag{14}$$

Where:

f_l: bus stop location factor
v_{cl}: curb lane traffic volume at intersection (pcu/h)
c_{cl}: curb lane capacity at intersection (pcu/h)

4. DATA SET AND EMPIRICAL ANALYSIS

4.1. Data set

This article uses a sample of eight bus stops at four points on urban arterial roads (Ho Tung Mau-Xuan Thuy-Cau Giay Road) in Hanoi city for empirical analysis (see Figure 1). These bus stops are allocated on the busiest bus corridor in Hanoi city, which crosses the major universities (such as Hanoi National University, Thuongmai University, Academy of Journalism and Communication, etc.).

Figure 1. The location map of bus stops on Ho Tung Mau-Xuan Thuy-Cau Giay Road, Hanoi city (Source: Google Map).

There are 6 traffic lanes (3 lanes for each direction) on Cau Giay and Xuan Thuy Road, and 10 traffic lanes (5 lanes for each direction) on Ho Tung Mau Road. The necessary data for the bus stop capacity estimation (bus and traffic volume, dwell time of buses at stops, traffic signals, stop type, number of loading areas at stops, etc.) were investigated at the site by the camera and other devices in April 2021. The traffic volume and the operation of bus vehicles at stops will be recorded by camera, then expected inputs (bus dwell time and traffic volume) will be measured in the office. All stops are on-line bus stops (where buses stop in the traffic lane), with bus lane type 2 (buses may move into adjacent lane). Bus stop 01 (Thuongmai University) has two loading areas for two directions, while there is only one loading area at others stops (Bus Stops 02-04). Regarding the influence of nearby signalized intersections on the operation of bus stops, Bus Stop 04 is not influenced by signal, while Bus Stops 01, 02, and 03 are influenced by signal at nearby intersections (see Table 1).

Table 1. Estimated capacity of bus stops compared with actual demand of buses at stops.

Bus stop	**Direction**	**Stop type**	**Number of loading areas at stop**	**Number of traffic lane**	**Bus lane type**	**Loading area design**	**Location of stops**
01	Inbound	On-line	02	05	2	Linear	Far-side
	Outbound	On-line	02	05	2	Linear	Near-side
02	Inbound	On-line	01	03	2	Linear	Far-side
	Outbound	On-line	01	03	2	Linear	Near-side
03	Inbound	On-line	01	03	2	Linear	Near-side
	Outbound	On-line	01	03	2	Linear	Far-side
04	Inbound	On-line	01	03	2	Linear	Not influenced
	Outbound	On-line	01	03	2	Linear	Not influenced

This study examines the stop capacity during the morning peak hour (7:00-8:00) and afternoon peak hour (17:00-18:00). The survey results of dwell times at stops 01-04 are shown in Table 3, Table 4, and Table 5, respectively.

Table 2. Dwell times at the Bus Stop 01 on Ho Tung Mau Road (Thuongmai University).

Time	**Direction**	**Number of buses** (vehicle)	**Average dwell time** (second)	**Standard deviation**	**Coefficient of Variation of dwell time (Cv)**
7:00 – 8:00	Inbound	45	6.51	2.29	0.35
17:00 – 18:00	Inbound	41	10.71	5.61	0.52
7:00 – 8:00	Outbound	45	8.76	3.67	0.42
17:00 – 18:00	Outbound	45	7.42	2.70	0.36

Table 3. Dwell times at the Bus Stop 02 on Xuan Thuy Road (Hanoi National University).

Time	**Direction**	**Number of buses** (vehicle)	**Average dwell time** (second)	**Standard deviation**	**Coefficient of Variation of dwell time (Cv)**
7:00 – 8:00	Inbound	44	8.82	3.69	0.42
17:00 – 18:00	Inbound	45	7.64	3.06	0.40
7:00 – 8:00	Outbound	38	8.76	2.68	0.31
17:00 – 18:00	Outbound	40	7.75	2.46	0.31

Table 4. Dwell times at the Bus Stop 03 on Xuan Thuy Road (the Academy of Journalism and Communication).

Time	**Direction**	**Number of buses** (vehicle)	**Average dwell time** (second)	**Standard deviation**	**Coefficient of Variation of dwell time (Cv)**
7:00 – 8:00	Inbound	53	8.62	2.27	0.26
17:00 – 18:00	Inbound	45	7.64	3.06	0.40
7:00 – 8:00	Outbound	45	7.44	2.09	0.28
17:00 – 18:00	Outbound	35	8.4	3.01	0.36

Table 5. Dwell times at the Bus Stop 04 on Cau Giay Road (Caugiay Post Office).

Time	**Direction**	**Number of buses** (vehicle)	**Average dwell time** (second)	**Standard deviation**	**Coefficient of Variation of dwell time (Cv)**
7:00 – 8:00	Inbound	38	8.76	2.68	0.31
17:00 – 18:00	Inbound	32	8.34	2.54	0.30
7:00 – 8:00	Outbound	50	6.48	1.87	0.29
17:00 – 18:00	Outbound	43	8.14	2.69	0.33

The curb lane traffic volumes of the three arterial roads are presented in Figure 2. This shows that the traffic volume for inbound direction is much higher than this for outbound direction during the morning peak hours. The traffic composition on Xuan Thuy road for two directions during morning peak hours is presented in Figure 3. It can be seen that motorbikes take a vast majority of traffic flow on the road, accounting for 79% and 88% for outbound and inbound direction, respectively. Passenger cars take around 10-20% of the traffic volume, while other vehicles (bicycles, buses and trucks) account for a small proportion.

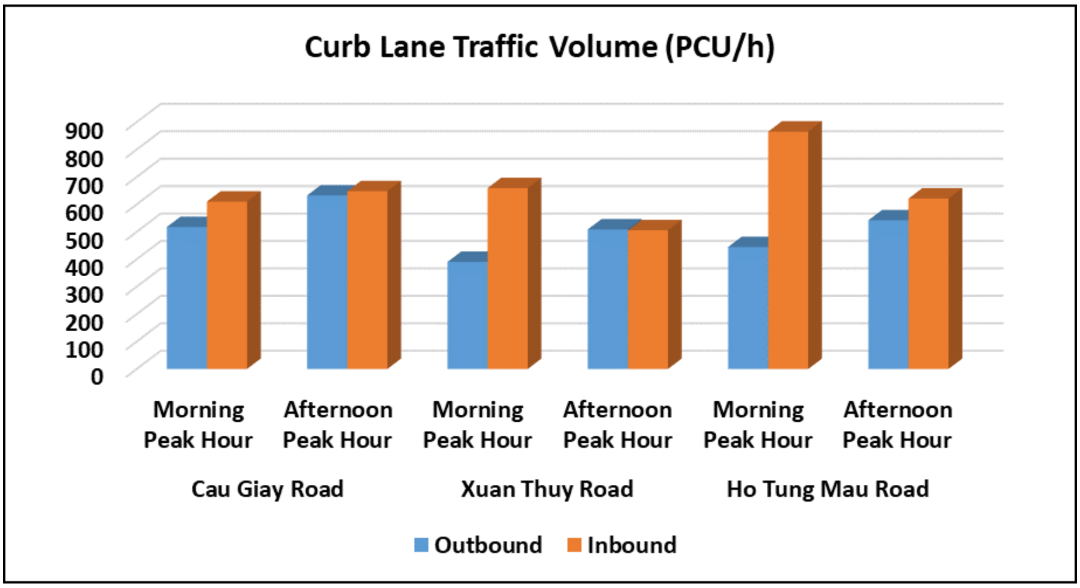

Figure 2. The curb lane traffic volume of the three arterial roads.

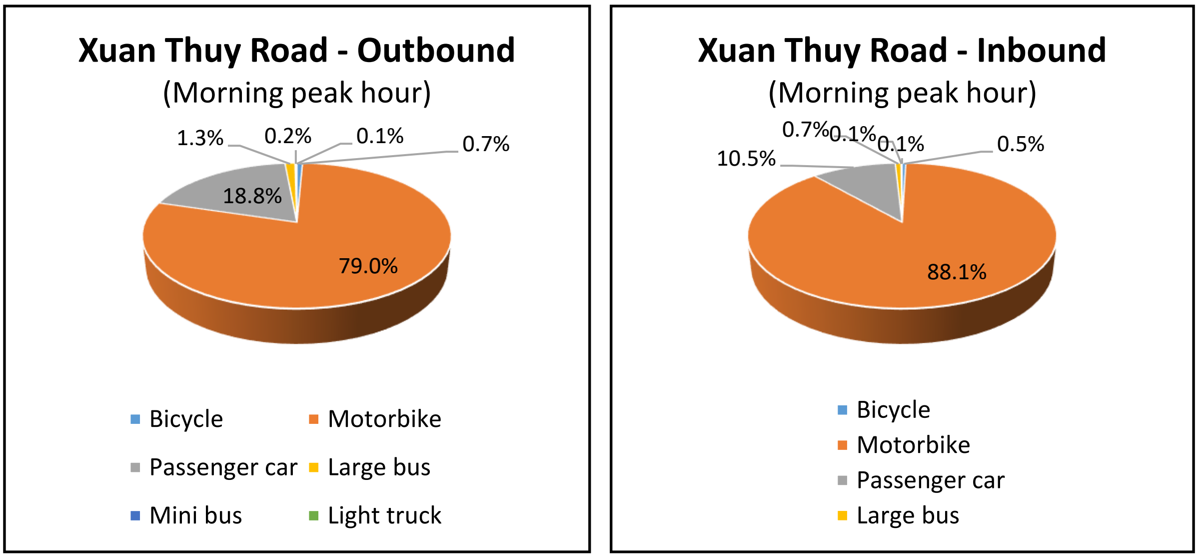

Figure 3. The traffic composition on Xuan Thuy Road during morning peak hours.

4.2. Results and discussion

The design bus stop failure rate of 7.5% was used for empirical analysis in this study because the considered roads are located outside the downtown areas. The results of the capacity estimation of bus stops are shown in Table 6. Of the four stops, Bus Stop 02 (at the Hanoi National University) has the lowest capacity, while Bus Stops 01 and 03 have better capacities. The obtained results also show that the capacities of Bus Stops 02 and 04 (for both directions) and of Bus Stop 03 (for inbound direction) cannot meet the actual demand of buses at these stops (meet around 50%-80% of the actual demand). These results accurately reflect the actual operation of bus stops on the site, where bus vehicles are regularly congested before the loading areas of stops during peak hours. The queue of buses before stops partially causes traffic congestion for other vehicles on these roads and significantly affects the total travel time and schedule reliability of buses during peak hours. There are numerous reasons why Bus Stop

03 (for outbound direction) has better capacity than others, but the most conspicuous one stems from the fact that the curb lane traffic volume for outbound direction is significantly low. Additionally, the upstream traffic signal has little effect on the operation of this stop.

Regarding Bus Stop 01, there are two loading areas at the stop for each direction, so two bus vehicles can stop at the loading areas simultaneously. As a result, it has the highest capacity among given stops and meets the actual demand of buses at this stop. This provides a feasible solution for the capacity improvement of Bus Stops 02-04.

Table 6. Estimated capacity of bus stops compared with actual demand of buses at stops.

Bus stop	**Direction**	**Number of loading areas at stop**	**Time**	**Loading area capacity B_l** (Vehicle/h)	**Capacity of bus stop B_s** (Vehicle/h)	**Actual demand of buses** (Vehicle/h)	**Actual demand/ Stop capacity** (%)
01	Inbound	02	7:00 – 8:00	83	42	52	123.8%
			17:00 – 18:00	70	60	52	86.7%
	Outbound	02	7:00 – 8:00	59	51	52	102%
			17:00 – 18:00	78	52	52	100%
02	Inbound	01	7:00 – 8:00	70	31	62	200%
			17:00 – 18:00	76	43	62	144.2%
	Outbound	01	7:00 – 8:00	76	41	62	151.2%
			17:00 – 18:00	79	32	62	193.8%
03	Inbound	01	7:00 – 8:00	96	39	62	159%
			17:00 – 18:00	92	50	62	124%
	Outbound	01	7:00 – 8:00	101	75	62	82.7%
			17:00 – 18:00	91	61	62	101.6%
04	Inbound	01	7:00 – 8:00	91	41	71	173.2%
			17:00 – 18:00	93	40	71	177.5%
	Outbound	01	7:00 – 8:00	104	56	71	126.8%
			17:00 – 18:00	92	40	71	177.5%

In case there are two loading areas at Bus Stops 02 and 04 and Bus Stop 03 for inbound direction, the estimated capacities of these stops are presented in Table 7. The results show that the stop capacities significantly increase and meet the loading demand of buses.

Table 7. Estimated capacity of bus stops with two loading areas at the stops.

Bus stop	**Direction**	**Number of loading areas at stop**	**Time**	**Capacity of bus stop B_s** (Vehicle/h)	**Actual demand of buses** (Vehicle/h)	**Actual demand/ Stop capacity** (%)
02	Inbound	02	7:00 – 8:00	55	62	112.7%
			17:00 – 18:00	76	62	81.6%
	Outbound	02	7:00 – 8:00	73	62	84.9%
			17:00 – 18:00	57	62	108.8%
03	Inbound	02	7:00 – 8:00	68	62	91.2%
			17:00 – 18:00	88	62	70.5%
04	Inbound	02	7:00 – 8:00	73	71	97.3%
			17:00 – 18:00	70	71	101.4%
	Outbound	02	7:00 – 8:00	98	71	72.4%
			17:00 – 18:00	71	71	100%

5. CONCLUSION

This article employs the TCQSM's methodology to get insights into the design capacities of several bus stops on arterial roads in Hanoi, Vietnam. The results achieved indicate that the capacities of most examined bus stops (Bus Stops 02, 03, and 04) are considerably lower than the actual demands of buses on the considered roads, although the highest value of bus stop design failure rate (7.5%) is applied for roads located outside the downtown areas.

It is notable that Bus Stop 01, consisting of two loading areas at the stop for both directions, has the highest capacities for the morning and afternoon peak hours, which meet the actual demands of buses on Ho Tung Mau Road. This demonstrates that adding more loading areas at the bus stops can be one of the appropriate and feasible solutions for the capacity improvement of Bus Stops 02, 03, and 04 in particular and other busy bus stops in Hanoi.

This article examines the capacities of a small sample, including eight bus stops, during peak hours on three arterial roads in Hanoi city. Another limitation is that this paper uses the default values in TCQSM for empirical analysis of bus stops in Hanoi city, which may affect the accuracy of obtained results. Future studies should use a larger sample of bus stops for empirical analysis to get more comprehensive results. Additionally, the influence of traffic signals and turning traffic flows at nearby intersections on the capacity of bus stops should be further studied. Finally, the coefficients used in the stop capacity model should be further studied and modified to be better suitable to the mixed traffic conditions on urban roads of Vietnam.

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