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Should water taxi service in Phnom Penh be abandoned or sustained?

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Abstract: *Water taxi (WT) transport has been considered as an alternative solution to help reduce urban traffic congestion in Phnom Penh, Cambodia. This transportation is an alternative mode of travel that can save both time and money. Water taxi service was launched in April 2018 as an alternative public transport mode that allows users to save both time and cost. WT was suspended in March 2020 due to the spread of Covid-19 pandemic and was reopened in November 2021. The number of passengers using WT has been decreased and unstable. This paper examines current operational services of WT in Phnom Penh under condition of mixed water traffic with other vessels and ferries. It further presents the potential of water taxis for future development whether it shall be abandoned or sustained. A comprehensive literature review was conducted to gather insights from similar studies in other cities. Data on vessel traffic, water traffic volume, and peak hours were collected through on-site observations, GPS tracking of vessels and historical records. Family fishing boats were found to be high in longitudinal traffic, while medium-sized ferries were found to be high in transversal traffic. A micro-simulation tool was also used to analyze the operational services of WT in accordance with existing WT's departure schedule. Results showed that WT has its potential as an alternative public transport mode for citizens, which helps to enhance overall mobility; thus, WT shall be sustained.*

Keywords: Abandon; Sustain; Phnom Penh; Water traffic, Water taxi

1. INTRODUCTION

1.1 Background

Phnom Penh, the capital city of Cambodia, has grown very fast for the past 20 years [1]. During rapid growth of vehicles, the city has remarkably experienced significant traffic congestion and air pollution, particularly during peak hours which have had negative impacts on urban livability. To address these challenges, policymakers and transportation planners explored alternative modes of transportation, including water taxi service. Water taxi service had the potential to provide a sustainable and efficient mode of transportation, particularly in areas where there is high demand for travel along waterways. The proposed water taxi (WT) service for Phnom Penh aimed to provide a more reliable, structured, and regular service. The system would involve a fleet of modern, safe and efficient vessels that serve multiple routes and stop at key points along the city's waterfront. One of the key benefits of this system could be the integration of water taxis with the city's existing public transport infrastructure, such as bus services, which provide better connectivity across the city. Ministry of Public Works and Transport (MPWT) launched public WT (or taxi boats) service in April 2018.

1.2 Problem statement

In March 2020, Phnom Penh City Hall temporarily suspended public water taxi and city bus services, as a measure to prevent the spread of Covid-19 pandemic. This service was resumed in November 2021. When reopened, the number of passengers decreased. There were originally four water taxis in service; but later there was a decline in a number of passengers, so the number of water taxi operations were reduced to two boats [2]. Many passengers appeared to worry about the safe operation of the taxi boats and they raised specific inquiries regarding security on water. Over 50% of the passengers simply engaged in leisurely rides on both weekends and weekdays. Although boat trip is swift, convenient, and free for workers, it

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still fails to attract much interest from citizens. On some days, there is no passenger traveling via WT. People coming near the port were just sitting, relaxing, and enjoying the river sights. With interviews with CBA staff and people nearby WT‘s station, many commuters considered boats unsafe and having to obtain onward transportation is a hassle. Due to limited number of operational boats, a considerable delay was experienced by several passengers who had to wait for an extended period before boarding. Times in departure schedule were also modified to accommodate more passengers. Public boat service doesn’t receive many passengers. This is probably because of the competition with other public transport modes (i.e., the public city bus), which is currently available in parallel route to the WT between Ta Khmao and Phnom Penh. Since the current demand for WT in Phnom Penh remains questionable, shall WT service be abandoned or sustained?

1.3 Objective

This paper examines operational services of WT in Phnom Penh, focusing on their interactions with mixed water traffic shared by other vessels and ferries and constraint from navigational obstructions within waterway. Noted that there are no previous studies on urban water taxi service available and very limited literature on this topic. The data and results from this study are expected to provide primary inputs into policy discussion regarding future development of urban public transport in Cambodia.

1.4 Scope and limitation

This study is mainly focused only WT operation in Phnom Penh city. Time for vessel traffic count survey follows existing WT‘s implementation schedule in 2019. Study did not consider effect of water flow during flood season. It is assumed a number of taxi boats can be increased while commuters increase.

2. WATER TAXI SERVICE AND ITS NAVIGATING CONSTRAINT IN WATERWAY IN PHNOM PENH CITY

2.1 Water Taxi Service

Water taxi service is a form of public transportation that uses inland waterway to transport passengers between different locations within a city. It is an alternative mode of traveling that can save both time and money. WT route is on Tonlé Sap and Bassac rivers. During rainy or flood season, WT services could get fewer passengers than dry season due to safety concern. WT services operated as scheduled from Russey Keo area, the northern part of Phnom Penh, to Ta Khmao city, the southern part of Kandal province, and vice versa. A one-direction journey covers a distance of roughly 15 kilometers of equivalent roadway. There were four boats operating from 7.00 am to 5.00 pm, 7 days a week. Two boats ran from south to north, while the other two boats operated in the reverse direction, from north to south. During journey, WTs stop at five stations named Russey Keo, Old Market, Chaktomuk, Chbar Ampov, and Ta Khmao Port. Except for Chhbar Ampov located on eastern side of river, all stations were situated in western side of rivers. Russey Keo, Old Market, and Ta Khmao stations are connected with bus stations for passengers’ convenience in switching between land and water transport. WTs were painted blue which two were bought from Vietnam and two were rented from the Royal Express Boat Company. Each water taxi equipped with air-conditioners and life jackets could carry up to 60 passengers. Travel time between stations typically ranges from 10 to 20 minutes and there is an approximate 10-minutes to dock at each station. Crews are well-trained and accomplished swimmers. Speed of boats is restricted to 20kph to prevent generating a significant wake that could pose a danger to smaller vessels navigating in rivers. All taxi boats were new brands and two larger models featured a Western-style toilet, which was considered a luxurious amenity. Boats always remained close to riverbank, providing reassurance in case of any potential accidents. Tickets are available at ticket offices at each stop. WTs were launched with a special promotion offering free rides for four months. Cost of boat taxi fares differed based on distance traveled, ranging from the most affordable ticket at 1,000 riel ($0.25) to the highest-priced ticket at 8,000 riel ($2). It is free of charge for monks, handicap, students, the elderly (70 years and older), children under 1 meter tall, factory workers, teachers, and athletes [2]. Ministry has collaborated with PiPay, a mobile payment application in Cambodia, to facilitate the sale of water taxi tickets. After official inauguration, MPWT handed over the responsibility and obligation of service to the Phnom Penh Municipality.

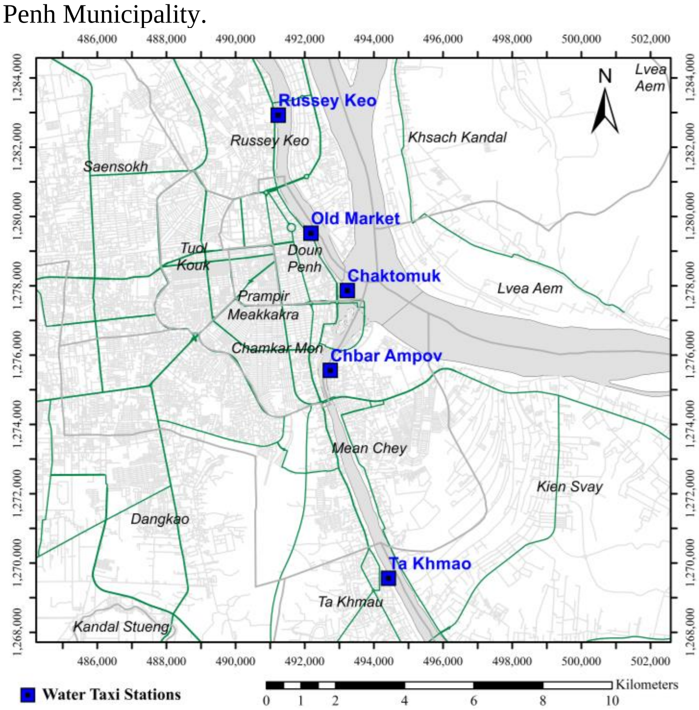


Fig. 1. Map of WT stations.

Table 1. Schedule of Water Taxi Boat in Phnom Penh in Nov 2019 [1].

Time	**Morning**					**Afternoon**			
Direction	**From Russey Keo Station to Ta Khmau Station**								
Boat No.	1	2	3	4		1	2	3	4
Russey Keo Station	7:00	7:30	9:30	10:00	**Time break**	13:00	13:30	15:30	16:00
Old Market Station	7:20	7:50	9:50	10:20		13:20	13:50	15:50	16:20
Chaktomuk Station	7:30	8:00	10:00	10:30		13:30	14:00	16:00	16:30
Chbar Ampov Station	7:40	8:10	10:10	10:40		13:40	14:10	16:10	16:40
Ta Khmao Station	8:00	8:30	10:30	11:00		14:00	14:30	16:30	17:00
Direction	**From Ta Khmau Station to Russey Keo Station**								
Boat No.	3	4	1	2		3	4	1	2
Ta Khmau Station	7:00	7:30	9:30	10:00	**Time break**	13:00	13:30	15:30	16:00
Chbar Ampov Station	7:20	7:50	9:50	10:20		13:20	13:50	15:50	16:20
Chaktomuk Station	7:30	8:00	10:00	10:30		13:30	14:00	16:00	16:30
Old Market Station	7:40	8:10	10:10	10:40		13:40	14:10	16:10	16:40
Russey Keo Station	8:00	8:30	10:30	11:00		14:00	14:30	16:30	17:00


(a) (b) (c) (d)

Fig. 2. (a) Water Taxi or Taxi Boat (Source: [2]), (b) Jetty in Russey Keo Station, (c) Ticket Selling Counter, (d) Ramp to jetty.

2.2 Navigating constraint by shape of Chaktomuk Confluence

Chaktomuk, also known as confluence of the Mekong, Tonlé Sap, and Bassac Rivers, is a significant river system located in Phnom Penh, the capital city of Cambodia [3]. Name "Chaktomuk" known in the Khmer language translates to "Four Faces" signifying the four branches of the three rivers [4]. Chaktomuk Rivers' confluence creates a distinct geographical feature in Phnom Penh that shapes the city's development and urban planning. River system provides essential resources and economic opportunities, supporting agriculture, fisheries, and transportation networks. Furthermore, the rivers contribute to the overall biodiversity of the region, serving as habitats for various aquatic species.

Tonlé Sap River plays a crucial role in hydrological system of Chaktomuk. The standout characteristic of lake is its impressive hydrology, which involves a unique phenomenon where flow direction of the Tonlé Sap River changes seasonally. During the dry season, from November to April, Tonlé Sap River empties its waters into Mekong River through Chaktomuk confluence at Phnom Penh due to gravity force. Conversely, in the wet season, from May to October, water levels in Mekong River become higher than those in Tonlé Sap which creates a pressure gradient that causes Tonlé Sap River to reverse its direction and flow back into Tonlé Sap lake or Great Lake which is located northwest of Phnom Penh (Fig. 6a) [5]. Both Bassac and Lower Mekong River flows out of Chaktomuk toward southern Vietnam and finally enters the South China Sea. This confluence creates an intricate network of river channels and islands, forming a unique and vibrant ecosystem.

2.3 Navigating constraint by pyolons and vertical clearance of bridge connecting Koh Pich to Koh Norea

Norea City, alternatively called Koh Norea Satellite City, is a new urban region constructed on a man-made island and reclaimed land within Phnom Penh. The enormous satellite city of Koh Norea, spanning an impressive 125 hectares, is situated along Mekong River near Bassac River's entrance and located in Chbar Ampov district's Niroth commune. This island is being connected to Koh Pich (Diamond Island) and National Road No.1 through Koh Pich-Koh Nora Bridge. This cable-stayed concrete bridge that spans crossing Bassac River measures 490.5 meters in length and 24.50 meters in width, comprising three primary segments for vehicles and an additional sidewalk for pedestrians. Bridge‘s superstructure is upheld by a pair of 60-meter-tall cable-stayed pillars adorned with uniquely distinctive Khmer carvings. During flood season, minimum distance between water surface and bridge for ship crossings is 8 meters. Once construction of this bridge is finished, the bridge will play a significant role in easing transportation of people from the capital to National Road No. 1, particularly alleviating congestion at Monivong Bridge and Kbal Thnal flyover. As a result, travel durations from Chbar Ampov to central Phnom Penh and Riverside can be substantially reduced and lead to quicker journeys. Phnom Penh City Hall is currently operating ferry services from Koh Nora to Koh Pich to reduce traffic congestion on National Road No. 1, While construction works for the bridges linking Koh Pich to Koh Norea satellite city are underway [6].

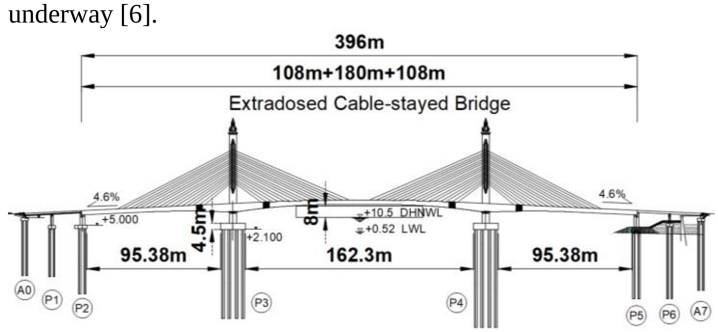


Fig. 3. Elevation view of Koh Pich-Koh Norea bridge.

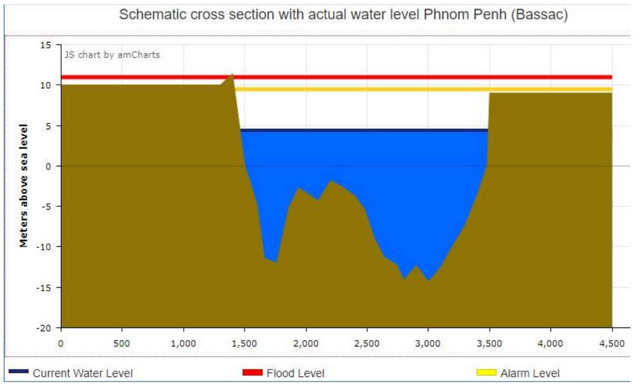


Fig. 4. Schematic cross section with actual water level at Bassac station in Phnom Penh (Source: [7]).

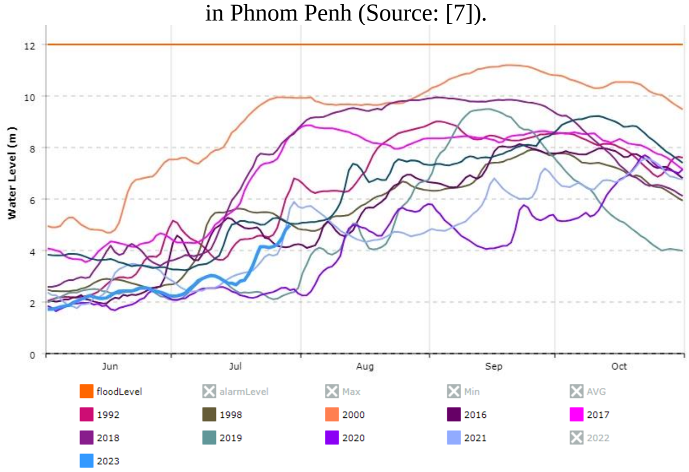


Fig. 5. Water level at Bassac station in Phnom Penh (Source: [7]).

3. RELEVANT LITERATURE

Many previous studies described overview of WT services and raised issues. Lessons learned from other cities informed development of strategies and recommendations tailored to specific context of Phnom Penh.

Over time, importance of water-based transportation has progressively decreased when compared to road-based transportation. In Bangkok, there has been a rapid shift from water-based transportation to road-based transportation since the 20th century (Iamtrakul et al., 2008) [8]. As a result, most waterway networks have been replaced with roads, which has led to various problems with existing system, such as inadequate accessibility, lack of inter-modal linkages, and safety concerns. Attractiveness of water transport services is determined by several aspects, including safety (both for the boat and pier), comfort, convenience (reliability and fare), activity, and landscape (natural and cultural).

Proper implementation of water taxi services has proven to be quite profitable in developed countries, as demonstrated by research conducted by (Bari et al., 2020) [9]. In 2010, the Bangladesh Inland Water Transport Corporation (BIWTC) launched a water taxi service spanning 16 kilometers, connecting Gabtoli with Dhaka. Regrettably, the service was terminated as a result of management issues. While the water taxi system was recognized as crucial for time-saving, alleviating traffic congestion, and decreasing accidents on the road, its inherent issues have the potential to diminish the expected advantages.

McNamara et al., n.d. [10] presented suggestions for establishing and developing a well-structured water taxi system in Victoria Harbour. Although some vessels still operate as water taxis, they lack sufficient organization to provide an efficient service.

Cooke et al., n.d. [11] present a summary of the findings from an examination of the livelihoods of water taxi operators in the Grenadine Islands of Grenada and St. Vincent and the Grenadines. Assessment also considered the vulnerability situation and the methods that individuals use to sustain their lives. The findings indicate that water taxi operators rely on fishing as a means to support their livelihoods, both for personal sustenance and for selling fish to yachts, with a particular emphasis on the latter.

Rawson et al., 2016 [12] created two concepts to measure navigation capacity. First approach involved analyzing the spatial utility of a navigation channel to handle vessels, known as "Level of Service," using vessel density and pier demand. Second approach calculated capacity of a channel to operate safely, referred to as "Level of Safety," by creating a risk model based on evaluated encounters between vessels. Level of Safety measures collision risk for vessels navigating.

3.1 Level of Service

Navigation capacity in congested waterways was assessed by applying Level of Service (LOS) method, which is commonly used in road transportation and developed by Transportation Research Board of the United States in 1965 for their Highway Capacity Manual 2000 [12] [13]. Unlike road-based, vessel traffic in Phnom Penh city has no divided lanes and is free flow. Vessel traffic is considered as freeway denoted in HCM 2000 [13]. The core principle of this approach asserts that with an increase in traffic density, average speed declines, utility of waterways decreases, and congestion develops. Navigation LOS was divided into several categories [12], [14]:

- LOS A - There is no navigation obstacle with an empty waterway, free flow, and no conflicts between users.
- LOS B - Waterway has not reached its maximum capacity with free navigation. There is moderate amount of open water which requires looking out for other users but plenty of room to maneuver.
- LOS C - Amount of vessel traffic is close to or has reached its maximum capacity, resulting in some congestion. Satisfactory sailing conditions need to watch out for other traffic but are safe for sailors with good skills.
- LOS D - Waterway has exceeded its maximum capacity, causing a disruption in the flow of vessel traffic. This is evidenced by congestion, queuing, and a decrease in vessel speeds. It needs to constantly watch out for traffic to avoid collisions, which requires skill and experience to safely navigate.
- LOS E – Vessel traffic is jammed and frequently has to stop or wait for other boats to pass; many near misses, unsafe for inexperienced sailors.

Table 2. Level-of-service thresholds for a basic freeway segment (Source: HCM 2000) [13].

LOS	Density Range (pc/km/ln)
A	0–7
B	> 7–11
C	> 11–16
D	> 16–22
E	> 22–28
F	> 28

Manual calculation of traffic density of taxi boats is performed by assuming vessel speed is constant and following duration from departure schedule between each terminal.

$$D = \frac{F}{S} \qquad \text{(Eq. 1)}$$

Where D: Density (ves./km/ln), F: Flow (ves./hr/ln), S: Speed (km/hr).

3.2 Level of Safety

Level of safety against vessel collisions, also known as Collision Avoidance is a crucial aspect in maritime transportation. It is achieved through a combination of vessel design, navigational aids, collision avoidance systems, and adherence to international regulations. Various performance indicators can be utilized, including collision incidence rates, near-miss reports, and compliance with collision prevention regulations. International maritime organizations, such as the International Maritime Organization (IMO) have developed comprehensive regulations including the International Regulations for Preventing Collisions at Sea (COLREGs). These regulations establish rules and guidelines that govern vessel operations and promote safe navigation, such as maintaining proper lookout, giving way to other vessels, and using sound signals to communicate intentions. Vessel design and technological advancements also contribute to collision avoidance. Features such as radar systems, double-hull designs for tankers, collision avoidance systems, and maneuverability-enhancing technologies improve situational awareness, alertness, and response capabilities of vessel operators. In this study, authors did not find qualitative level of safety but comprehensively reviewed on regulation.

Son et al., 2020 [15] assessed traffic distributions around waterway bridges to propose various safety distances for ships. Presence of a bridge across a waterway poses a safety risk for ship passage, potentially leading to accidents. Nevertheless, there is currently no established guideline in Cambodia for the appropriate safe distance that should be maintained between a bridge and a ship. Global reports indicate frequent occurrences of significant collisions between ships and bridges, with severe incidents involving bridges and ships happening at least once annually on a global scale.

Ma et al., 2022 [16] introduced a method for assessing the efficiency of active and passive safety measures in mitigating ship-bridge collisions.

Rawson et al., 2014 [17] detail one example of a practical approach to domain analysis for a busy section of the River Thames in Central London. The results correlate well to known high-risk collision areas on the river.

4. METHODOLOGY

4.1 Study Area

The study area is particular concern to Chaktomuk and its legs as it constitutes the busiest area of rivers in terms of traffic movements and has highest perceived risk profile [17].

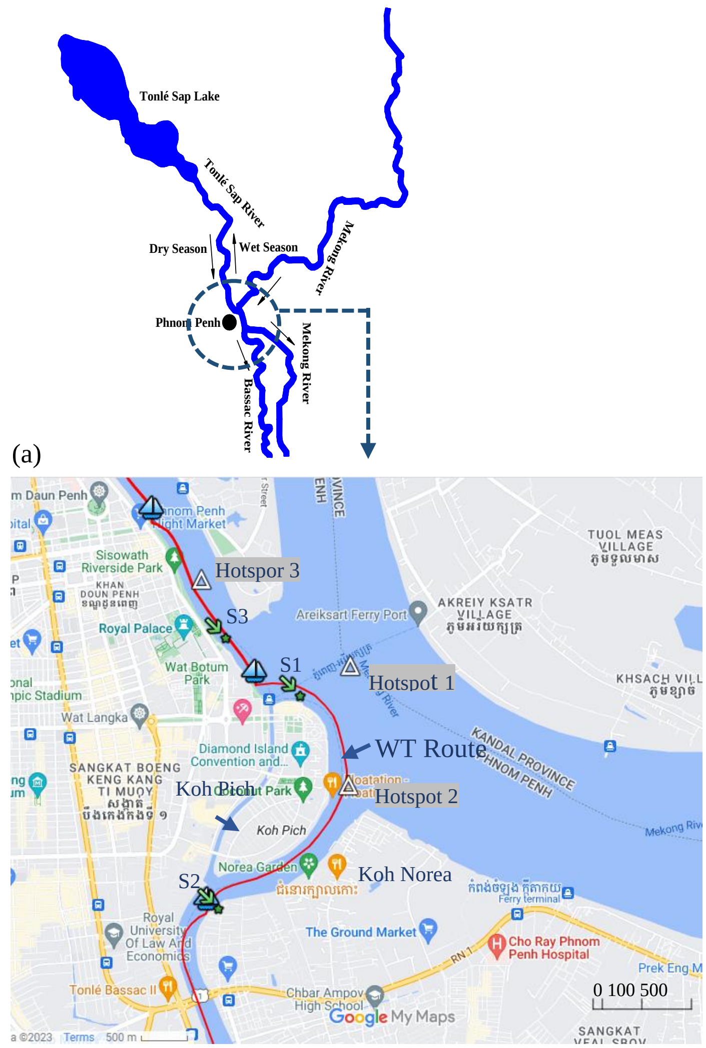
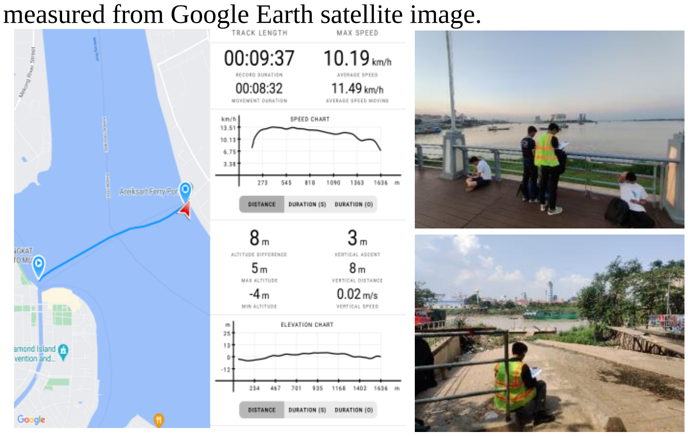


Fig. 6. (a) Tonlé Sap system (Source: [17]), (b) Map of Chaktomuk confluence in Phnom Penh.

4.2 Data collection

Data used in this study was collected through a combination of primary and secondary sources. Secondary data was gathered from City Bus Authority (CBA), various scholarly articles, reports, published documents, and newspapers. Primary data was collected by interviewing with CBA and conducting vessel traffic counts. These count surveys are conducted along and across water taxi's route at three stations, so-called S1 (Koh Pich), S2 (Chbar Ompov), and S3 (Royal Palace) as shown in Fig.6b. Vessel data are collected in all directions for both Inbound and Outbound to Chaktomuk river intersection. While surveying along waterway route, each river's leg is divided into six zones. The cross traffic from Phnom Penh to Akreiy Ksatr and vice versa was also counted. Surveys began on 15-Jan-2023 and ended on 16-Jan-23. Counting is from 6:00 a.m. to 6:00 p.m., conforming to existing WT 's schedule in 2019. For cross ferries, peak hours and days were selected by interviewing passengers, ticket sellers, and ferry operators. Desire speed (Fig. 7a) and route of ferries across river and tourist boats were tracked by hand-held Global Positioning Satellite (GPS) receiver. The longitudinal traffic speed was checked by measuring distance from Google Earth and dividing it by duration from start to end of travel points. Due to temporarily abandoned service, WT speed of 15-25 km/hr is estimated by interviewing WT operators. Surveys were done in dry season during low water level while waterway width was smaller than during flood season. When traffic is crowded and busy, ferry operators navigate faster. Because of limit of port capacity, maximum number of parked ferries is four at Phnom Penh riverfront side. Some dimensions of vessels can be measured. If measuring on real vessels is impossible, an approximate size is measured from Google Earth satellite image.



(a) (b)

Fig. 7. (a) Speed chart by GPS instrument, (b) Activities of vessel traffic count survey.

4.3 Future traffic demand forecast in inland waterway in Chaktomuk confluence

After receiving results from vessel traffic survey, these data were achieved as base-year traffic and projected to 2035, which is consistent with master plan of Phnom Penh city. For future traffic demand forecast, vessels are categorized into two groups. One is passenger vessels to transport passengers including WT and tourist boat. Another is cargo vessels to deliver goods and materials.

4.3.1 Prediction for passenger vessels

It is expected that as the numbers of passengers rise, there will be a corresponding increase in the number of vessels. Traffic forecasts are derived by extrapolating vessel proportions based on passenger numbers and population from the base year (2019) to the target year (2035). Estimation of future WT passengers and numbers of WTs are calculated:

$$Passengers\ of\ WT_{2035} = Passengers\ of\ WT_{2019} \times \frac{Population_{2035}}{Population_{2019}} \quad \text{(Eq. 2)}$$

$$Numbers\ of\ WT_{2035} = Numbers\ of\ WT_{2019} \times \frac{Passengers\ of\ WT_{2035}}{Passengers\ of\ WT_{2019}} \quad \text{(Eq. 3)}$$

From above equations:

$$Numbers\ of\ WT_{2035} = Numbers\ of\ WT_{2019} \times \frac{Population_{2035}}{Population_{2019}} \quad \text{(Eq. 4)}$$

Population in Phnom Penh city in 2019 and 2035 can be estimated from JICA study (Table 3) with unit of 1000 people and population is above 5 years old [18].

Table 3. Population Estimate in Phnom Penh [18]

Year	2019	2020	2025	2030	2035
Phnom Penh	2,189.50	2,189.50	2,471.10	2,598.70	2,626.30

4.3.2 Prediction for cargo vessels

Future cargo vessels in logistics are predicted by using similar increment rate.

Traffic demand forecast for 2035 can be calculated by: $T = \frac{(1+r)^N - 1}{r} \cdot T_0$; where r: Annual growth rate (%), N: Design period (Year), T_0: Base-year traffic.

Due to insufficient data of vessels in recent previous years, growth rate in this study is estimated from average growth in trend of container volumes (Fig. 8), with principle that cargo ships increase while container volumes increase. These container volumes at Phnom Penh Port were collected by JICA in 2022 [18].

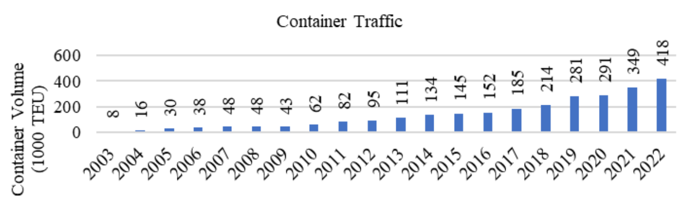
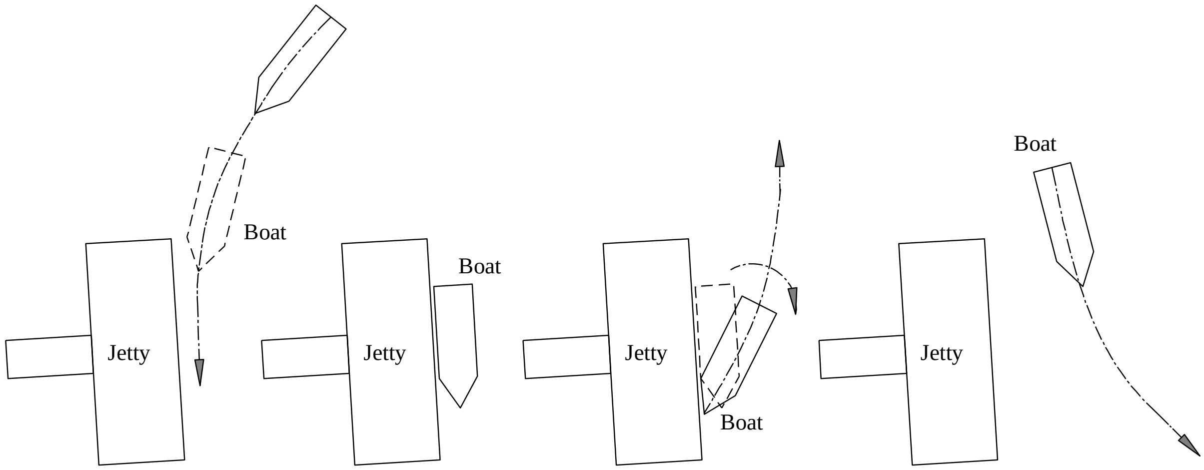


Fig. 8. Trend of Handling Container Volume at Phnom Penh Port [18].

Till 2035, project of Phnom Penh–Akreiy Ksatr Bridge is predicted to be completed and cross ferries will be no longer available.

4.4 Pier or Jetty Capacity for WT

A water taxi docking process involves several steps to ensure the safe and efficient arrival of WT at the jetty. In Phnom Penh city, WT needs some procedures to dock on jetty as following:



(a) **Fig. 9.** The process of docking of each WT on jetty.

All WT operations are currently suspended. Docking times are estimated from surveys of similar modes, including tourist boats and cross ferries and interviewing with City Bus Authority (CBA) stuffs. Average durations spent docking in Phase 1, Phase 2, Phase 3, and Phase 4 are 3 seconds, 5 seconds, 1 second, and 1.5 seconds respectively. Total average docking time is 10.5 seconds. From MPWT record, WT‘s docking duration was approximately 10 minutes in each jetty [19]. To dock respectively, each WT needs to wait to complete all phases of movement of another forehead boat. The Number of WTs docking per jetty and an hour is defined as pier or jetty capacity.

$$\text{Each pier capacity: } \frac{60}{10}\frac{Boat-Trip}{hr}=6\frac{Boat-Trip}{hr}$$

From existing schedule, WT is operated in 8 hours per day. The maximum capacity of each jetty allowing to dock is

$$Maximum\ jetty\ capacity = 6\times 8\frac{Boat-Trip}{day}=48\frac{Boat-Trip}{day}$$
(a)

If WTs are designated and occupied to run 4 trips per day as shown in Table 1, maximum number of WT that jetty can support is

$$Maximum\ numbers\ of\ WTs=\frac{48\dfrac{Boat-Trip}{day}}{4\,Trip}=12\frac{Boat}{day}$$

4.5 Vessel traffic flow simulation model

Simulation techniques can be used to examine the movement for traffic in the river [20]. It provides movement detail of ships in a waterway without the need for an exact mechanical model of each ship. Main objective of vessel traffic flow simulation is to detect instances of vessel congestion, collision risks, and grounding hazards [21]. From results of vessel traffic count survey, all vessels together with water taxis are modeled in traffic simulation by using commercial package PTV-VISSIM, a microscopic simulation software developed by PTV Group. This software can be used to simulate the traffic of different modes of transportation such as cars, buses, and water taxis in inland waterways. Departure and time interval of WTs in simulation model are based on existing implemented schedule in 2019. Simulation is considered for pillars and pilecap of Koh Pich-Koh Norea bridge. The numbers of taxi boats in simulation are assigned and studied in one direction only. Simulation output provides delay time, queue length, travel time, flow, density and speed while congested. These parameters link to find Level of Service (LOS). Model simulated movement of vessels through the waterway network, taking into account the characteristics of the vessels including size, pattern, speed, route, direction, traffic composition, etc., and traffic patterns. For WTs, numbers of boats are chosen from maximum capacity of pier to check for congestion.

Traffic simulation models are built at three locations. Firstly, it is considered at Kaoh Norea‘s bridge (Hotspot 2) where waterway width of Basac River shrinks due to backfill of Koh Pich island and a new bridge is being built. Secondly, simulation model is proposed at Chaktomuk confluence location (Hotspot 1) where longitudinal and transferal vessel traffic can conflict. Present vessel traffic in Chaktomuk‘s river is slightly dense. Stream of vessels is compressed in this area. Final location is set at royal palace (Hotspot 3) where other traffic from other river legs diverted to. Fig. 6b shows Hotspot locations.

In the model, each vessel is studied and assigned with actual size with safety domain, which is an area around the vessel that captain wants to keep clear of other vessels. This domain, determined through consultation with river users, is dynamic and is created by establishing a static buffer around the sides and stern of the vessel, as well as a dynamic "nose" that expands as the vessel's speed increases and contracts when maneuverability decreases [12]. To create these boundaries, a seven-meter (7m) buffer and dynamic nose which can be extended forward depending on type of vessel and speed over ground [17]. Models are run for one hour during peak hour.

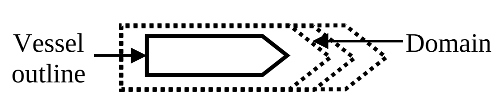


Fig. 10. Proposed domain shape surrounding a vessel outline.

Table 4: Numbers of surveyed vessels from 6:00 a.m. to 6:00 p.m.

Survey Location	Family Fishing Boat	High speed boat	Cruise Tourist Boat	Medium-sized Ferry	Big-sized Ferry	Vessel/ Boat delivering goods	Vessel delivering sand	Total
S1, Koh Pich (Inbound: East to West)	26 (10.9%)	-	-	103 (43.1%)	105 (43.9%)	3 (1.3%)	2 (0.8%)	239 (100%)
S1, Koh Pich (Outbound: West to East)	19 (8.5%)	-	-	111 (49.6%)	94 (42.0%)	-	-	224 (100%)
S2, Chbar Ompov (Inbound: South to North)	74 (63.2%)	1 (0.9%)	-	-	-	26 (22.2%)	16 (13.7%)	117 (100%)
S2, Chbar Ompov (Outbound: North to South)	56 (62.2%)	2 (2.2%)	-	-	-	14 (15.6%)	18 (20.0%)	90 (100%)
S3, Royal Palace (Inbound: North to South)	45 (33.3%)	6 (4.4%)	27 (20.0%)	-	-	54 (40.0%)	3 (2.2%)	135 (100%)
S3, Royal Palace (Outbound: South to North)	52 (42.6%)	5 (4.1%)	20 (16.4%)	-	-	5 (4.1%)	40 (32.8%)	122 (100%)
Total 3 Stations:	272	14	47	214	199	102	79	927

The simulation model of ship traffic on waterway for presented study has the following features:

a) microscopic – every ship is considered separately as an object;

b) domain based – distances of following ships are based on ship domain theory;

c) Two dimensions – movement of vessels are modeled in longitudinal, lateral and slant direction of waterway route

d) kinematic – ships are modeled at line intervals (of length L) moving with uniform speed along the given section of waterway, speed changes (if any) are immediate [21].

5. ANALYTICAL RESULTS AND DISCUSSION

Vessel traffic survey conducted along the Tonlé Sap and Bassac Rivers from 6:00 a.m. to 6:00 p.m. is shown in Table 4. Station 1 at Koh Pich reveals that there is high traffic on Phnom Penh-Akreiy Ksatr cross ferries. Both Station 2 at Chbar Ompov and Station 3 at Royal Palace demonstrate a larger amount of family fishing boats (Table 4). In terms of navigation difficulties, the survey identified two areas where congestion was high, causing delays in vessel maneuvers. These areas were port of Phnom Penh-Akreiy Ksatr cross ferries and Koh Pich-

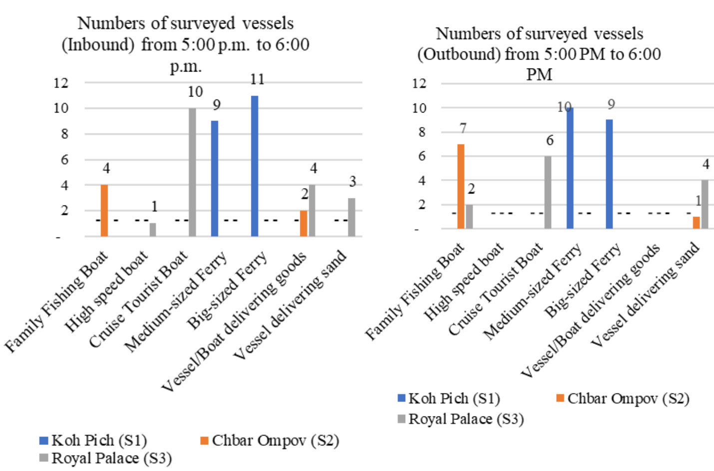


Fig. 11. Numbers of surveyed vessels during peak hour.

Koh Norea Bridge.

The study examined potential impact of increasing numbers of water taxis on level of service or congestion in Phnom Penh City. Manual calculation and simulation are performed to compare. LOS of both results is slightly different. However, simulation provides better results due to smart behavior that its speed can be accelerated or decelerated while detecting obstruction, conflict area, and priority rules. LOS still remained A for base-year and projection-to-2035 vessel traffic (Table 5). Results indicate that as the number of water taxis increases, but level of congestion remains low. WT operation can support up to 48 boat-trip in one direction or 12 boats with 4 round trips per day without causing significant vessel traffic congestion.

Table 5: Level of service (LOS) by simulation.

Numbers of Water Taxis (Boat-Trip)	Study Year	Density [D] (ves./km/ln) (LOS)		
		Hotspot 1	Hotspot 2	Hotspot 3
2	2023	0.059 (A)	0.060 (A)	0.396 (A)
48	2035	2.980 (A)	2.967 (A)	3.058 (A)

Based on aforementioned outcomes and actual observation, congestion is still low due to sufficiently wide Chaktomuk confluence and its legs. Another contributing factor is the limited volume of existing vessel traffic. Additionally, cross ferries will be terminated due to completion of Phnom Penh-Akreiy Ksatr bridge project, leading to a reduction in cross traffic in 2035.

6. CONCLUSIONS AND FUTURE WORKS

6.1 Conclusions

This study provides an overview of water taxis operation and vessel traffic in Phnom Penh City. Vessel traffic survey in Phnom Penh shows comprehensive data on vessel types, traffic volume, and compliance in surveyed area. Recorded data can serve as valuable information for policymakers and transport authorities to manage and alleviate congestion issues effectively. Simulation-based approach presented in this paper provides a useful tool for estimating level of service for congestion in inland waterway transport in Tonlé Sap and Bassac rivers, which are WT's routes. With congestion studied above, water taxis have significant potential as an alternative mode of transportation, enhance overall mobility, and shall be sustained. Moreover, water taxis can contribute reducing carbon emissions and improving air quality, which is particularly important for a rapidly urbanizing city. These findings provide a foundation for informed decision-making by policymakers, researchers, practitioners, transport authorities, and stakeholders involved in managing and developing the waterways of Phnom Penh. It can also serve as a basis for future research in the field of marine transportation and urban planning.

6.2 Recommendations

Beyond HCM 2000 threshold, if level of service increases rapidly, it leads to longer travel times, reduced service quality, and increased risk of vessel collisions. In overall, there is a need for continued investment in transportation infrastructure in Phnom Penh City to support growth of water taxi operations. This could include the development of a centralized control center to monitor boat operations and manage traffic flow, construction of additional docking points along the river to reduce congestion at existing docks, and the installation of navigational aids to help boats navigate safely and avoid collisions. Additionally, waterway transportation can be developed by considering some systems and concerns including:

6.2.1 Implement of vessel traffic separation scheme

In Koh Pich-Koh Norea Bridge location, water passage is shrunk and restricted by bridge's pillar and pilecap. It is a solution to divide fairway between bridge pillars by using vessel traffic separation scheme. Implementation of vessel traffic separation scheme (VTSS) aims to divide fairway between bridge pillars for water taxis and other vessels to enhance safety and efficiency of vessel traffic by segregating different types of vessels into designated lanes. Proposed VTSS will divide the fairway into distinct lanes, allocating one lane exclusively for water taxis and the other for vessels. VTSS minimizes risk of collisions and ensures the smooth flow of maritime transportation. Clearly marked and visible navigational aids, such as buoys, beacons, or signage, should be strategically placed along the fairway to guide vessels and indicate the boundaries of the separate lanes. These navigational aids should be designed to be easily identifiable, even in varying visibility conditions, to ensure the effectiveness of the traffic separation scheme.

6.2.2 Implement of vessel tracking system

Vessels, including water taxis, should be equipped with radio communication devices to facilitate real-time information exchange and navigation instructions. Additionally, vessel tracking systems, such as Automatic Identification System (AIS), can provide visibility and situational awareness to monitor vessel movements and prevent potential conflicts and collisions. AIS enables vessels to exchange vital information such as position, speed, and course, allowing them to take appropriate action to avoid collisions. Even though this particular area of Chaktomuk confluence is mostly wide and unrestricted, the presence of cross traffic in multiple directions significantly raises likelihood of maritime accidents, particularly ship-ship and ship-bridge collisions. Using AIS could minimize these risks.

6.2.3 Concerning and warning to vertical clearance of Koh Pich-Koh Norea Bridge

According to data from Mekong River Committee (MRC), highest recorded flood level in year 2000 during the rainy season was 10.5 meters, whereas the bridge only provides an approximate clearance of 8 meters (Fig. 3) [7]. This poses a specific warning for large-scale vessels, especially barges delivering sand. During the dry season, the width of the Bassac river decreases, resulting in a low water level of approximately 2 meters. Therefore, all vessels are mandated to navigate near the adjacent bridge's middle pillars. This situation leads to the potential development of congestion and an increased risk of collisions among vessels due to the limited space available for safe passage.

6.3 Future works

It is important to note that simulation was based on certain assumptions, such as a fixed demand pattern and no external factors affecting the system. Therefore, the results may not accurately reflect the real-world scenario. One example is referred to new inland waterway transport project, namely Funan Techo Canal, which is announced by Cambodian government. After completion, Bassac river is predicted to have more dense traffic, navigation, and logistics system. Water taxis are influenced by other special event, such as water festival. Further studies could be conducted to evaluate the robustness of the water taxi service under different scenarios. On the other hand, due to uncertainties in water velocity, flow, depth of water, wind, distribution, ship interactions, heavy regional traffic, and other factors, next research is needed to take into account these parameters in model for inland waterway traffic flow. In addition, future research could explore additional ways to manage vessel traffic flow and improve risk of vessel collisions. Next studies can also examine the feasibility and potential benefits of implementing other transportation modes, such as trains, to complement water taxi service and reduce congestion on land during peak hours.

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