

# Initial Feasibility Study of Multi-rotor eVTOL Aircraft for Cross-border Urban Air Mobility Between Singapore and Neighbouring Countries

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**Abstract**— As a country surrounded by water and sandwiched between two neighbouring states, Singapore’s geographic location is suitable for cross-water intercity Urban Air Mobility (UAM) transportation study. In this feasibility study, the use of multi-rotor electric Vertical Take-Off and Landing (eVTOL) is considered and findings on the cross-border visitor statistics between Singapore-Malaysia and Singapore-Indonesia are shared to reflect the potential demand for cross-border transportation. The points of interest for each of the countries are also identified, and the various existing common modes of transport used for cross-border journeys with their associated fares and duration are presented. To evaluate the feasibility of cross-border UAM from Singapore, an analysis of its journey duration gains and tradeoffs are compared against that of conventional modes of transportation to project an estimated fare for UAM services. The study then concludes with the challenges and limitations to determine if and how UAM would be a feasible option for cross-border transportation into and out of Singapore in the near future.

**Keywords**—unmanned aircraft systems (UAS), eVTOL, multi-rotor, urban transportation, urban air mobility (UAM)

## I. INTRODUCTION

One of the many envisioned use of Unmanned Aircraft Systems (UAS) is the on-demand transportation of people between and within metropolitan cities, providing users an additional transport option that is convenient and fast. Commonly referred to as Urban Air Mobility (UAM), it is defined as the safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems [1]. In the past decade, the aviation industry witnessed the emergence of companies looking to provide UAM in the form of on-demand air taxi service. Companies such as Uber [2], Volocopter [3], and Ehang [4] have released whitepapers to document their efforts and proposed Concept of Operations (ConOps); some of them have even conducted successful flight trials in prominent cities around the world. Civil Aviation Authorities (CAA) across the globe have also been formulating regulations to enable the safe use of UAS, such as European Union Aviation Safety Agency’s (EASA) Easy Access Rules for Unmanned Aircraft [5] and Federal Aviation Administration’s (FAA) Unmanned Aircraft Traffic Management (UTM) ConOps [6].

As UAS continues to garner interest worldwide with increasing use cases in various sectors ranging from commercial, military, security, and recreation, Singapore as an aviation hub stands to gain from advancements in

UAS technologies with UAM being a potential contributor of the mobility aspect in the country’s list of Smart Nation Initiatives. As Singapore’s urban density, air and maritime traffic are projected to rise in the coming years, as evident by more high-rise building projects, the construction of Tuas port, and Terminal 5 of Changi airport, traffic congestions would be a prevalent problem should existing infrastructures be unable to cope with the increasing traffic demands, resulting in a transport system that causes wastage of time, money and resources. Thus, it may be useful to consider the future prospects of having UAM in Singapore to facilitate the movement of people across her national borders in a safe, orderly and expeditious manner.

## II. CROSS-BORDER DEMAND AND POINTS OF INTEREST

Singapore sits on the southern end of Malaysia peninsular and has a land area of 728.3 square kilometers. Both countries are physically connected via two link ways, namely the Second Link Bridge to the west of Singapore and Johor Causeway to her north. Since year 2010, Singapore has at least 10 million visitors to Malaysia every year [7], topping Malaysia’s list of foreign visitor arrivals and forming slightly greater than half of the total number of Asian visitors to Malaysia [8]. 59.5% of visitors travel to Malaysia by land, suggesting that land transport is the dominant mode of transportation by Singapore visitors while air transport forms the second common mode at 34.7%. Conversely, Malaysia places fourth in Singapore’s list of foreign visitor arrivals with 878,000 Malaysia visitors coming into Singapore during the first three quarters of year 2019 [9]. It is also reported that Johor, Malacca and Kuala Lumpur are the top three shopping destinations by foreign visitors in Malaysia as of 2018 [8]. Despite being separated by a short 1km bridge on Johor Causeway, crossing can take between 1 to 2 hours on a normal day and even longer during peak periods and on weekends [10].

In 2019, Singapore was placed third in Indonesia’s list of foreign visitor arrivals with 1.9 million visitors [11]. Given that no physical connection between both countries exist, the two modes of transportation available are via sea and air. Indonesia’s Bintan and Batam islands, located southeast of Singapore and right across the Singapore strait, are popular hotspots to Singapore visitors looking for a short vacation getaway. Both islands are commonly accessed via ferry due to cost and convenience.

In this study, vertiports are arbitrarily placed at several key locations around Singapore namely at Woodlands Checkpoint, Tuas Checkpoint, Tanah Merah Ferry Terminal, and Harbourfront Centre. They are labelled as VN (Vertiport North), VW (Vertiport West), VE (Vertiport East), and VS (Vertiport South) respectively. The proposed vertiport locations are illustrated in Figure 1.

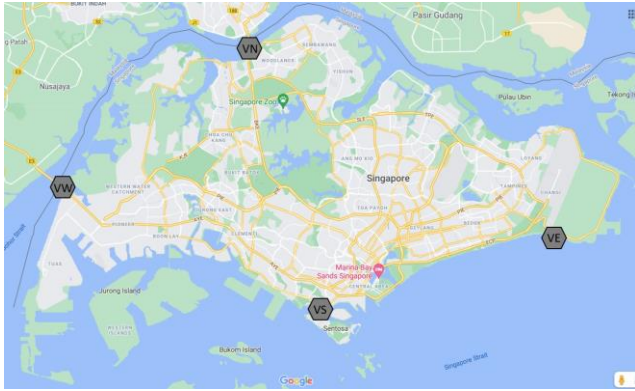


Figure 1. Arbitrary Vertiport Placement in Singapore

The primary reason for these vertiports' placement is to strategically coincide them with the presence of Customs, Immigration and Quarantine (CIQ) facilities, and to enable a fair comparison between UAM and its rival conventional modes of transport. Since these locations are in relatively remote areas along Singapore's coastal shorelines, they pose a lower operational risk to the general population while improving their proximity with the respective points of interest they serve. VN is designed to primarily serve Johor and its immediate vicinity since it is right across the border, while VW serves more destinations in West Malaysia such as Malacca and Kuala Lumpur. This arrangement not only accounts for the relatively shorter direct distance between VW and west Malaysia destinations compared to VN, it also considers the relatively lower operational risk involved as UAM aircraft using departing VW can transit to Malaysia's western coastline for the cruising phase of flight relatively faster with reduced overland flying as compared to departing via VN. VS and VE will serve Batam and Bintan islands with Bintan exclusively served by VE due to them being relatively nearer to each other compared to VS-Bintan pair. Inter-vertiport transit within Singapore and UAM operations within Singapore are not covered in this study and this study only considers multi-rotor electric Vertical Take-Off and Landing (eVTOL) aircraft for the purpose of providing UAM services as represented by Volocopter 2X [12] and EHang 216 [13] models as examples. Table 1 shows the key specifications of both eVTOL aircraft considered in this study.

Table 1. Key specifications of eVTOL aircraft

|                             | Volocopter 2X | EHang 216 |
|-----------------------------|---------------|-----------|
| Optimal cruise speed (km/h) | 70            | 100       |
| Maximum Range (km)          | 27            | 35.4      |

#### A. Singapore – Malaysia

Land crossing between Malaysia and Singapore can be done using personal vehicle, public bus, coach, or railway.

If travelling by airplane, airlines generally only provide direct flights to destinations that are reasonably far enough which, in this case, refers to destinations beyond Malacca. Should visitors wish to travel to Malacca or Johor by commercial flight, a transit is required at Kuala Lumpur but such transit cases are not considered in this study. Ferry services towards west Malaysia are available but not usually preferred due to limited operators and destination served, and relatively longer journey duration coupled with lack of cost effectiveness.

Transportation fares in this study are usually obtained directly from the service providers or online fare search engines such as Skyscanner [14] for air fares, Transitlink [15] for public bus served by SBS Transit, KTM Berhad [16] for railway service, and Busonlineticket [17] for coaches. For the case of personal vehicle, the Honda Civic 1.6 i-VTEC car is used as an example and some minor calculations are involved to generate the cost involved for the journey. The vehicle's key specifications are shown in Table 2, and it is assumed that the vehicle departs Singapore with a full fuel tank as checkpoint regulations require vehicles to have their petrol tanks at least three-quarter full before crossing borders.

Table 2. Specifications for Honda Civic 1.6 i-VTEC car

|  |       |
|--|-------|
| Average speed (km/h)                     | 100   |
| Fuel Consumption (km/L)                  | 14.9  |
| Fuel Tank Capacity (L)                   | 47    |
| Fuel Cost in Singapore (SGD/L)           | 2.336 |
| Fuel Cost in Malaysia (SGD/L)            | 0.80  |
| Maximum Range on a Single Full Tank (km) | 700.3 |

This study assumes that UAM aircraft flies directly towards their destination from their origin vertiport while airline operated commercial flights trajectories were obtained from online sources [18]. The trajectories for both modes of aerial transport are approximated on Google Maps and measured to obtain the distance travelled. The same method is applied to land modes of transport except that the trajectories are based on their respective ground infrastructure such as roads and railway tracks and thus, the distance covered by all modes of transport and duration are not the same. Except for commercial flight, which originates and concludes at airports, all other modes of transport will be assumed to originate at the respective CIQ facilities and terminate at their respective terminals or stations near the heart of the destination city. Figure 2 shows the routes undertaken by all the transport modes in this study.



Figure 2. Transport Routes for Singapore-Malaysia

Due to the limited range of eVTOL aircraft, stops are required along the journey towards west Malaysia to facilitate battery change, assumed to take 5 minutes per stop, which will be reflected in the overall journey duration. Figure 3 shows the operational coverage of both eVTOL aircraft models considered in this study towards west Malaysia while Table 3 provides a summary of the

journey duration, distance, and fares for all modes of transportation from Singapore to Malaysia destinations.

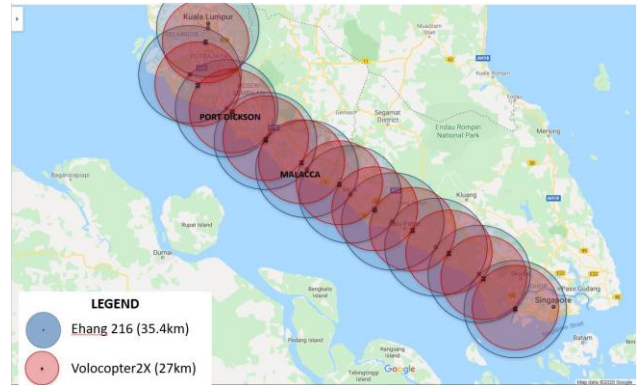


Figure 3. Operational Coverage of eVTOL Aircraft towards West Malaysia

Table 3. Transport summary for Singapore-Malaysia

| Johor          |       |            |       |         |          |           |               |
|----------------|-------|------------|-------|---------|----------|-----------|---------------|
|                | Car   | Public Bus | Coach | Railway | Airplane | Ehang 216 | Volocopter 2X |
| Distance (km)  | 2.27  | 2.27       | 2.27  | 2.29    | N.A      | 2.00      | 2.00          |
| Duration (min) | 3     | 5          | N.A   | 5       | N.A      | 3         | 3             |
| Fare (SGD)     | 1.45  | 1.84       | N.A   | 5       | N.A      | N.A       | N.A           |
| Malacca        |       |            |       |         |          |           |               |
|                | Car   | Public Bus | Coach | Railway | Airplane | Ehang 216 | Volocopter 2X |
| Distance (km)  | 224   | N.A        | 224   | 222.45  | N.A      | 200       | 200           |
| Duration (min) | 135   | N.A        | 240   | 311     | N.A      | 145       | 202           |
| Fare (SGD)     | 35.57 | N.A        | 13    | 13      | N.A      | N.A       | N.A           |
| Kuala Lumpur   |       |            |       |         |          |           |               |
|                | Car   | Public Bus | Coach | Railway | Airplane | Ehang 216 | Volocopter 2X |
| Distance (km)  | 335   | N.A        | 335   | 368.45  | 356.63   | 311.40    | 311.40        |
| Duration (min) | 201   | N.A        | 270   | 424     | 60       | 233       | 318           |
| Fare (SGD)     | 53.20 | N.A        | 22    | 22      | 55       | N.A       | N.A           |

**B. Singapore – Indonesia**

Ferry rides to any one of the three ferry terminals in Batam, namely Harbourbay, Sekupang, and Batam Centre Point) typically departs Singapore’s Harbourfront Centre in the south while Bintan island is served by ferry from Tanah Merah Ferry Terminal only. Even though there is an aerodrome on Bintan (Hang Nadim International Airport), there is no direct commercial flight service between Singapore and Bintan. Figure 4 illustrates the ferry routes between Singapore – Batam and Singapore – Bintan as well as the proposed UAM routes for the same destinations. Table 4 consolidates the distance and fares based on the routes shown in Figure 4. Similar to the concept applied for the case of Singapore-Malaysia, the trajectories for ferry in Figure 4 are based on actual ferry

routes while UAM will take a direct route from origin vertiport to the ferry terminals at the destination.

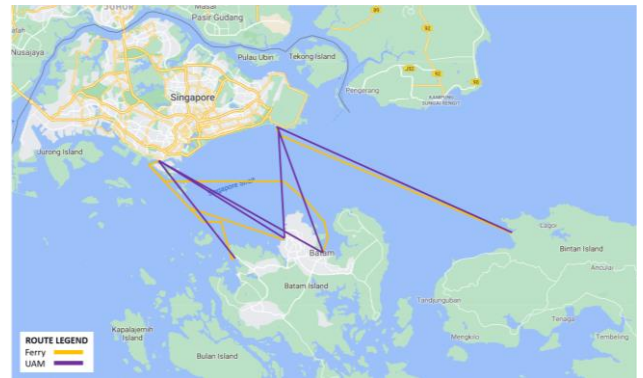


Figure 4. Transport Routes for Singapore-Indonesia

Table 4. Transport summary for Singapore-Indonesia

| Batam (from Harbourfront, VS) |            |               |                    |               |                               |               |                    |               |               |
|-------------------------------|------------|---------------|--------------------|---------------|-------------------------------|---------------|--------------------|---------------|---------------|
| Destinations                  | Harbourbay |               |                    | Sekupang      |                               |               | Batam Centre Point |               |               |
|                               | Ferry      | Ehang 216     | Volocopter 2X      | Ferry         | Ehang 216                     | Volocopter 2X | Ferry              | Ehang 216     | Volocopter 2X |
| Distance (km)                 | 26.93      | 23.29         | 23.29              | 26.58         | 19.56                         | 19.56         | 38.26              | 30.21         | 30.21         |
| Duration (min)                | 60         | 14            | 20                 | 50            | 12                            | 17            | 70                 | 18            | 31            |
| Fare (SGD)                    | 32         | N.A           | N.A                | 25            | N.A                           | N.A           | 25                 | N.A           | N.A           |
| Batam (from Tanah Merah, VE)  |            |               |                    |               | Bintan (from Tanah Merah, VE) |               |                    |               |               |
| Destinations                  | Harbourbay |               | Batam Centre Point |               | Distance (km)                 | Ferry         | Ehang 216          | Volocopter 2X |               |
|                               | Ehang 216  | Volocopter 2X | Ehang 216          | Volocopter 2X |                               |               |                    |               |               |
| Distance (km)                 | 17.86      | 17.86         | 21.66              | 21.66         | 41                            | 40.65         | 40.65              |               |               |
| Duration (min)                | 11         | 16            | 13                 | 19            | 60                            | 30            | 40                 |               |               |
|                               |            |               |                    |               | Fare (SGD)                    | 45            | N.A                | N.A           |               |

Although there is no ferry service between Tanah Merah Ferry Terminal and Batam, the possibility of UAM serving these two points is being explored as the direct distance between them is relatively closer than the conventional Harbourfront - Batam pair for Batam Centre Point and Harbourbay only. Evidently, a shorter route translates to shorter journey duration and possibly lower fares for passengers [19]. UAM operation for Harbourfront – Bintan is not considered as the direct distance between these two points is beyond the operational range of both eVTOL aircraft and the presence of air traffic complications near VE due to arrivals and departures of commercial flights at Changi International Airport to its north are not considered in this study. The UAM flight durations in Table 4 have accounted for the necessary stops for battery change, which is also assumed to take 5 minutes per stop, for certain destinations and Figure 5 shows the UAM operational coverage for both Indonesia islands.

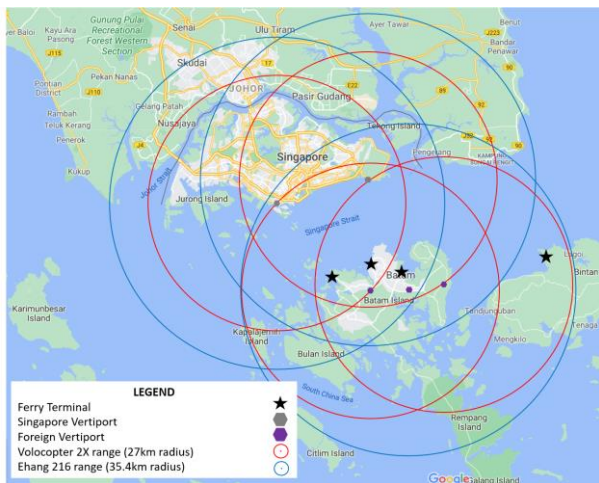


Figure 5. Operational Coverage of eVTOL Aircraft towards Batam and Bintan Islands

As illustrated in Figure 5, the operational range of both eVTOL aircraft can serve at least two ferry terminals in Batam without requiring battery stop enroute but for the case of Bintan, the aircraft would minimally require 1 battery stop on Batam island before proceeding to Bintan. However, for Volocopter 2X aircraft departing VS to Bintan, at least 2 stops are required for the aircraft to

successfully cover Bintan ferry terminal under the flight condition with no external influence as the aircraft could only cover the western shores of Bintan otherwise.

### III. ANALYSIS AND EVALUATION

#### A. Singapore – Malaysia

Based on data in Table 2, Figures 6 and 7 shows the transport duration and cost/fare respectively for various modes of transport from Singapore to Malaysia.

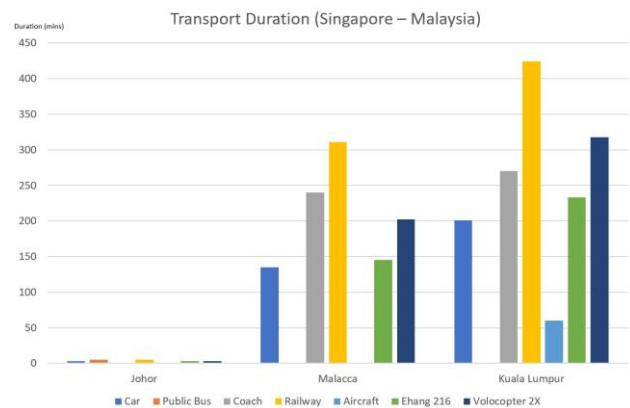


Figure 6. Transport Duration (Singapore - Malaysia)

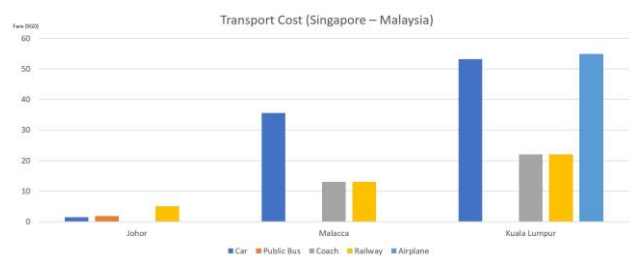


Figure 7. Transport Cost (Singapore - Malaysia)

As observed, transport duration is very competitive between Woodlands and Johor Checkpoints, assuming there is no traffic jam or delay, largely due to the short journey distance and all modes of transport are routed directly towards the destination. The distinction will be very apparent should there be a traffic jam on the causeway mainly affecting personal transport, public buses and coach since railway operates exclusively on its

own tracks and on a fixed schedule thus, they are immune to traffic congestions. The transport duration trade-offs also appear to be more distinct for further destinations such as Malacca and Kuala Lumpur. Using the faster of the two eVTOL aircraft, the Ehang 216, its duration is comparable to that of a car but for the furthest destination in this study, the fastest mode to Kuala Lumpur is achieved by commercial flights operated by airlines, which uses approximately one-third of the duration of its next fastest mode of transport (car). The eVTOL aircraft spends about 25 and 45 minutes of the journey duration on battery changing stops when travelling towards Malacca and Kuala Lumpur respectively. Generally, coaches are not used deliberately for border crossing only as they are meant for long journeys with the intention to provide travellers with extra comfort.

In terms of transport cost, journey between Woodlands and Johor Checkpoints is very price competitive with price ranging between SGD1.84 to SGD5 for an approximately 2km journey which takes between 3 to 5 minutes. Based on the result show in Figure 7, it appears that personal transport cost the lowest, but this may not be so after considering the toll fees applicable at both checkpoints which costs approximately SGD8.50 in total, thereby putting the cost at about SGD2 per passenger if the car is fully occupied with 5 passengers. Hence, public bus would be the most economical mode of transport just for border crossing between the two checkpoints as it is cheap, convenient and readily available at various bus stops unlike railway which requires prior booking, operates on a strict schedule and needs to be boarded at designated railway station. For Malacca, although coach and railway have the same fares, the former offers a relatively shorter journey duration. When compared to transport by car, which is the fastest conventional mode of transport to Malacca, the coach offers a positive trade-off between fare and journey duration (63.45% cheaper in fare, 43.75% longer journey duration) while the trade-off by railway is not as favourable (63.45% cheaper in fare, 56.59% longer journey duration). For Kuala Lumpur, the air fare for direct flight is about the same as the travel cost using personal car yet provides significant time savings. Despite air fare costing twice that of coach or railway, commercial flights provide at least twice the time savings of any other modes of transport (generally 50% cheaper in fare for coach and railway but journey duration is 70% longer for car, 77.77% longer for coach and 85.85% longer for railway).

Air taxi fares for services towards Malaysia would be very price sensitive due to the presence of alternatives for consumers especially for the short journey towards Johor where passenger comfort is not of utmost priority. Considering that air taxi is a form of on-demand transportation with additional elements of comfort and privacy, air taxi operators may offer fares slightly higher than cars primarily because not all travellers own personal cars and the transport duration using UAM is about the same as cars albeit slightly longer by 7.4%. For travellers to justify their expenditure, every dollar spent should bring about certain gains in the form of shortened journey duration, comfort or privacy. However, UAM would face heavy competition for far destination such as Kuala

Lumpur due to the presence of commercial flights as a strong rival both in terms of fares and time savings.

### B. Singapore – Indonesia

Figures 8 and 9 are referenced from Table 3. As illustrated from Figure 8, UAM provides significant savings in journey duration compared to the conventional mode of transport via ferry. This is in lieu of UAM's direct route towards the destination, which means a shorter distance travelled, and relatively higher cruise speed than ferry. While UAM generally have no problems serving Batam destinations, it would usually require at least 1 battery stop in Batam to reach Bintan island. While ferry is the only competition air taxi operator would face, the competition lies in the presence of multiple ferry service providers serving the routes and the frequency of ferry service – typically 1 ferry per hour per service provider. In this case, air taxi fares may be priced higher than ferry given its on-demand advantage, its significantly shorter and faster journey with the addition of comfort and privacy.

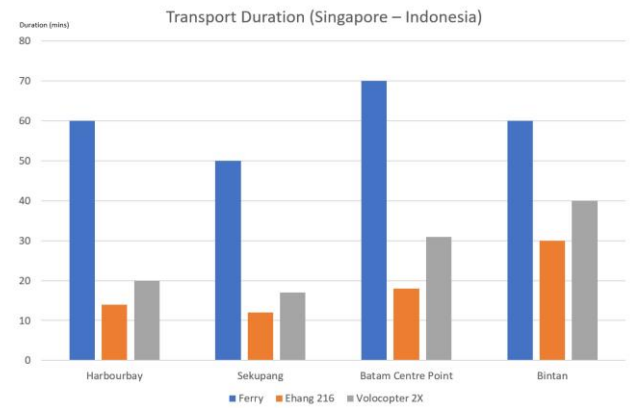


Figure 8. Transport Duration (Singapore – Indonesia)

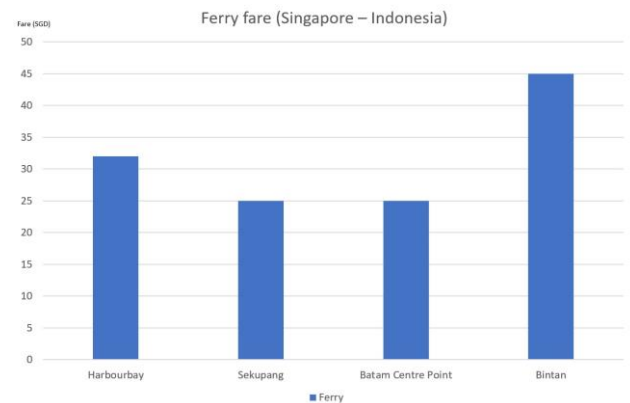


Figure 9. Ferry Fare (Singapore – Indonesia)

## IV. LIMITATIONS AND CONCLUSION

This study was conducted during early COVID period, which started in late 2019, and as such, the fares presented in this study may not accurately reflect the normal pre-covid fares nor does it represent fares post-covid period. Air taxi service fares are also not reflected due to lack of official disclosure on fares by potential air taxi companies despite Uber's brief mention of its fare model costing USD5.73 per passenger mile initially before ideally

getting to USD0.44 per passenger mile [20]. Generally, UAM stands an advantage against commercial air transport in the service of very short-haul routes which airlines are not operating on, for example direct flights between Singapore and Johor, Malacca or Bintan airports. This is largely due to commercial aircrafts requiring a runway and ground handling services as well as their extensive equipage and higher capacity for cargo and passengers that restricts their flexibility as a point-to-point mode of transport. However, the use of multi-rotor eVTOL aircraft for cross-border travel is largely limited by the flight performance and characteristic of multi-rotor aircraft, the battery technology affecting the flight endurance as well as cruising speed of the aircraft. Furthermore, the UAM scenarios presented in this study omitted the intervention of Air Traffic Management (ATM) procedures by Air Traffic Control (ATC), lacked the presence of infrastructures and external factors such as weather which would advocate certain flight routing or deviations rather than perfect direct to destination routes.

While multi-rotor eVTOL aircraft limitations are not very restrictive for short routes such as between Singapore – Batam, Singapore – Bintan or Singapore – Johor, further destinations proved to be a challenge for these aircraft but this could be solved upfront using fixed-wing eVTOL aircraft. Fixed-wing eVTOL aircraft could drastically improve the operational range of UAM aircraft, enabling it to cruise faster and higher, providing significant reduction in transport duration thereby giving UAM a stronger standing and greater competitive edge. For example, considering Hyundai's S-A1 fixed-wing eVTOL aircraft, which has a targeted cruise speed of 290km/h and a projected range of 100km, it requires only 1 battery stop for journey to Malacca, 2 stops to Kuala Lumpur and could effectively cover Bintan island without requiring any stops at all. Figure 10 shows the operational coverage of Uber's S-A1 aircraft when departing VW.

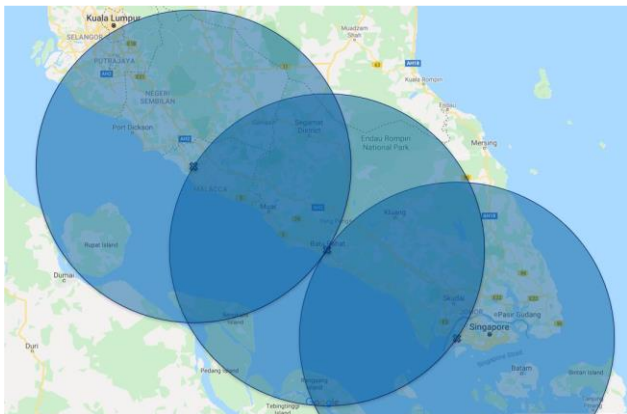


Figure 10. Operational coverage of Hyundai S-A1

Even though the use of multi-rotor eVTOL UAM for cross-border journey from Singapore to Malaysia and Indonesia is not impossible, its feasibility is very much limited to very short journeys to Johor and Batam. In years to come, cross-border travel between Singapore and Johor could be further enhanced with the construction of the Johor Bahru–Singapore Rapid Transit System (RTS) which may result in an even more competitive UAM rate

for Woodlands-Johor routes. Furthermore, to ensure that the UAM service is seamless and convenient, developments would need to be expected for UAM services within Singapore where travellers can embark on cross-border journeys simply by visiting any vertiport to their convenience since these vertiports would have already been serving local transport demands [21]. These local vertiports can also The feasibility study for UAM within Singapore based on demand additional studies would need to be conducted to ascertain the safety of such operations by assessing the risk on third-parties as well as development of procedures and regulations to integrate such operation with that of manned aircraft flying at low altitudes.

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