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Design of the Numbers of Vertiports and Air Taxis for Business Realization of On-Demand Air Mobility in Tokyo

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September 2019

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ABSTRACT

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Title
Design of the Numbers of Vertiports and Air Taxis for Business Realization of On-Demand Air Mobility in Tokyo

Abstract
With the gradually increasing population, road congestion has become a major challenge that is plaguing major metropolitan cities across the globe. In the recent years however, with the advent of Urban Air Mobility (UAM), the transportation system is once again expected to take a giant leap forward in improving our mobility and the way we live through on-demand air mobility or air taxi service.

With the purpose to improve mobility of citizens in metropolitan area, this study analyzes the required infrastructure needed to support on-demand air mobility. At first, with the past taxi trips data, the study estimates the demands of potential customers that have the highest likelihood to use on-demand air taxi service in Tokyo. A concept of operation of the on-demand air taxi service is proposed, as well as the proposal for installing a fixed number take-off and landing points, referred as vertiports, across Tokyo. With the aim to lower capital and infrastructure construction cost, different numbers of vertiports and air taxis are simulated to meet the predicted demands of trips. The results show that only a small number of vertiports and air taxis are required to obtain a significant time savings for the majority of air taxi trips. Unfortunately, on some unusual trips, air taxis’ performances are on par or worse in comparison with ground taxis’ due to the transportation time required to travel from and to the vertiports. This can be resolved by significantly increasing the density of the vertiports scattered in Tokyo, creating ubiquitous on-demand air mobility but with much higher cost in infrastructure. In exchange for the benefits of time savings, depending on the distance, on-demand air taxis fares are expected to be 40-60% more expensive in comparison to the ground taxis fares.

Keywords
On-demand, air taxi, flying car, vertiport, Tokyo, demand analysis
ACKNOWLEDGEMENTS

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Secondly, I would like to show my thankfulness to Prof. Yoshihide Horiuchi for his feedback and to have introduced me to the President of Daiwa Motor Transportation Co. Ltd., Mr. Maejima, who kindly provided data invaluable to this research. I also appreciate the support and assistance of Assistant Professor Ms. Nakamoto, and representative from Cartivator, Mr. Nakamura, throughout this research.

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CHAPTER I INTRODUCTION

1.1 Needs of Urban Air Mobility

Over the last century, the birth of aviation industry has significantly changed the way we live, work, and travel. Innovations and researches in Urban Air Mobility (UAM) have prompted us to rethink the existing mobility solutions to take it to the next level. Starting from small Unmanned Aircraft Systems (sUAS), which are already available to hobbyists and regular people, to the new prototypes of flying cars that will redefine our travel experience. The rise of UAM related researches and technology have renewed the hopes of on-demand air mobility, with the goal to shorten the travel time within and between metropolitan regions by utilizing Vertical Take-Off and Landing (VTOL) feature[1].

UAM and on-demand air mobility can be part of the solutions needed to address the transportation issues that are plaguing countries across the world. Nowadays, many people have been relying on ground vehicles as one of the primary methods of transportation. In the developing countries especially, public transportations are often overcrowded and suffer from delay, which result in lower reliance from middle to upper class people causing an increase in the number of cars. With the increasing number of cars, traffic congestions have become daily occurrences in many big cities around the
world, with people spending hours daily stuck in traffic jams. As travelling by a flying car would essentially bypass any kind of congestion issues that commonly occur, shorter travel time can be easily achieved. Indeed, flying cars are unlikely to replace the traditional existing transportation systems. Instead, flying cars are able to present new opportunities that did not exist before, as flying cars enable people to travel farther in a faster and safer manner while enhancing their travel experience. As the network of mobility increases, on-demand air mobility will allow people to flow in an affordable way, seamlessly. Figure 1.1 below presents an illustration of how vertical mobility using flying cars are able to augment the existing transportation systems by providing an alternative transportation method through the sky.
While many people may think that flying cars are something that still far away in the future, the reality may not be as far as we expect. Many global and new startup companies invested in the research and development of flying car. In 2018, Ehang announced that its latest Ehang 184 to be the world first self-driving car to flight autonomously at low altitude[3]. However, before this can become a reality there are still a lot of technology challenges and constraints that needs to be addressed. Technology challenges may include but not limited to auto-cruise control systems, obstacle sensing and avoidance, passengers auto-eject function or parachute technology for emergency
landing, lightweight materials, reliable power electronics, and higher-energy-density battery [4]. Of course, to ensure that UAM will have a future in our city, safety is a paramount in enabling on-demand air mobility. Cwerner states that public perceptions of vertical mobility uses are also contingent on perception of urban safety, and if a major accident occurs, especially one with fatalities, then the pendulum of urban air travel will dramatically swing in favour of restrictionists[5]. Ensuring the public that UAM is safe is a major task that the industry has to face. Furthermore, Vascik[6] also identified operational constraints that may inhibit near or far-term implementation of on-demand air mobility such as aircraft noise and community acceptance, the availability of ground infrastructure, community access to take-off and landing areas, aircraft interaction with air traffic control, and the flight density achievable in an uncontrolled airspace. Addressing these operational constraints would also play an important role to integrate flying cars to take flight in the existing transportation system. This paper aims to address the ground infrastructure and air taxi availability constraints for on-demand air mobility service implementation in Tokyo 23 wards area (hereinafter referred to simply as “Tokyo”). Through numerous source such as population data, taxi service, and the availability of existing infrastructures, the study believes that with a small number of ground infrastructures investments, on-demand air mobility may be able to meet the
demands required in Tokyo.

1.2 Transportation Issue in Tokyo

Tokyo as one of the largest metropolis cities in the world is relatively free of serious urban problems. As a major transportation hub, world economic and industrial center, Tokyo boasts as one of the lowest crime rates in the world and free of inner city problems[7]. With the expansive and reliable train systems, Tokyo is also often widely recognized to have the best public transportation systems in the world and had been used as a role model in other countries, with most recently in Indonesia for their Jakarta Mass Rapid Transit (MRT) and Light Rail Transit (LRT) project[8]. At the first glance, and with comparing the current transportation condition with other developing metropolises in the world, Tokyo may be free of transportation problems. However, looking at a bit deeper, issues or concerns that needs to be addressed do exists. Nakamura[7] found that roads in Tokyo have fairly high congestion levels with narrow streets that often caused travel times to be difficult to predict. Meanwhile, during rush hours popular train lines need to transport over 100,000 passengers on 30 trains/hour. Aside from unpredicted delay during rush hours, this also caused passengers to experience unpleasantly crowded trains. This finding is not a surprise as Boelens[9] finds that Tokyo is ranked first in population density in comparison with other metropolises in the world, as shown in Figure 1.2 below.
Due to the high population density, the housing costs in Tokyo are also more expensive than other parts in Japan, thus prompting many people to opt to live outside of central Tokyo. People living in the neighboring provinces are depending on the train systems on daily basis to travel to and from their workplace. The Figure 1.3 below shows census data in 2010 with the estimated number of people commuting into Tokyo, with Kanagawa, Saitama, and Chiba prefectures are recorded with the highest number of commuters. With the flood of people commuting to Tokyo, traffic condition and public transportation in Tokyo are regularly overloaded. According to the census data, in 2010, commuters from out of prefecture, constitutes of more than 30% of the proportion of workers in Tokyo as shown in Figure 1.4 below. Due to the large number of people and their varieties of income, needs, and expectations, on-demand air mobility service would
be able to provide specific target users for a safe, reliable, and fast transportation means in Tokyo.

Figure 1.3 Population Commuting into Tokyo Metropolis by Prefecture (2010) [10]

Figure 1.4 Proportion of Workers in Tokyo [10]
1.3 Flying Car Type

As there is currently no size, design, model, or performance standard for flying cars, each company presented their own flying car prototypes, making their performances vary greatly. In general, however, flying car can be categorized into two different types, multi-rotor and fixed-wing.

1.3.1 Multi-Rotor Type

Multi-rotor type typically uses either a small number of giant rotors or a large number of small rotors to accommodate the vertical propulsion needs located on top of the vehicle. Unlike helicopter who simply use one or two rotors, with optional tail rotor, multi-rotor type utilizes four or more rotors as a mean of propulsion. Volocopter 2x shown in Figure 1.5 below utilizes eighteen rotors, while Italdesign and Airbus Pop. Up in Figure 1.6 utilizes four giant rotors.
Multi-rotor type generally requires less space to land as no wings are involved, however, multi-rotor performance is generally lower in comparison to the fixed-wing type. As each company proposed their own design, even similar multi-copter type may differ greatly in specifications and performances. The following Table 1.1 shows the released Volocopter 2x performance specifications.

Table 1.1 Volocopter 2X Performance Specifications[11]

<table>
<thead>
<tr>
<th>Performance Specification</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Maximum Range (km)</td>
<td>27</td>
</tr>
<tr>
<td>Maximum Cruise Speed (km/h)</td>
<td>100</td>
</tr>
<tr>
<td>Maximum Flight Time (minutes)</td>
<td>27</td>
</tr>
</tbody>
</table>

1.3.2 Fixed-Wing Type

As the name suggest, fixed-wing type refers to flying cars that use wings as the propulsion method. However, it is worth noting that to enable VTOL fixed-wing flying
cars use multiple rotors that are attached to the wings or body of the vehicle. Joby Aviation’s Joby S2 flying car design as shown in Figure 1.7 below is one example of fixed wing vehicle which uses multifunctional rotors technology for electric propulsion[13]. As the requirement to be needing runway to take-off or landing would limit the use cases of flying car, most of the companies that are building flying cars today ensure that their design are VTOL capable.

Figure 1.7 Joby S2[14]
CHAPTER I INTRODUCTION

Figure 1.8 Bell Nexus[15]

Figure 1.9 Lilium Jet[16]
The primary advantages of fixed-wing type flying car is the ability to travel at much faster speed and longer distance in comparison to the multi-rotor type counterpart at the cost of extra space requirement during take-off and landing. Similar to the multi-rotor performance specification, fixed-wing type performance specifications also vary greatly based on each company design. The following Table 1.2 shows the performance specifications of Lilium Jet.

<table>
<thead>
<tr>
<th>Table 1.2 Lilium Jet Performance Specifications[16]</th>
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<tbody>
<tr>
<td>Maximum Range (km)</td>
</tr>
<tr>
<td>Maximum Cruise Speed (km/h)</td>
</tr>
<tr>
<td>Maximum Flight Time (minutes)</td>
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1.4 Air Taxi

The on-demand air mobility aim is to provide air transportation service in urban area as needed and prompted flying car companies to develop their flying cars to be
suitable for this purpose. The vehicle used in on-demand air mobility are simply referred
to air taxis or flying taxis. The Bell Nexus shown in Figure 1.8 above is one of the fixed-
wing flying car models, which is specifically designed for air taxi. With hybrid electrical
or hybrid hydraulic propulsion system equipped with VTOL capability, the aircraft is
capable of operation in airplane mode and helicopter mode optimized to provide urban
air taxi transportation service that can alleviate ground traffic congestion, reduce carbon
emissions, and increase productivity, thereby providing a faster and more efficient means
of transportation[18]. In Consumer Electronic Show (CES) 2019, Bell unveiled the Bell
Nexus design with the maximum speed of 288 km/h and capability to fly up to 241 km.
Bell patent includes two different versions of air taxi models, one that hold one passenger
and a pilot, and one that holds up to six passengers.

As the means of a more efficient transportation, ideally, air taxi should be able to
take-off and land from any locations. However, the author believes that this approach may
not be scalable as the number of small Unmanned Aircraft Systems (sUAS) and other
flying cars increase in the future. Furthermore, obtaining authorization to take-off and
land anywhere within a city would be much more difficult rather than from designated
and pre-determined locations, hereinafter referred as “vertiports”. Taking these into
consideration, Nneji [1], Uber[19], and this study proposed to introduce air taxi service
as an extension of the existing ground taxi service.

A typical trip (depicted in Table 1.3), from the perspective of a passenger, would include six steps. In the first step, (1) the passenger requests the transportation service from a smartphone application. During this request stage, (2) the application identifies the start and end point of the trip, (3) as well as identify the take-off and landing locations. (4) The application immediately checks the current weather condition for the start location, end location, as well as the routes between the locations. If the weather condition permitting, passenger will be able to continue the reservation process and (5) have the option to schedule the trip a couple hours in advance, as well as (6) able to specify whether transport service to and from vertiport is required. Should transport service to vertiport is not required, passenger(s) would be required to arrive at the start vertiport using other means. On the other hand, if passenger requested ground transportation service, a nearby ground taxi would be automatically alerted and proceed to pick up the passenger(s) after the reservation process completed, as shown in step 2 in Table 1.3.

Upon arrival at the vertiport, in step 3, passenger(s) disembarks the taxi and proceed to board the air taxi. The process continue to step 4 where the passenger(s) simply enjoy the air taxi ride to land at the closest vertiport to the destination. Upon arrival, in step 5, the passenger(s) disembarks at the destination vertiport where, in step 6, a ground taxi is
already waiting to take the passenger(s) to their final destination.

Table 1.3 Typical Air Taxi Trip [20],[21],[22],[23]

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1)</td>
<td>Reserve service by smartphone application</td>
</tr>
<tr>
<td>2)</td>
<td>[Opt.] Taxi service pick-up</td>
</tr>
<tr>
<td>3)</td>
<td>Board air taxi from nearest vertiport</td>
</tr>
<tr>
<td>4)</td>
<td>Enjoy the air taxi ride</td>
</tr>
<tr>
<td>5)</td>
<td>Arrive at the destination vertiport</td>
</tr>
<tr>
<td>6)</td>
<td>[Opt.] Taxi service to final destination</td>
</tr>
</tbody>
</table>

1.5 Vertiport

As mentioned in the previous section, the ground infrastructure to accommodate take-off and landing of air taxis is one of the most critical requirements to support UAM. This paper will refer the term for Take-Off and Landing Area (TOLA), as vertiport to represents the type of airport for vehicles that has the capability to take-off and land vertically. At the time of this writing, there is no standard term used to refer TOLA or vertiport, thus other papers or companies may refer the terms differently such as vertistops, skyport[24], or voloport[22]. Volocopter and Skyport announced in May 2019 Greentech Festival, Berlin that the first vertiport (referred as voloport by Volocopter and Skyport) to be built by end of 2019 in Singapore[25].
To truly deliver a door-to-door experience to people in urban area, a dense number of vertiports would be required. Unfortunately, according to NASA\cite{NASA} market research in 2018 the cost of ubiquitous vertiports would be too high and may be unprofitable. However, by utilizing the synergies with ground transportation, air taxi service may be able to serve some highly dense areas, such as Tokyo, as a small number of vertiports would be able to serve certain population target. Furthermore, Tokyo also houses a large number of unused emergency heliports that are largely unused. The next section will introduce more about active and unused emergency heliports in Tokyo.

1.6 Active and Unused Emergency Heliports in Tokyo

In August 2018, Uber as one of the companies that have been pushing for air taxi service, had publicly stated that they have shortlisted Tokyo as one of the five cities for
CHAPTER I INTRODUCTION

the first commercial release of air taxi service in 2023[27]. Although in Uber Elevate Summit 2019 Uber revealed that Melbourne will be the first city outside of United States to trial their Air Taxi project, the author believes Tokyo is still an attractive city for on-demand air taxi service due to the large number of unused emergency heliports that are concentrated in central Tokyo.

According to document from Japan Ministry of Land Infrastructure, Transport and Tourism, there are currently six active heliports in Tokyo[28]. The locations of these heliports are as follow:

- Tokyo Heliport (Public): Koto-ku, Shin-Kiba 4-chome, Tokyo
- Tokyo Metropolitan Police Department: 2-1-1, Kasumigaseki, Chiyoda-ku, Tokyo
- Ministry of Internal Affairs and Communications: 2-1-2, Chugaya Ward, Tokyo
- Tokyo Asahi Shimbun Co., Ltd: 5-2-2, Tsukiji, Chuo-ku, Tokyo
- ARK Hills Mori Building: 1-12-32 Akasaka, Minato-ku, Tokyo
- Shibaura Tokyo Warehouse and Transportation: 3-5-10 Kaigan, Minato-ku, Tokyo

Only Tokyo Heliport, the first on the list, is actually available for public use. The rest are only for private use. It is worth mentioning however, that there is Tokyo to Narita helicopter charter service from ARK Hills Mori building available for public use, showing on the possibility that business arrangement of renting the space for air taxi use is a possibility. However, due to the restrictions, it is hard to imagine using the rest of the active heliports for on-demand air mobility as the helicopter service are already using
From the data courtesy of Air Asahi, one of the helicopter service provider in Japan, in Tokyo 23 wards area alone, there are 66 emergency heliports located on the rooftop of buildings where helicopter can make a rescue landing. However, 19 of these emergency heliports are located at hospitals or a detention center, which are not ideal for air taxi service. This means that there are 47 emergency heliports available as shown in Figure 1.12 below. Although the size of the emergency heliports are small, as an air taxi is expected to weight less and has smaller frame compared to a helicopter, the author believes that using these emergency heliports for pick up and dropping-off passenger with air taxis would be an attractive proposal.
The primary reason of a large number of heliports in Tokyo is due to provincial regulation that all tall buildings above 100 meters are required to have emergency take-off and landing area. So far, these emergency take-off and landing areas are mostly unused, and we believe some of these areas can be repurposed for vertiports.

Despite having a large number of emergency heliports, nevertheless, building appropriate vertiports are still necessary. The emergency heliports are ideal for quick pick-up and drop-off passengers, but at most these emergency heliports may only hold one air taxi, which is not ideal as there will be times when an air taxi need to recharge.
their battery, causing the respective vertiport to be unavailable for other air taxis. In short, a bigger and modern vertiports are still needed. However, with the already available network of emergency heliports available to use, a small number of vertiports may suffice to meet the demands in Tokyo.

![Rooftop Vertiport](image)

**Figure 1.13** Rooftop Vertiport is able to hold Numerous Air Taxis[29]

### 1.7 Urban Air Mobility Traffic Management Issue

In order to make Urban Air Mobility a reality, many challenging issues are essential to be resolved. While companies are focusing on the development of the flying cars or air taxis, it is imperative to look at the rules and regulations on how these units can fly in the urban airspace system. Figure 1.14 shows a snapshot of what potential urban air mobility may looks like. The snapshot shows very little separation between flying cars, and
CHAPTER I INTRODUCTION

whether this is realistic or not is a question remains to be answered.

However, it is worth noting that traffic management is not only involving separation and routes of flying cars or air taxis. It would involve planning of the trips, such as scheduling to ensure that the specific air space route can be used, as well as planning for emergencies. It also needs to consider collision avoidance to ensure no collision in mid-air. Furthermore, ground infrastructure or the vertiports locations, numbers and capacities need to be considered to support the numbers of flying cars or air taxis in the system. Off course, regulations and rules for other flying aircraft such as drones and helicopters need to be accounted for as well. The overview of this traffic management issues are shown in Figure 1.15 below.
The study originally focused on the control issue, depicted in the dashed-red box in Figure 1.15. However, the author found at UTM (Unmanned aircraft system Traffic Management) Symposium held in March 2019, extensive study of collision avoidance and control of sUAS had already been extensively studied. Due to this, the author shifted focus to the design of the number of vertiports and air taxis to support business realization of on-demand air mobility, which is shown in the solid-red box in Figure 1.15. Evaluating the number of vertiports and air taxis are important factors to be considered as they would be the bottlenecks that may limit the growth of demands, which may affect the merits of using on-demand air mobility.

1.8 Objective of this Study

The main objective of this study is to support the realization of on-demand air
mobility in Tokyo through the design of numbers of vertiports and air taxis. The required locations and quantities of ground infrastructure service, namely the vertiports, are necessary to support and facilitate air taxis and their customers in Tokyo and can be seen as one of the bottlenecks to realize on-demand air mobility as building infrastructure will cost space and money. Similarly, number of air taxis in operation need to be investigated as having air taxis that empty all the time, due to the lack of demands, would be just an unnecessary cost, while having too little air taxis would be unacceptable as ensuring faster and safer transportation choice would be the objective of on-demand air taxi system. Considering this, the study seeks to propose the minimum number of vertiports and air taxis required, by the use of simulation based on the data of expected demands received from an actual taxi company to balance the infrastructure necessary with the expected demands.

A multi-agent simulation replicating on-demand air taxi operation concept was created to simulate the use cases in Tokyo while considering other variables that may affect the air taxi operation such as weather and demands. The associated objectives are to verify that on-demand air taxi is beneficial to customer as a mean of transportation within Tokyo and to provide guidelines to on-demand air mobility service provider of recommended infrastructure and investment needed to realize UAM in Tokyo.
At the high level, the objectives of the study can be seen on Figure 1.16 below, while the red box highlights what is the focus of this study. The number of demands are obtained through historical taxi data from Daiwa. Furthermore, user merits would drive the price and demands of air taxi. In order for on-demand air taxi service to have merits to its passengers, the service has to ensure that on-demand air taxi is significantly faster than ground taxi. Furthermore, customers’ waiting time for the service also have to be short enough to ensure faster trip completion. In order to improve these two values, number of vertiports and air taxis of the system have to be increased. However, increasing the number of vertiports and air taxis would be a cost to the air taxi company, which may eventually influence the price and demands of air taxi. Essentially, a good balance of the number of vertiports and air taxis have to be determined, while ensuring consumers merits to ride on-demand air taxi remains high. The simulation software is required as it allows the author to measure the user merits as the system variables change, which is an important objective in this study.
1.9 Literature Review

Since early 2010s, with the availability of sUAS, commonly known as drone, many previously challenging tasks had become easier and simpler to be completed. From photography and video, survey, parcels delivery, and search and rescue, sUAS has proven its value to assist us in our daily life. Military forces across the globe also often used drone for reconnaissance or other military purposes. While its usage are still restricted, sUAS has opened a new frontier as people start looking for air transportation solution to alleviate congestion issue plaguing major cities around the world. While personal flying cars would be the utopia, realizing this would be challenging and may take a considerable amount of time, and would not happen without a more advanced technology,
standardization in regulation, as well as public acceptance. Realizing these barriers during our research, we believe very specific use cases such as on-demand air taxi and air ambulance may help us to convince the public about flying car, and provide time to allow the technology to mature. As air ambulance usage is very limited, the author focuses the study to on-demand air mobility or air taxi instead. In order to design and propose an ideal air taxi service for Tokyo, we need to look past researches related to air taxi and UTM, as well as looking into real data of current land transportation system in Tokyo.

First, the concept of operation of air taxi has been proposed by many companies and researched intensively. Nejei and her team[1] have highlighted air taxi concept of operation in their research which include multiple phases from passenger request of flight through mobile application, up until arrival at the destination by air taxi. While automation on this case is still limited due to the use of pilot, we believe that achieving full automation on air taxi operation would be challenging in the early stage of air taxi service. Therefore, we believe that on-demand air mobility, with pilot onboard and partial automation, can be realistically planned for 2035 in Tokyo Metropolis, which also aligns to the roadmap towards air transportation revolution published from Japan Ministry of Economy, Trade and Industry as shown in Figure 1.17. Of course, with the advancement of technology and society acceptance, we do believe that in the future that fully automated
Furthermore, in order to realize a scalable and efficient Urban Air Mobility, vehicle-to-vehicle communication technology, which is part of Intelligent Transportation System (ITS) application also had been studied. The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT), developed by United States Department of Transportation, has provided a common framework for planning, defining, and integrating intelligent transportation systems[32]. ARC-IT, as shown in Figure 1.18 is a mature framework, which provides common basis for planners, and engineers with differing concerns to conceive, design and implement systems using a common language.
The example of the application of this framework is vehicle-to-vehicle Intersection Movement Assist, which provides safety measure when car crossing intersection and detects dangerous cars through vehicle-to-vehicle communication, as shown in Figure 1.19 below.

Figure 1.18 Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)[32]
Next, in the sUAS or drone area, many researches investigating efficient traffic management also had been studied. Battista[34] proposed an air highway implementation to ensure separation between drone traffic in a dense area which performs better than free flow traffic. On the other hand, Yakovlev coined a new algorithm for new path finding method for multi-copter sUAS. Although, traffic rules and regulations for on-demand air mobility may differ to each other, ultimately, both sUAS and on-demand air mobility would exist in the same airspace, and may share many similar behavior in UAM. Golding defined two different metrics to measure density of traffic in an airspace. The first is minimum closing time, which is the measurement of how long the ownship have before another vehicle might collide with it[35]. The second metric is the number of close aircraft,
which provides some insight into how often the ownship will avoid one aircraft only to have maneuver again to avoid a different one and how many other aircraft the ownship needs to be tracking\[35\].

Moreover, studies on UAM have been increasing exponentially within the last year as well. One very interesting research is a paper by Bosson[36] from NASA Ames Research Center that evaluated Autonomous UAM network management and separation in Dallas-Forth Worth metroplex. Using NASA developed AutoResolver algorithm[37], Bosson found in a dense two-hour traffic scenario, when spatial horizontal separation was reduced to 0.1 nmi (185m) the total delay decreased by 7.3%, and when the temporal separation was reduced from 60s to 45s, the total delay decreased by 28.4%, with total conflict resolutions decreased by 26% and 17% respectively. To safely manage UAM traffic in a dense area is a very challenging task, and while simulation can help in analyzing and mitigating the risks, lawmakers and government may not be convinced in a sudden implementation of UAM, which have little room for mistakes. Fortunately, in Tokyo 2035, we believe that demands for air taxi service would be low, which provide us some time to build the confidence in the system and work with larger horizontal separation to focus on the safety. Researches on reducing noise issue produced by the rotors used in air taxi[38] also had been conducted. Vascik[39] defined the scaling of
noise annoyance through literature survey, and found that noise annoyance to be subject to five mechanisms: acoustic (e.g. frequency, duration), secondary effect (e.g. vibrations, blown dust, shadows), privacy (e.g. altitude, number), listener (e.g. fear of service, noise sensitivity), and situational (e.g. time of day, day of week, weather) properties of the aircraft operation. Furthermore, it is also worth noting that flying car noise is also significantly more audible during the take-off and landing phases.

In regards to vertiports placement, in his paper Holmes[40] argued that 30 minutes’ drive from the take-off and landing facilities would be quite fortunate in the case of United States. However in Japan, this statement may hold true in rural area where population is much less and traffic jam is rare, but in the fast-paced urban area like Tokyo, driving for 30 minutes to the closest vertiport would likely cancel out the benefit of using air taxi in the first place due to well networked train system. In a more recent study, German[41] argues that placement between 7-8 vertiports in a dense area concentrated area of San Francisco Bay would be able to meet demands for a maximum 10-minute driving time neighborhood. In order to achieve an easy to reach on-demand air mobility service in an urban area, placement and number of vertiports have to be carefully measured in order to handle the customer demands efficiently.
1.10 Purpose and Originality

Despite the novel approach of resolving congestion issue using UAM, air taxi may not be suitable as a transportation solution to all metropolis in the world. Although, on-demand air taxi is expected to cost much less than helicopter ride sharing service the cost is still expensive in comparison to other means of ground public transportation and, except for people with high income, most people are unlikely to use the service on regular basis. As a reference, Lilium estimated that six minutes flight of air taxi would cost about ¥7,500, while eight minutes flight for the same distance using Uber helicopter ride sharing service would cost about ¥21,500[42].

With the goal to reduce, and ultimately eliminate, wasted time on the road due to congestion, this paper analyzes whether Tokyo can be a good candidate city to develop on-demand air mobility service. As discussed in Section 1.4, the number of vertiports and air taxis, are considered as one of the primary bottlenecks of delivering a ubiquitous on-demand air mobility service in an urban area. By analyzing the taxi demands in Tokyo, as well as, identifying the popular locations of the trips, the author seeks to answer the following three main questions. First, is to determine how many vertiports would be required to satisfy the expected demands of on-demand air mobility in Tokyo in 2035. The second is to investigate how many air taxis in service would be required to satisfy
the demands while ensuring that customer would not be waiting for more than 5 minutes to obtain on-demand air mobility service. Finally, armed with the knowledge of optimal number of vertiports and air taxi, the author ascertains how much time can air taxi save when comparing with other means of transportation for commuters in Tokyo.

Previous studies such as German[41] used combination of census data, Google Maps API, and optimization to determine vertiports placement and number in an area. Furthermore, German[41] considers that each flying car would travel only on one specifically designed route, which would not be scalable as the number of routes increase. Meanwhile, Vascik [38] used combination of current helicopter service data, census data, and consumer wealth data to understand the estimate of on-demand air mobility demands and use the existing heliports as vertiports to propose on-demand air mobility operation. This study on the other hand, obtained an actual taxi trip data from a taxi company in a high-density area to forecast and measure the demand of on-demand air mobility. Once the expected demands are identified, the study utilized multi-agent simulation software, Anylogic, to visualize and measure travel and waiting time that influence the users merits in on-demand air mobility by analyzing the impact of the number of vertiports and air taxis, which have never been done in previous study before.
1.11 Personal Motivation

Working in a fast-paced and always changing Information Technology industry, I was involved in many different IT projects where I had to work with people from different background and discipline. Throughout my career, I had been involved in poorly managed projects, such as one where needs and requirements are not clearly defined, which then lead to a poor execution, lengthy delays, and subpar solutions. Having experienced this, I was motivated on learning the necessary techniques and skills that can empower me to contribute more on future projects.

As a master’s candidate in Keio’s System Design and Management, I studied systems engineering as well as project management, with focus on complex problem solving using systems thinking approach. I realized that the flying car project is a good opportunity to give me the exposure to solve complex issue and utilize the skillset that I learned through the courses of my graduate school. Similar to several Information Technology projects that I have been involved in the past, flying car system is a novel and unexplored territory, and extensive researches and collaborations need to be done to address many questions and issues surrounding the system. I strongly believe that not only technical skills sets are required in solving both IT and flying car projects, but extensive collaborations and communications are paramount in ensuring the success of
1.12 Structure of this Paper

The study is separated into three main phases. First, the study collected and analyzed data gathered through technical meetings and discussions, site visits, and workshops to identify the challenges and barriers of realizing on-demand air mobility in Tokyo. Afterwards, sample data were gathered by obtaining actual taxi trips history from a taxi company, which then would be analyzed to gather new insights of customer demands and behavior. Finally, a simulation was developed to portray, verify, and validate our speculated findings by using demands analysis data gathered from the previous steps. The process of research design and methods overview can be seen in Table 1.4 below.
### Table 1.4 Research Design and Methods

<table>
<thead>
<tr>
<th>Research Method</th>
<th>Research Objective</th>
<th>Processes</th>
</tr>
</thead>
</table>
| 1. Workshops    | • Gain knowledge of existing researches  
                 • Identify current challenges to on-demand air mobility in Tokyo  
                 • Identify the researches needed to implement on-demand air mobility in Tokyo  
                 • Estimate the potential needs of on-demand air mobility in Tokyo | • Visited Cartivator workshop in Nagoya  
• Attended Drone Expo 2019 and UTM 2nd Symposium in 2019  
• Discussions with Doctor Helicopter pilot, Sightseeing Helicopter pilot, President of Daiwa Motor Transportation Co., Ltd. were conducted  
• Technical meetings with industry experts, such as researchers from Toyota, Cartivator, were regularly held |
| 2. Taxi Trips Historical Data | • Understand the customer behavior of taxi trips in Tokyo  
• Analyzing the demands of taxi trips in Tokyo | • Taxi past historical data were gathered and analyzed  
• Data were summarized and presented in meaningful graphs  
• Developed hypotheses to speculate expected outcome |
| 3. Simulation Model | • Verify and validate the hypotheses by using multi-agent simulation with data gathered from the previous phase  
• Gain insight of the infrastructure and vehicle needs to realize on-demand air mobility in Tokyo 23 wards  
• Measure the performance and time saving benefits of on-demand air taxi in comparison with ground taxi | • Parameters to be used in the simulation were identified and determined  
• On-demand mobility simulation for Tokyo 23 wards were developed using Anylogic software  
• Results were gathered and summarized to be presented in meaningful graphs |
CHAPTER II METHOD

The study seeks to explore a new frontier opportunity for on-demand air mobility service in a highly populated urban area by presenting its findings as accurate as possible.

To achieve this, the methods used in this study contain:

- **Workshop, Site Visits, and Discussions Data** | To gain knowledge of the industry, explore the issues that need to be addressed, as well as obtaining firsthand information from subject matter experts.

- **Analysis of Taxi Trip Historical Data** | To gather an accurate representative of the expected on-demand air mobility demands in Tokyo, the past taxi data trips history were analyzed.

- **Development of Hypotheses** | Based on previous studies, discussions, and taxi data, hypotheses were developed to answer the research questions.

- **Simulation Model** | Simulation setup and logic were discussed. The simulation allows the author to verify the previous hypotheses and measure the performance and benefits of on-demand air mobility

2.1 Workshop, Site Visits, and Discussions

In order to obtain relevant and accurate data and information, the author as a member of Keio University Flying Car Laboratory, visit sites, workshops, museum, and
companies that may be able to provide relevant data to the study. Discussions with the subject matter experts, such as helicopter service providers, helicopter pilots, flying car engineers, and a taxi company president. This section would provide the information of the visits and discussions that had been done during this study, while the findings would be explained in Section 3.

In May 2018, Keio University Flying Car Laboratory team visited Chiba Hokusoh Hospital, one of the hospitals in Japan that provide Doctor Heli service, which is the air ambulance service in Japan. The visit provided the team with the opportunity to see the helicopter closely, as seen in Figure 2.1, and discussion with one of the helicopter pilots as well as one of the doctors to gather the information relevant to our researches.

Figure 2.1 Visit to Doctor Heli Team at Chiba Hokusoh Hospital on May 2018
Keio University Flying Car laboratory team also visited Cartivator’s workshop, as the only company in Japan that is researching flying car, in Nagoya on November 2018. Figure 2.2 shows a photo inside of Cartivator workshop. Unfortunately, as Cartivator research is still in progress, a more detailed photo of the inside of the workshop cannot be shown. We are able to meet with Cartivator’s engineers, as well as see directly the progress of their project.

![Cartivator Workshop](image)

**Figure 2.2 Visit to Cartivator Workshop on November 2018**

The visit to Nagoya did not only ended with Cartivator, as we also visited Toyota Commemorative Museum of Industry and Technology to study about car and Toyota. The museum display the factory building used by the Toyota group in the past, and allow us to easily learn about shifts in technology of the industry through dynamic displays and machine demonstrations.
In order to experience about travelling short distance by air, our laboratory also visited Excel Air Service at Urayasu Heliport. As one of the companies who provide sightseeing helicopter service in Japan, we are able to experience riding a helicopter and ask questions to the helicopter pilot as well as the manager of the company to understand about the service and potential demands.
As flying car shares many similarities with sUAS, the author also visited Drone Expo 2019 held in March at Makuhari Messe. The author able to meet and discuss with many industry experts, listen to presentations on the latest research on drone, and see the latest drone functionalities and performance through live demonstrations.
In March 2019, the author also attended UTM Symposium at University of Tokyo to listen and study about the most recent studies of UTM fields. Furthermore, aside from the above already mentioned visits, we also held a number of discussions and meetings with industry experts, such as representative from Daiwa Motor Transportation Co., Ltd., Aero Asahi, Toyota, and Bell Helicopter pilot who provided us with continuous feedbacks and guidance throughout the research.

2.2 Analysis of Taxi Trips Historical Data

In order to estimate the expected customer demand of transportation in Tokyo, taxi trips data were gathered. After a discussion with the President of Daiwa Motor
Transportation Co., Ltd., Mr. Maejima, Daiwa agreed to kindly provide us with the historical taxi data for the purpose of the research.

The data format received from Daiwa are very comprehensive and recorded in Excel spreadsheets and consist of 55 different columns of information. All of the data are in Japanese, and the author translated the relevant information to English. As not all of the 55 columns of information were relevant to this research, only 12 columns were shortlisted and used. The sample data can be seen in Table 2.1 below.

**Table 2.1 Historical Data Fields and Sample from Daiwa Taxi**

<table>
<thead>
<tr>
<th>Data Category</th>
<th>Data Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>2019/04/26</td>
</tr>
<tr>
<td>Vehicle #</td>
<td>1422</td>
</tr>
<tr>
<td>Trip #</td>
<td>22</td>
</tr>
<tr>
<td>Departure Time</td>
<td>2019/04/26 17:30</td>
</tr>
<tr>
<td>Departure Location</td>
<td>東京都港区芝公園2丁目</td>
</tr>
<tr>
<td></td>
<td>Shibuya Koen 2-chome, Minato-ku, Tokyo</td>
</tr>
<tr>
<td>Arrival Time</td>
<td>2019/04/26 18:14</td>
</tr>
<tr>
<td>Arrival Location</td>
<td>東京都大田区羽田空港3丁目</td>
</tr>
<tr>
<td></td>
<td>Oota-ku, Haneda Airport 3-chome, Tokyo</td>
</tr>
<tr>
<td>Actual Distance</td>
<td>18.4</td>
</tr>
<tr>
<td>Actual Drive Time</td>
<td>0:25:00</td>
</tr>
<tr>
<td>Vehicle Operation Time</td>
<td>0:36:00</td>
</tr>
<tr>
<td>Fare</td>
<td>7220</td>
</tr>
<tr>
<td># of Passengers</td>
<td>1</td>
</tr>
</tbody>
</table>

All the data received from Daiwa were analyzed and the results are studied for the purpose of this research and presented on Chapter III.
2.3 Development of Hypotheses

Tokyo is unique in a way, due to the unusually high density and small area. High crowds and congestions are norm, but to support this a well-established train and road infrastructure ensure that the people would not have any issue in reaching their destination. Nakamura[7] found that 78% of commuters in Tokyo 23 wards would use mass public transport, while the taxi users are consist only less than 5% of commuters in Tokyo 23 wards. With an expected of relatively small demands for travel only within 23 wards, we expect that:

**H1 |** A small number of vertiports (between 8-12) located in central and easy to access area are enough to meet the majority of customer needs in Tokyo 23 wards.

Furthermore, the results of taxi trips data received from Daiwa also shown that the majority of demands for longer taxi trips that occurred within 23 wards only happen during nighttime. Due to the noise concern sensitivity, flying at night would be a big hurdle to resolve, and we expect that air taxis can only be flown during daytime, which likely to impact the number of customer demands, as well. Therefore, this brings us to believe that:

**H2 |** Due to low expected demands, a small number (between 6-8) of two passengers air taxis would suffice to meet the commuters demands in Tokyo 23 wards, while ensuring that commuters would not wait for more than 5 minutes.

Lastly, due to the small number of vertiports, ubiquitous on-demand air mobility
would not be possible. This translates that customers are likely need to walk, take a
ground taxi, or other means of transportation to reach the vertiport to take-off, as well as,
to travel to the final destination from the vertiport where they land. These introduced
significant delay to the whole trip, which lead us to believe that:

| **H3** | Due to the relatively small area of Tokyo and well-established road and train
infrastructure, we expect that air taxi can save only up to 30% of the commuters’ time
in comparison with other means of transportation. |

2.4 Simulation Model

In order to verify and validate the hypotheses stated in the previous section, a multi-
agent simulation software, Anylogic, is used to conceptualize the situation at Tokyo. This
section will discuss the details of the simulation setup.

2.4.1 Simulation Area

The area of our interests are Tokyo area. Therefore, we limit our simulation setup
to only the Tokyo 23 wards, which means that start and end location of the trip orders are
also only within the Tokyo 23 wards. The area covered for the simulation are shown in
Figure 2.6 below.
Aside from the geographical location of Tokyo 23 wards, two special areas are also defined in the simulation. The first one is a no-fly zone, which is located at Chiyoda, depicted in red border. The second area, depicted in blue border, is an area that encounters temporary no-fly condition. For our case, we decide a case of heavy rain, where traveling from and to the impacted area are not possible. While the red border is always visible all the time, the blue border is only visible on certain periods of time, which are triggered by
the data of rain probability or other weather restrictions in Tokyo. The close-up view of the two special areas can be seen in Figure 2.7 and 2.8 below.

2.4.2 Simulation Agents

There are six different agents that are being used in the simulation, as depicted in Table 2.2. Red dash line is also shown in the simulation to depict the air route used by the air taxi.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Represent</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="symbol" alt="Unoccupied ground taxi" /></td>
<td>Unoccupied ground taxi</td>
</tr>
<tr>
<td><img src="symbol" alt="Occupied ground taxi" /></td>
<td>Occupied ground taxi</td>
</tr>
<tr>
<td><img src="symbol" alt="Unoccupied air taxi" /></td>
<td>Unoccupied air taxi</td>
</tr>
<tr>
<td><img src="symbol" alt="Occupied air taxi" /></td>
<td>Occupied air taxi</td>
</tr>
</tbody>
</table>
2.4.3 Simulation Parameter

Parameters used in the simulation are determined and shown in Table 2.3 below. As we expect fluctuation on some parameters, such as air taxi speed and boarding or disembark time, random distribution is used to specify the value of each agent during runtime.

<table>
<thead>
<tr>
<th><strong>Table 2.3 Simulation Parameters</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation Time</strong></td>
</tr>
<tr>
<td><strong>Order Quantity</strong></td>
</tr>
<tr>
<td><strong>Order Generation Method</strong></td>
</tr>
</tbody>
</table>
| **Expected Demands** | Central Tokyo: 55%  
South Tokyo: 15%  
Remaining Area: 30% (random distribution) |
| **Air taxi Speed** | 180-200 km/h |
| **Air Taxi Max Passengers** | 2 people + 1 pilot |
| **Number of Air Taxi in the System** | 5 units |
2.4.4 Air Taxi Simulation Logic

The simulation is programmed using Java in the back-end; however, the flow of the simulation can be depicted as shown in Figure 2.9 below. At the start of the simulation, each air taxi would stand by on a randomly selected vertiport. Once an order comes in, an available air taxi would go to the nearest vertiport from the customer(s) current location, if there were no air taxi already available on the respective vertiport. During this stage, air taxi would always check the weather condition and ensure that the start and end location of the route are not hindered by conditions that may affect the flight, such as heavy rain or typhoon. Once customer(s) has boarded, the air taxi would deliver the customer(s) to the vertiport closest to the customer(s) final destination. Upon arrival, customer(s) would disembarks and the next steps are handled by ground taxi to take customer(s) to the final destination. Meanwhile, air taxi would go into maintenance stage to recharge battery, if required, and go back to standby awaiting the next orders.
2.4.5 Vertiports Location Candidates

While Tokyo have six active heliports and sixty-six emergency heliports, using the current active heliports may be challenging as they are owned by business and are actively being used by helicopter. However, the emergency heliports can be considered to be used as transit locations to pick-up or dropping-off passengers as close as possible to the destination. Unfortunately, the current emergency heliports are not spread evenly to cover Tokyo, and we expect that they are too small and can only support one air taxi at a time. Due to these reasons, we believe that installation of small number of vertiports, which
can support at least three air taxis, spread across Tokyo area are necessary for on-demand air mobility. For this study purpose, ten different locations are selected as candidate for vertiports locations.

These locations, shown in Table 2.4, are considered due to their centralized locations, easy access via public transportation, as well as highly popular location based on taxi trip data. The locations of these vertiports are spread across Tokyo to maximize the area covered.

**Table 2.4 List of Proposed Vertiports Location Candidates**

<table>
<thead>
<tr>
<th>No.</th>
<th>Location Photo</th>
<th>Location Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1" alt="Figure 2.10" /></td>
<td><strong>Figure 2.10 Tokyo Station[43]</strong></td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2" alt="Figure 2.11" /></td>
<td><strong>Figure 2.11 Arkhills[44]</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td><strong>Figure 2.12</strong> Meguro Station[45]</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td><strong>Figure 2.13</strong> Haneda Airport[46]</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td><strong>Figure 2.14</strong> Seijo Gakuen Mae Station[47]</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td><strong>Figure 2.15</strong> Nerima Station[48]</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>Figure</td>
<td>Station</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>7.</td>
<td>2.16</td>
<td>Shinjuku Station[49]</td>
</tr>
<tr>
<td>8.</td>
<td>2.17</td>
<td>Ayase Station[50]</td>
</tr>
<tr>
<td>9.</td>
<td>2.18</td>
<td>Kinshicho Station[51]</td>
</tr>
<tr>
<td>10.</td>
<td>2.19</td>
<td>Funabori Station[52]</td>
</tr>
</tbody>
</table>

2.4.6 Route

In this study, each vertiport services a limited number of routes, as in on-demand air mobility we believe that routes will be demand driven. Although static routes may exist for popular routes that are in high demands, other pre-determined routes may be modified or updated as demands shift. Passengers would ideally be able to reserve seats,
while the program optimized the route automatically based on the current weather condition, traffic density, and time it takes to complete the trip.

At the current model of on-demand air mobility studied and simulated on this paper, passengers would be transported by ground taxi if the location to the vertiport is too far. Due to the proposal of only having ten vertiports over Tokyo, ubiquitous on-demand air mobility would not be able to be achieved. However, the study investigated a potential approach of utilizing the existing unused emergency heliports in Tokyo as local vertiports that can help in transporting passengers faster. In Figure 2.20, if a passenger at location A, depicted with orange triangle, wants to go to location B, the passenger first would need to reach the nearest vertiport at Haneda, depicted with orange box. The air taxi then would transport the passenger to Meguro. However, location B is still too far from Meguro vertiport. Taking ground taxi would cause the trips to be significantly longer. The study suggests to utilize the unused emergency heliports in Tokyo as an extension to reach the destination as depicted by the red arrow in Figure 2.20. Unfortunately, due to limited time, the simulation on extending on-demand air mobility route to include emergency heliports is outside of the scope of the current study. The current study focuses on establishing the design of numbers of major vertiports and air taxis in Tokyo.
In summary, the current ten yellow vertiports location specified in this study are, the major vertiports, purposely located at central area, which are easy to access, in hope that in the expansion in the future, these vertiports may also support routes outside of Tokyo. On the other hand, the green vertiports in the simulation, which represent the existing emergency heliports are designed to be setup as more localized vertiports that only support limited intra-city travels, such as air travel between green vertiport to the
closest yellow vertiport and travel between green vertiports in the same area.

2.4.7 Collision Avoidance

In the early stage of the study, collision avoidance was one of the main objectives due to its importance in ensuring safe flight of Urban Air Mobility. The author studied several studies, and investigated four difference avoidance methods to compare its efficiency projecting a two ways traffic in an air intersection. The vertical avoidance method based on Battista’s study [34] shown in Figure 2.21, which prompt both vehicles to vertically avoid each other upon detection of potential collision within 250 meter. Next is the horizontal avoidance method discussed in Balachandran’s study [53] shown in Figure 2.22, which prompt the vehicle detected the potential collision to move sideways to avoid collision. As well as slow down method and stop method, which the authors came up with, shown in Figure 2.23 and 2.24 respectively. The slow down and stop method simply prompts the vehicle which is detecting the potential collision to either slow down or stop to allow the other traffic to pass through. The collision detection used in each method is triggered once the vehicles are located within 250 meter to each other. The early findings found that horizontal avoidance method performs slightly better in comparison with slow down and stop method, while vertical avoidance is lagging behind.
CHAPTER II METHOD

Figure 2.21 Vertical Avoidance Method

Figure 2.22 Horizontal Avoidance Method
However, after attending Drone Expo 2019 and UTM Symposium 2019, the author finds that extensive researches have been done on collision avoidance used for drone, which bares many similarities to the collision avoidance originally planned for this study.
Considering this finding, the author shifted the focus of the study and decided to the infrastructure requirements for on-demand air mobility instead. Furthermore, data from Daiwa also revealed that we are expecting low density of air taxi flights in the Tokyo in 2035, thus while collision avoidance is an important area that cannot be forgotten, we do not expect too many traffic in the sky. However, as part of ensuring the possibility of business realization of urban air mobility, the next section will discuss the findings on collision avoidance that the author found.

In her research, Ho suggested multiple layers for Conflict Detection and Resolution (CDR) system for drone usage which we implemented for air taxi[54], as shown in Figure 2.25. These multiple layers redundancy helps in ensuring prevention of collision. The inner layer, which is shown with red circle in Figure 2.25, is the radius of the actual drone, or in our case, air taxi. The middle layer, which is shown with yellow circle in Figure 2.25, is navigation system error, which is the first CDR redundancy. We proposed this size to be 100% of the physical radius size of the flying car. This layer acts as backup in preventing any positioning or navigation error that may occur during the flight. Lastly, the outer layer, shown with green circle in Figure 2.25, is the separation minimum, which is the actual separation distance that we need to keep between each air taxis. This is the second CDR redundancy, which is used in the CDR algorithm.
This brings the question of how long is the required separation minimum. Cook proposed a *well clear* definition standard for sUAS, where an ideal separation between each drone to be 1.2 km horizontally and 213 m vertically[55]. However, during one of our discussions with a helicopter pilot suggested that the horizontal distance is too long, and perhaps a couple hundred meter would be sufficient for flight using virtual flight rules (VFR).

Based on this feedback we look further into separation standard used by aircraft. In Australia, when using instrument flight rules (IFR), the horizontal separation standard is defined to be 9.26 km and vertical separation standard is set to be 305 m. On the other hand, in Australia as well, when aircraft is flying using VFR, both of the horizontal and vertical separation standard is reduced to 152 m[56]. As we expect an air taxi to fly using IFR with much lower speed in comparison to a commercial plane, we propose a separation
standard of 305 m both horizontally and vertically for air taxi service in Tokyo 2035, as shown in Figure 2.28.

Figure 2.26 Separation Minimum for IFR Aircraft[57]  Figure 2.27 Separation Minimum for VFR Aircraft[58]  Figure 2.28 Recommended Separation Minimum for Air Taxi[59]
CHAPTER III FINDINGS

3.1 Findings from Discussions

While hundreds of paper related to on-demand air mobility and UAM were found, very few of them actually focused on infrastructure required to support the technology, which is the vertiport. Vertiport is simply a take-off and landing area used for air taxi, placement, access, and demands had to be considered to optimize numbers and placement of this critical infrastructure. In his study, German[41] proposed optimization model for vertiports placement in San Francisco Bay Area for cargo delivery purpose, but the real data of cargo shipment were not obtained to verify the accuracy of the model. Furthermore, each aircraft used in the study was restricted to one single route, which is not scalable as the number of routes increase.

As part of the members of Keio Flying Car laboratory, numerous meetings and discussions with industry experts were also conducted. During one of the discussions with Aero Asahi, we able to receive the list of emergency heliports that are available in Tokyo to consider of their potential future use for UAM. Furthermore, in a discussion with Dr. Motomura from Chiba Hokusoh Hospital, we also learned from the Doctor Heli pilot that landing often becoming a challenge during a mission. Occasionally, helicopter had to land far away from the incident location due to lack landing space. We also learnt that during
winter or typhoon season, there are times when Doctor Heli would not be able to dispatch
due to weather condition.

In Keio Flying Car Laboratory, Payuaviorakulchai, investigates about cost of
operation of eVTOL (electric Vertical Take-Off and Landing) flying car[60]. She found
that as the distance increases, the costs of operation increases as well as shown in Figure
3.1 below. The costs of operation includes crew cost, battery replacement cost, energy
cost, maintenance cost, interest cost, and insurance cost among others. However, the costs
of operation do not include the pick-up passengers’ costs that the company has to bear
when there is no standby air taxi available on the selected vertiport and company profits
expectation.

![Figure 3.1 eVTOL Cost of Operation Based on Distance](image)

3.2 Findings from Analysis of Taxi Trip Historical Data

With the courtesy of Daiwa Motor Transportation Co. Ltd., Table 3.1. shows the
summary of one week data that we received, spanning between April 21 and April 27, 2019. A wider sample of data is actually ideal, but due to the huge number of data and limited time, one week of data was deemed sufficient to analyze the passengers behavior and ground taxi demands in Tokyo. During this time span, 62,499 trips are recorded.

As we are interested in the taxi trips where customers have more likelihood to benefit from air taxi, we separated the data into two columns. One where the taxi fares are less than ¥5,000 or approximately trips that are less than 8 km and the other one is where the taxi fares equal or more than ¥5,000 or approximately trips that are more than 8 km. If the trips are too short, we expect that there would be no need to use air taxi, as going to the vertiport with a ground taxi would lengthen the trips unnecessarily. Therefore, we expect that our passengers use base would be passengers that are using taxi and paying for more than ¥5,000 or using the ground taxi for trips that are approximately farther than 8 km.

Table 3.1 Taxi Trip Data Summary April 21-27, 2019

<table>
<thead>
<tr>
<th></th>
<th>&lt; ¥5,000</th>
<th>&gt;= ¥5,000</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Trips</td>
<td>57,899 trips</td>
<td>4,610 trips</td>
</tr>
<tr>
<td>Average Trips Duration</td>
<td>11 minutes</td>
<td>38 minutes</td>
</tr>
<tr>
<td>Average Actual Driving Time</td>
<td>7 minutes</td>
<td>28 minutes</td>
</tr>
</tbody>
</table>
CHAPTER III FINDINGS

<table>
<thead>
<tr>
<th>Approximate Trips Distance</th>
<th>&lt; 8km</th>
<th>&gt;= 8km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Trips Fare</td>
<td>¥1,460</td>
<td>¥8,881</td>
</tr>
<tr>
<td>Average Trips/Day</td>
<td>8,928</td>
<td>659 trips</td>
</tr>
<tr>
<td>Number of Passengers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 person</td>
<td>84%</td>
<td>81%</td>
</tr>
<tr>
<td>2 people</td>
<td>11%</td>
<td>14%</td>
</tr>
<tr>
<td>3 people</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>4 people</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>&gt;4 people</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

First, we are interested in the area that are popular with the taxi passengers who use Daiwa taxi for more than 8 km or approximately more than ¥5,000. As the locations of taxi trip vary by wider margins, we grouped the Tokyo area by proximity, to six separate area as follow:

- Central Tokyo: Chiyoda, Minato, Chuo, Shibuya, Shinjuku, Bunkyo, Taito, Sumida, and Shinagawa
- South Tokyo: Oota
- West Tokyo: Setagaya and Meguro
- North Tokyo: Nerima, Suginami, Nakano, Itabashi, Kita, and Toshima
- North East Tokyo: Katsushika, Adachi, and Arakawa
• East Tokyo: Koto and Edogawa

Figure 3.2 shows the results of the area popularity. To measure the popularity of the area, each taxi trip would count as one point. As a taxi trip would consist of one start location and one end location, each of these location would be given 0.5 point. For example, if a trip record shows a passenger take a taxi from Chiyoda to Oota, then Central Tokyo and South Tokyo would be given 0.5 point each. This would ensure a fair distribution between start and destination, to measure the popularity of the area.

![Figure 3.2 Popular Area for Longer Distance Taxi Trip (¥5,000)](image)

Moreover, as we expect that demands of taxi also vary by time, we measured at what time people are often using taxi for longer distance travel. Figure 3.3. shows a graph
that is separated into eight different time frames over 24 hours window. Unexpectedly, the analysis shown that the majority of the trips occur between 21:00 to 03:00. The primary reason that we expect of higher than usual longer distance taxi trips is due to train schedule. Depending on the train company and route, trains in Tokyo are generally stop after midnight, and as people missed the last train, people have no choice but to take taxi to get home. Unfortunately, due to the expected noise constraint of flying with on-demand air mobility or air taxi at night, this finding signifies that we are potentially expecting a very low demands of air taxi during daytime as train still operating in daytime. It is also worth noting that Daiwa share in Tokyo is around 7.7% based on fleet size[61], thus this data is only a representation of taxi trips in Tokyo. The graph shows that over 12 hours window, Daiwa taxi only averaging 106 daytime trips/day. This brings an approximate of 1378 daytime trips/day if we consider equal distribution with other Taxi companies. Unfortunately, we believe that only a small fraction of the trips above may translate to air taxi trips. We are expecting between 5-8% shares out of total daytime trips/day, which brings to 60-80 air taxi orders/day.
CHAPTER III FINDINGS

Furthermore, we are also interested how distance may affect the trip time and taxi fare. First, Figure 3.4 shows the time needed to complete a trip in minutes by the actual distance between start and end location in km. As expected, the trip time completion will increase as actual distance increases, however, at the same time we also noticed heavy fluctuation in the graph, which we predict attributes to unpredictable road condition or congestion. On the other hand, in Figure 3.5, where we compare the actual distance travelled with the taxi fare, we notice much less fluctuation in the price. We will compare these findings on the next section after we start observing the results of on-demand air mobility simulations using multi-agent software.
Figure 3.4 Ground Taxi Trip Time based on Actual Distance
3.3 Findings from Simulation

First, in order to determine the quantity of vertiports that suitable to the demands and ground traffic conditions in Tokyo, we run a number of simulations with different numbers of vertiports. Figure 3.6 shows the results of the trip time saved of using air taxi with four, seven, ten, and thirteen vertiports when comparing the air taxi trip time with ground taxi trip time. We can immediately observe that increasing from ten to thirteen vertiports only increase the time saving by a modest amount, while increasing the vertiports quantity from four to seven improved the time saving a significant amount.
Figure 3.7 shows the effect of time savings improvement by increasing number of vertiports. The study found that as the number of vertiports increase, the effect of time savings is saturated. We observed an average of 83% boost in time saving when vertiports are increased from four to seven, and an average of 50% rise in time saving when vertiports are increased from seven to ten, but only an average of 9% step up in time saving when vertiports are increased from ten to thirteen. The study believes that ten vertiports are enough to ensure coverage of the majority of Tokyo.

Figure 3.6 Comparison of Time Saved based on the Number of Vertiports
Once the optimal number of vertiports for the simulation were determined, the next step is to evaluate the number of air taxis that will be used in the simulation. Previous result of 10 vertiports setup is used. The goal is to find the number of air taxis needed in the simulation while ensuring that customers do not wait more than 5 minutes at the vertiports. The wait time for ground taxi is not considered as ground taxi is expected to arrive at customer location within a few minutes, thus waiting time is only measured when customers have arrived at vertiports and are waiting for air taxi service. With the expectation of fulfilling 60-80 order/day within 12 hours of operational time, the customers average waiting time/hour were simulated based by the number of air taxis that are set in the simulation.

Figure 3.8 shows the results summary of the simulation. With only one air taxi,
customers are expected to wait for 128 minutes on average, and the wait time decreases as the number of air taxi increases. When two air taxis are used, customers are waiting 52 minutes on average, which are still not realistic for the purpose of on-demand air mobility. Next, with three available air taxis customers waiting time are further reduced to 16 minutes on average and with four available air taxis customers have to wait for about 9 minutes on average. Finally, with five air taxis in the system, customers are only expected to wait for 4 minutes on average. Increasing the number of air taxis from this would bring the wait time further down, which then peaks at seven air taxi where customers are waiting for less than a minutes or do not need to wait at all on average.

Figure 3.8 Average Customers Waiting Time in Minutes by Number of Air Taxi
Using ten vertiports and five air taxis as the base of our simulation, we found in the majority of the trips that are less than 10 km, air taxis tend to perform much poorly in comparison with ground taxis as depicted in Figure 3.9. Furthermore, between 10-15 km, the differences of trip time between air taxi and ground taxi are also very small, to the point that it may not worth the cost of using air taxi. However, air taxis seem to perform better for longer distance trips starting from 15 km, and the trips time gap between ground taxis continue to increase as ground taxi needs longer time to reach the destination while air taxis are able to stabilize their trip time due to the ability to travel in air.

![Figure 3.9 Trip Time based on Methods of Transportation by Actual Distance](image)

As this study aims to find how much time that customers able to save by using air taxis in Tokyo, the saved time when using air taxi for each trip is measured in percentage
as shown in Figure 3.10. As there are possible outliers in the datasets for unusual trips, 10% of the extreme data sets are removed, which brings the average time saving of using air taxi to 126%.

Figure 3.10 Time Saving Percentage Compared to Ground Taxi by Actual Distance

In order to justify in using on-demand air taxi in comparison of ground taxi, fare or cost of the service that the customers need to pay to use the service needs to be evaluated. In Section 3.1, findings from Payuhavorakulchai, who investigates the operation cost of using flying car based on distance was discussed, however, her findings do not consider three different costs. First, Payuhavorakulchai’s study does not consider the cost of ground taxis, which are necessary to take the passengers to the vertiport before taking-off with air taxi and to take passengers to their final destination from the vertiport after landing with air taxi. Second, her research also does not include about possible cost that
the company has to consider when air taxi needs to pick-up the customer from a vertiport where there is no standby air taxi available. Lastly, her study also does not consider the company profits expectation.

By adding these three different costs to the cost of operation from Payuhavorakulchai’s study, the author believes that on-demand air mobility cost is possible to be predicted as follow. First, based on the data from Daiwa, the ground taxis cost needed for urban air mobility is averaged to be ¥1,460. However, we need to multiply this by two as the ground taxis need to take passenger(s) to vertiport at the first half of the trip, and to take the passenger(s) to the final destination at the second half of the trip, which then brings this cost to be ¥2,920. Furthermore, based on Payuhavorakulchai’s study, air taxi pick-up cost for 6 km distance is estimated to be approximately ¥2,100[60]. However, this cost is not required when there is already an air taxi on stand-by on the selected vertiport, which we approximate to be half of the time. Therefore, the air taxi pick-up cost is estimated to be half of ¥2,100, which brings the cost to be ¥1,050. Lastly, profit for the company is estimated to be 30% of the direct operation cost is considered to the fare cost that the passengers need to pay to use the on-demand air taxi. Figure 3.11 below shows the estimate comparison of fare for on-demand air taxis in comparison with fare for ground taxis. As the distance increase, the price differences
between air taxi and ground taxi diminish. For trips with distance between 15 km and 30 km, the on-demand air taxi trips are estimated to be, 40-60% more expensive compared to the ground taxi. However, for trips with distance of 33 km, the results found that on-demand air taxi is only 22% more expensive compared to ground taxi.

Figure 3.11 Fare Comparison of On-Demand Air Taxis and Ground Taxis based on Distance
CHAPTER IV DISCUSSIONS

The study explored the infrastructure and operation needs of on-demand air mobility service in Tokyo by using real taxi history data and multi-agent simulation software. In this section, findings related to each hypothesis will be discussed.

Hypothesis 1 | The study had hypothesized that small number of vertiports (between 8-12) located in central and easy to access areas are enough to meet the majority of customer needs in Tokyo 23 wards. The findings from the simulation showed that increasing the number of vertiports from 10 vertiports to 13 vertiports only boosted the trip time saving by 9%, while increasing from 7 vertiports to 10 vertiports boosted the trip time savings by 50%. Although this study does not explore increasing the number of vertiports for more than 13, the author expects that the improvement in time savings will be marginal should more than 13 vertiports are set up, assuming that the demands do not change.

Hypothesis 2 | Due to low expected demands of air taxi, of 60-80 orders/day, the study had hypothesized that a small number, between 6-8 air taxis, of two passengers air taxis will suffice to meet the demands of commuters in Tokyo 23 wards. Moreover, this hypothesis also has a constraint, where the findings has to ensure that the commuters would not have to wait for more than 5 minutes to board air taxi at the vertiport. Even
with the restrictive constraint, the study found that only 5 air taxis are necessary to meet these demands in Tokyo 23 wards, in which commuters are only expected to wait for 4 minutes on average.

**Hypothesis 3** | Finally, due to the relatively small area of Tokyo 23 wards and well-established road and train infrastructure, the study hypothesized that air taxi can only save only up to 30% of the commuters’ time in comparison with other means of transportation. However, after analyzing the results of time savings difference between air taxi and ground taxi, the study found that the average time saving of using air taxi is up to 126% compared of using ground taxi. However, the study also found that using air taxi for trips that are less than 10 km are very likely to take longer time compared with ground taxi, while trips between 10-15 km would depends on the road conditions and routes taken. The simulation results found that the trips that have more than 15 km in actual distance seems to be the trips that benefits air taxi the most. Increasing the number of vertiports would reduce this distance, however, as hypothesis 1 found, significant numbers of vertiports would be required to see an actual impact, where we may need to reach ubiquitous on-demand air mobility.

4.1 Suggestions for Air Taxi Operation

Investing in a novel business would be challenging and exciting at the same time.
CHAPTER IV DISCUSSIONS

With the strict restrictions with Japan’s rule, regulations and citizens acceptance probably would be the primary challenges in establishing on-demand air mobility in Tokyo. With historically strong economic in automotive industry, however, Japanese Government has also contributed and supported the researches on Urban Air Mobility such as the establishment of Drones and Robots for Ecologically Sustainable Societies (DRESS) project. Research and development of drones and flying car in Japan have progressed exponentially in the recent years.

Making a business realization of on-demand urban air mobility in Tokyo would be a long road as the expected target would be in 2030s, as new technology and researches on flying car progress. While making an ubiquitous on-demand urban air mobility may not be realistic by that time, non-ubiquitous on-demand urban air mobility is very likely. The findings from this research have proven that with just ten vertiports in Tokyo and five to seven air taxis in the system, it is likely that the service may be useful as air taxis would be able to help passengers to save 126% of their time on average. It is worth noting however, that on-demand air taxi fare will be 40-60% more expensive to the existing ground taxi and related market researches have to be done to ensure that people are willing to spend more money for the transportation service in exchange of time savings. In the next section, we would discuss further works and researches that can be done to help
realizing on-demand urban air mobility in Tokyo.

4.2 Future Works

This study attempted to use taxi historical data of analyzing customer behavior and needs to transportation demands in Tokyo area. Taxi passengers tends to spend more money compared to train or bus passengers in exchange of convenience and time savings, thus taxi passengers are generally the more likely target customers of on-demand air mobility. However, it is worth noting that as transportation in Tokyo infrastructure are very well developed, train system may occasionally be faster than taxi due to traffic jam impact. To improve the accuracy of the study, analyzing long distance train commuters in Tokyo area should be conducted to analyze further on-demand air mobility demands.

Furthermore, the findings for this research found that air taxi benefits longer distance travel for above 15 km. The area of 23 wards of Tokyo is too narrow to optimize the air taxi service. The literature review also found a large percentage of commuters in Tokyo are from neighborhood prefecture, thus expanding the simulation to cover larger area would improve the knowledge of this study as well. Due to time constraint, the data used to form this conclusion is also data that only span for one week from a single taxi company. However, a longer span of data and data from different taxi companies in Tokyo should also be considered to improve the accuracy of these findings.
Moreover, study to verify the demands based on the expected fare of on-demand air taxis also need to be done. In exchange of faster service using air taxi, we have to verify that people are also willing to pay more money as well. If people are unwilling to spend 40-60% more money on their transportation service by on-demand air taxis, it would be difficult to justify the service. As the name says, it is possible that the service will be popular for very niche market or when people have an emergency or an urgent event that they cannot afford to be late. However, regular or daily usage of the on-demand air taxi service will be unlikely except for the riches.

Lastly, survey and interview of regular citizens of Tokyo are also needed to understand public acceptance of the new transportation system. Japan is heading towards aging population, and people may be reluctant for changes that may affect their lifestyle. Understanding their concern and attempt to raise awareness ahead of time, would be important to realize of on-demand air mobility in Tokyo.
CHAPTER V CONCLUSIONS

This study contributes in bringing six major findings for providing on-demand air taxi service in Tokyo in 2035.

At first, through the data from Daiwa taxi, the study found that the majority of trips where air taxis can potentially be considered as a mean of transportation mainly occurred at night. Due to the noise concern, however, these can be proven difficult to be realized.

Furthermore, the study found that installing ten vertiports at the different locations strategically placed across Tokyo would be sufficient to support on-demand air mobility infrastructure. Moreover, a large number of air taxis are not necessary, as we do expect small number of orders/day, five to seven air taxis, with a couple spare units for maintenance time would be sufficient for on-demand air taxi service.

With the above specified recommendation of vertiports and air taxis, the study found that on-demand air taxi is able to provide time savings of 126% compared when using regular ground taxi. Moreover, the study also found that trips that are longer than 15 km, would be the ideal distance for on-demand air mobility service. Unfortunately, trips that are less than 10 km, would not be a good candidate for on-demand air mobility service as potentially the time to reach vertiports will outweigh the total trip time of using regular ground taxi. Meanwhile, determining whether to use air taxi or ground taxi for the
trips that are in between 10 and 15 km, would be tricky as this would depend on the area proximity to the vertiports as well as the current road condition.

Lastly, the study also found that for trips that are between 15 km and 30 km in distance, air taxis would generally 40-60% more expensive than the cost for regular taxi. As the distance increases, the cost difference between air taxi and ground taxi diminishes. For trips with distance of 33 km, the study finds that on-demand air taxi would cost only 22% more expensive compared to ground taxi. This reinforces the belief that on-demand air taxi is more suitable for longer distance transportation.

The author of this paper hopes that these findings would be beneficial for future research study as well as implementation of on-demand air mobility in Tokyo.
REFERENCES


A1 Simulation Tool

The multi-agent simulation software used in this research is Anylogic University Edition 8.4.0. In order to use the software, a USB dongle shown in Figure A1.2 would be necessary to be connected to the computer.
Anylogic program is based on Java, thus having some knowledge on Java programming language would be beneficial when using the software. However, even without Java knowledge, with the help of Anylogic’s friendly Graphical User Interface (GUI) and studying Anylogic published tutorials, it may be possible to use the software to certain degree.

A2 Anylogic Tutorial

As a multi-agent tool, Anylogic is very powerful and rich in features, and describing how to work with Anylogic would be outside of the scope of this thesis. However, some pointers on the configuration and settings done in this study would be explained.

A2.1 Project Structure

Aside from the Main section, five different agents were used in this project, AirTaxi, emergencyHeliPort, Order, Vertiport, and gTaxi.
The Main section is the bread and butter of the project. This is where you design the Animation, Statistic tools, and where you would create new agents.
Figure A2.2 Animation Section of Tokyo On-Demand Air Taxi System Project

Figure A2.3 Statistic Section of Tokyo On-Demand Air Taxi System Project
The animation used in this project is an interactive GIS Map, which can be accessed from the Pallete section, then **Space Markup -> Gis Map**

![Space Markup Pallete](image)

**Figure A2.4** Space Markup Pallete

Next, the AirTaxi agent section is where you would program the air taxi behavior.

This can be set using flowchart, thus the behavior can be easily adjusted.
Next, the emergencyHeliPort agent is currently only used to display emergency heliport available in Tokyo by viewing it with a green building in the map. Therefore, the agent itself does not contain any program.
Next, the Order agent is where the customer demands is being stored. Several parameters and variable are being set here, such as customer current location and customer waiting time.

![Figure A2.7 Order Agent Overview](image)

The next agent is the Vertiport agent, where the demands are generated. The vertiport agent job is to ensure that air taxi would be available on the customer ends as well as becoming the point of contact for ground taxi.

![Figure A2.8 Vertiport Agent Overview](image)

The last agent, gtaxi or ground taxi, functions is to simply transfer passengers from passenger location to the nearest vertiport where air taxi awaits.
A3 Simulation Code Snippets

A3.1 Air Taxi Agent Code Snippets

- pickupCustomer state

  ```java
  checkRain.restart();
  
  // only if there is no air taxi available at the passenger location
  timeEntryAction = time(SECOND);
  ```
moveTo(order.custCurrentLoc.getLatitude(),
order.custCurrentLoc.getLongitude());

- **checkWeather state**

  ```
  main.rainOn &&
  ( (order.custCurrentLoc.getLatitude() == main.NHK
    放送技術研究所.getLatitude())
   && order.custCurrentLoc.getLongitude() ==
    main.NHK 放送技術研究所.getLongitude()) ||
  (order.custDestLoc.getLatitude() == main.NHK 放送技術研究所.getLatitude())
   && order.custDestLoc.getLongitude() ==
    main.NHK 放送技術研究所.getLongitude())
  ```

- **moveToDestination state**

  ```
  // deliver customer to requested destination
  timeEntryActionD = time(SECOND);
  oval.setVisible(true);

  moveTo(order.custDestLoc.getLatitude(),
  order.custDestLoc.getLongitude());
  order.moveTo(order.custDestLoc.getLatitude(),
  order.custDestLoc.getLongitude());
  ```

- **moveToAnotherDestination state**

  ```
  Vertiport NHKV = findFirst(main.vertiports, v ->
  v.getLatitude() == main.NHK 放送技術研究所.getLatitude() &&
  v.getLongitude() == main.NHK 放送技術研究所.getLongitude());
  Vertiport newTargetVertiport =
  getNearestAgent(filter(main.vertiports, v-> v != NHKV));

  order.success = false;

  moveTo(newTargetVertiport.getLatitude(),
  newTargetVertiport.getLongitude());
  // if agents moving together
  ```
if(order.person.isVisible())
    order.moveTo(newTargetVertiport.getLatitude(),
    newTargetVertiport.getLongitude());

A3.2 Vertiport Agent Code Snippets

- GenerateDemand

//find destination
Vertiport targetVertiport = null;
List targetVertiports = findAll(main.vertiports, v ->
    v != currentVertiport); //find all potential vertiports

if(randomTrue(0.25))//55% orders to vertiport in Tokyo
    targetVertiport = tokyostaV;
else if (randomTrue(0.20)) //20% order to arkhills
    targetVertiport = arkhillsV;
else if (randomTrue(0.10)) //10% order to Meguro
    targetVertiport = hanedaV;
else if (randomTrue(0.15)) //15% order to Haneda
    targetVertiport = hanedaV;
else // remaining 30% to the rest
    targetVertiport = randomWhere(main.vertiports, v ->
    v != currentVertiport && v != arkhillsV && v !=
    hanedaV && v != tokyostaV && v != meguroV && v != NHKV);

Order order = main.add_orders(currentVertiport,
    uniform_discr(1,3), targetVertiport); // creates new order

if (main.rainOn && (currentVertiport == NHKV ||
    targetVertiport == NHKV)) {

order.success = false;

} else {
    order.success = true;
    order.startWaitingForAirTaxi = time(MINUTE);

    AirTaxi aTaxi = order.getNearestAgent(filter(main.airTaxis, v-> v.inState(AirTaxi.standby)));
    if (aTaxi != null)
        send(order, aTaxi);
}