Analysis of Alternate Vertiport Designs

Megan Taylor
Systems Engineering and Operations Research
George Mason University
Fairfax, USA
mtaylo39@gmu.edu

Asya Saldanli
Systems Engineering and Operations Research
George Mason University
Fairfax, USA
asaldanl@gmu.edu

Andy Park
Systems Engineering and Operations Research
George Mason University
Fairfax, USA
apark22@gmu.edu

***Abstract*— Advances in technology enable the deployment of an Urban Air Mobility (UAM) transportation system for congested metropolitan areas. A key element of UAM are vertiports, the infrastructure that electric vertical takeoff and landing vehicles (eVTOLs) use to land and take-off. A Vertiport Design Tool (VDT) was developed for use by architecture firms designing vertiports to evaluate operational trade-offs between vertiport surface area and vehicle throughput. A stochastic Monte Carlo simulation was developed to calculate vehicle throughput for different vertiport design alternatives, safety risk, and noise constraints. Results show that for every 420 m^2 increase in vertiport surface area, the throughput increases by one vehicle per hour. For this, the time between vehicle arrivals also needs to decrease by 5 minutes for more arrivals to occur.**

Keywords— Urban Air Mobility, stochastic Monte Carlo simulation, vertiport, vertiport analysis

I. Context Analysis

A. *Enterprise description*

Surface transportation is a source of friction for local economies such as the Washington DC area. These sources of transportation include cars, limos, ride sharing, taxis, and mass transit including buses, metro, and VRE. They are costly, congested, and unsustainable. They are a large use of fossil fuels, and have impacts including economic productivity, climate change, and quality of life. To combat this problem, the Urban Air Mobility Transportation System (UAM-TS) is being developed. Using UAM-TS passengers can fly over the urban congestion.

Advances of new technology such as electric Vertical Take-off and Landing vehicles (eVTOLs), better batteries and motors, advanced communication systems, autonomous navigation, and advanced surveillance systems enable UAM. An infrastructure, vertiports, must allow for vertical take-off and landing in urban environments. Designing and building them is a complex process that will be discussed.

B. *Responsibility of Architects in the Design of a Vertiport*

Architects currently design heliports with 3D modeling of the area and different methods of site selection to meet regulations such as the structure and water regulations. They analyze the airspace to ensure the proper landing and takeoff of the vehicles. However, they do not consider the dynamic operations of vehicles, such as noise analysis, safety risk analysis, and the sequence of vertiport operations.

C. *Vertiport operations*

A vertiport is a type of airport for aircraft that land and take-off vertically with operations that includes aircraft landing and take-off, passenger disembarking and embarking, pre and post flight checks, aircraft battery charging/swapping and maintenance. These operations are usually executed in the order shown in Figure 1Figure 1.

Figure 1. Sequence of Vertiport Operations

D. *Vertiport Designs Configurations*

This paper discusses three different Vertiport designs with different characteristics. They all have different safety and noise levels, surface areas and costs.

1) *Multi-Function Single Pad*

The Multi-Function Single Pad, shown in Figure 2, performs all the vertiport operations on a single pad. The estimated cost of this design is $350,000, its typical dimensions are 39 by 69 meters, and it has a lower throughput compared to other Vertiport designs.

Figure 2. Multi-Function Single Pad

2) *Hybrid Design*

The Hybrid vertiport design has one landing/take-off pad, and two/three staging areas. The eVTOL first lands on the landing/take-off pad, then travels to one of the empty staging areas. At the staging area, passengers disembark, maintenance and battery swapping are completed, and new passengers embark. Then, eVTOL travels back to the landing/take-off pad and takes off from there. This design has two different versions. The first version, shown in Figure 3, has one landing/take-off pad, three staging areas and triple tracks. The estimated cost of the triple tracks version of the hybrid design is $950,000. The second version, shown in Figure 4, has just two staging pads decreasing the cost to $750,000. These designs occupy a larger surface area of 72 by 99 meters.

Figure 3. Hybrid: Landing Pad with Trio Staging Pads

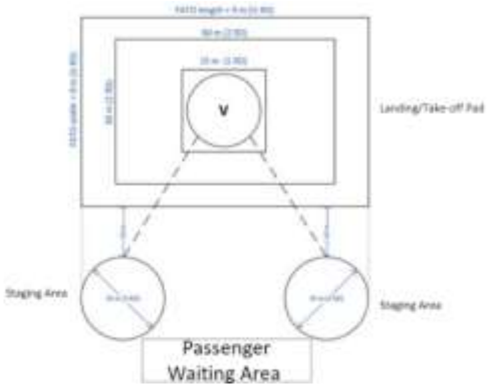

Figure 4. Hybrid: Landing Pad with Twin Staging Pads

3) *Linear Single Function Pads*

The Linear Single Function Pads vertiport design has all the operations carried out on separate pads. There are two versions of this designs, the first with double tracks, one landing pad, one take-off pad, and two disembarking, maintenance and embarking pads. The first version of the design is shown in Figure 5, and its estimated cost is $1,600,000. The second design version, shown in Figure 6, has a single track and one pad for each vertiport operation, decreasing the cost to $1,150,000. These designs occupy the largest surface area 69 by 168 meters.

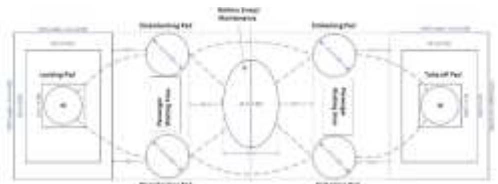

Figure 5. Twin Linear Single Function Pads

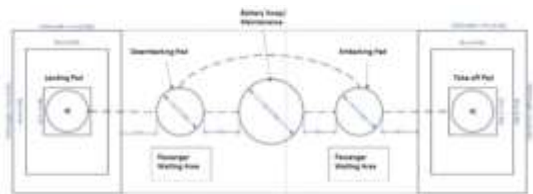

Figure 6. Solo Linear Single Function Pads

E. *Constraint: Noise*

Noise is a design constraint for the community around a vertiport. It directly affects the acceptance by the community. A noise contour map, Figure 7. , was produced for the Multi-Function Single Pad design to show the expected noise levels on and around this specific design. The Noise is a function of the arrival and departure flight paths. The noise concentration for residences in the vicinity of the Vertiport is determined by the number of arrival and departure flight paths and the number of flights on each flight path. Multi-function Single Pad designs can have 4 flight paths (e.g. N, E, S, W). If flights are distributed equally amongst the flight paths, residents on the flight paths will experience only 25% of the total noise.

Hybrid designs will have 3 flight paths (e.g. W, N, E), as vehicles are prohibited from flying over staging areas. The noise will be distributed 33% on each flight path. Linear Single Function Pads have six flight paths, the noise is concentrated on each flight path at 17%.

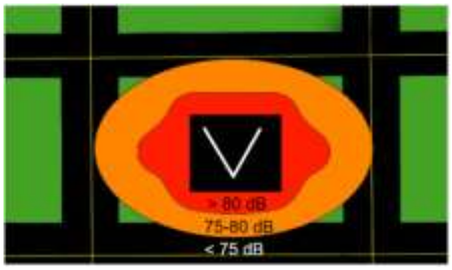

Figure 7. Noise Contour Map for Multi-Function Single Pad Design

F. *Constraint: Safety*

Safety is a key consideration for any system dealing with people. Vertiports are measured by several safety features: battery swapping away from passengers, landing/take-off away from passengers, and multiple flight paths.

G. *Constraint: Vertiport Elements*

According to the FAA Heliport Design Advisory Circular, vertiports must have at least one touchdown/lift-off pad with some key elements. The basic elements of a vertiport are a clear approach/departure path, a clear area for ground maneuvers, final approach and takeoff area (FATO), safety area, and a wind cone [1, p. 1]. Vertiports can include extra elements such as markers/markings and lighting.

Figure 8 represents the basic layout of a heliport and can be used for Vertiports [1, Fig. 3-1]. The Vertiport touchdown/lift-off pad consists of a touch-down and lift-off area (TLOF) contained within a final approach and take-off area (FATO), and a safety area that surrounds the FATO. FATO contains only one TLOF.

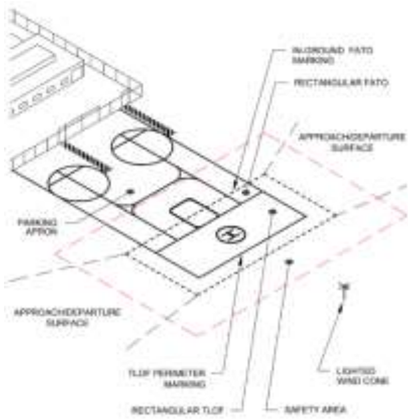

Figure 8. Transport Heliport Layout

Some of the key vertiport elements are explained below:

1) TLOF: TLOF is a load-bearing, generally paved area which the eVTOL lands on and/or takes off from. TLOF is centered on the load-bearing area (LBA), and on the major axis of the FATO. It is a rectangular surface whose minimum length and width is the rotor diameter (RD) of the eVTOL aircraft that will use that vertiport, but cannot be less than 50 feet (15.2 m). Paving of the TLOF depends on its location, if it's located on the ground-level, Portland cement concrete (PCC) would be used; if it's located on an elevated surface such as a rooftop, metal, concrete, or other materials depending on the local building codes would be used [1, p. 67].

2) FATO: FATO is a defined area over which the pilot completes the final phase of the approach to a hover or a landing and from which the pilot initiates takeoff. The FATO is a rectangular surface with the long axis aligned with the preferred flight path. The minimum width and length of a FATO is at least 2 times the maximum dimension of the eVTOL, but the width can't be less than 100 feet (30.5 m), and the length can't be less than 200 feet (61 m). At elevations above 1000 feet MSL, a longer FATO is required to provide an increased safety margin and greater operational flexibility. The FATO surface can be unpaved for ground-level vertiports, in such cases it should be treated to prevent loose stones and other flying debris caused by rotor wash. A vertiport with multiple touchdown/lift-off pads that support simultaneous approach/departure operations needs to have a minimum 200 feet (61 m) separation distance between its FATO areas [1, pp. 71-72].

3) Safety Area: Safety area is a defined area on a vertiport surrounding the FATO intended to reduce the risk of damage to eVTOL aircrafts accidentally diverging from the FATO. The safety area extends on all sides of the FATO for a distance of ½ eVTOL maximum dimension but not less than 30 feet (9 m). All fixed objects in a safety area projecting above the FATO elevation except for lighting fixtures must be removed. Any flammable materials, loose stones and any other flying debris caused by rotor wash must be cleared [1, p. 73].

H. Constraints: Vehicle Compatability

The FAA Heliport Design Advisory Circular uses helicopter rotor diameter for the measurements of the TLOF, FATO, and Safety Area. However, for vertiports, the maximum dimension of the eVTOL will be used to determine the surface area of the Vertiport (Figure 9) [2].

Figure 9. Helicopter vs eVTOL Dimensions

I. Constraints: eVTOL Batteries for UAM

Future batteries are expected to have 150 kWh of total battery energy, and rapid charging capability of 600 kW. They will have maximum charging time of 15 minutes [3]. One alternative to charging is battery swapping. On average, it takes 3 minutes to swap an eVTOL battery.

II. Stakeholder Analysis

A. Primary Stakholders

The primary stakeholders are community in the vicinity of the vertiport, inspection agencies, property owners, architecture company, construction company, and the UAM transportation system (Figure 10). The community is primary because they live in the vicinity of the vertiport and may be users of the system. Vertiport may increase taxes, noise and surface traffic congestion, but increase property values and commute times.

Inspection agencies are second important primary stakeholders because they strongly affect the process of building the vertiport. They inspect the area of the property and the vertiport. There are many different organizations that publish codes and regulations for the design of heliport and vertiport including FAA, OSHA, and NFPA.

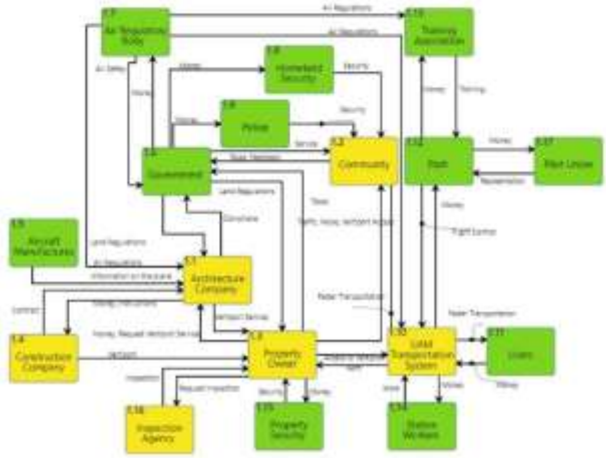

Figure 10. Stakeholder Interactions

B. Stakeholder Tensions

The primary stakeholder tension is between the community and the property owners (Figure 11). The community might not want a vertiport near their area because they might have complains about the noise and increased traffic, or a possible tax increase. A win-win occurs with an increase in property value and improved commute.

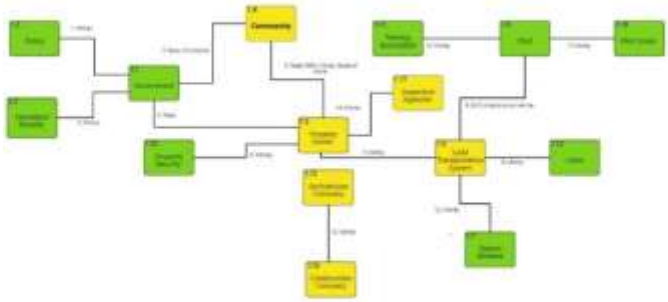

Figure 11. Stakeholder Tensions for Building and Operating Vertiport

III. Problem and Need Statement

A. Problem Statement

Vertiport design is complex because of dynamic operations. A helipad is not a vertiport and the analysis done for heliports is not enough for the high throughput expected for vertiports. Stakeholder tensions, noise and safety considerations need to be considered. Therefore, there is a knowledge gap for architecture companies in the process of designing and building Vertiports with the optimal configuration of operational pads on the Vertiports.

B. Need Statement

There is a need to fill the knowledge gap with a simulation of vertiport designs and their operations in order to compare operational differences of the designs, including noise, safety, and throughout. Also, there is a need to address strong stakeholder tensions between the community and the vertiport development.

IV. Concept of Operations

An architect designing a vertiport starts with a location with a feasible airspace where they want to construct a vertiport. They may have information, such as the dimensions, the expected vehicle interarrival rate, but need to compare designs analytically. A Vertiport Design Tool that outputs data analytics for alternate vertiport designs can be used. Such analysis includes the tradeoff between throughput and area, noise analysis, safety analysis, queue length, and vehicle wait time. The proposed design is a website, shown in Figure 12.

Figure 12. Vertiport Design Tool (VDT) Website

The process built into the Vertiport Design Tool contains three steps. The steps are (1) identify the constraints (dimensions), (2) simulate feasible vertiport alternatives, and (3) choose the best alternative. The architect interacts with the VDT throughout these three steps as shown in Figure 13. Each color represents each of the steps, in order of the VDT steps.

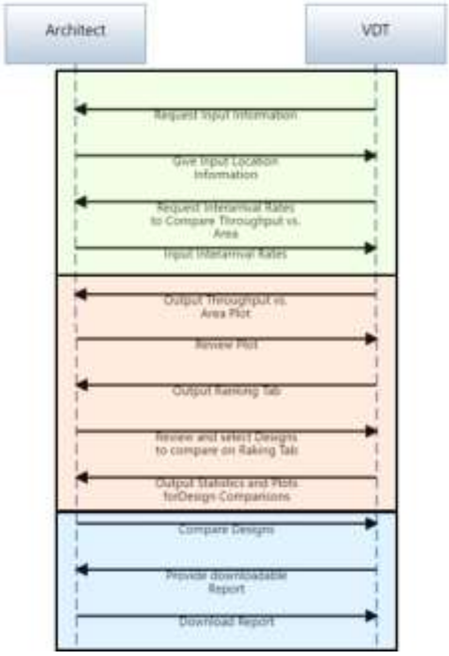

Figure 13. VDT's Process for Designing a Vertiport

V. Requirements

A. Vertiport Deign Tool (VDT) Mission Requirements

The VDT system shall: (1) rank the feasible vertiport designs for a location; (2) calculate throughput for each vertiport design within 1 vehicle count per unit time; (3) calculate the wait time of vehicles within 2 minutes of the wait time; (4) calculate the queue length of vehicles within 2 vehicles of the queue length; (5) correctly identify vertiport designs that fit in the given property dimensions within +/- 1 foot; (6) identify trade-off between area vs throughput; (7) identify constraints.

VI. Implementation

VDT is composed of 3 main steps. The first step is to identify the constraints. This requires comparing the desired vertiport location dimensions to the design configuration dimensions.

The second step is to simulate the feasible Vertiport design alternatives. This is done through a stochastic Monte Carlo simulation calculating the vehicle throughput for each of the designs, as well as the utility, safety risk score, noise levels, and vehicle wait time and queue length. The primary simulation objective is to determine the best design configuration for a location. Some assumptions include that all vehicles are electric and use standardized batteries, battery swapping is used, there are no battery failures, and the vertiport is working under perfect conditions.

The simulation models the sequence of vertiport operations beginning with vehicle landing and ending with the take-off. All three-design configuration discussed are modeled. The inputs to the simulation include: vehicle interarrival rate, the number of batteries at the location, the location dimensions, the number of modules (or pads) at the vertiport, and the number of staging areas at the Hybrid and Linear Single Function Pads designs. The outputs to the simulation are the vehicle departure rate, the queue length and wait times for aircraft, energy usage, battery wait time, and total time at the vertiport for vehicles.

The final step is to choose the best alternative by looking at the stimulation output obtained from the second step. This is ultimately done by the architect but is assisted by the VDT by using the utility. Utility is measured by three attributes: safety (weight (w_s) = 0.8), noise (weight (w_n) = 0.05), and vehicle wait time (weight (w_w) = 0.15), and is calculated by equation (1). Weights for each of these have been obtained by subject matter experts. The wait time for vehicles is calculated by averaging the wait time for all vehicles through the system. Safety risk score and noise score will be discussed below. Equation for utility:

$$Utility = w_s V(x_s) + w_n V(x_n) + w_w V(x_w) \qquad (1)$$

where

$$V(x_s) = \left(-\frac{1}{3}\right) * (safety\ risk\ score) + 1$$

$$V(x_n) = \left(-\frac{2}{105}\right) * (noise\ score) + \left(\frac{4}{3}\right)$$

$$V(x_w) = e^{-0.3*(wait\ time)}$$

A. *Safety*

Safety of vertiports can be measure based on three types of hazards identified for the VDT vertiport designs.

(1) collisions of eVTOL departure and arrivals. For an example, having arrivals from the north and having departures to the south is safer than having arrivals from the north and departure to the north. From the 3 design categories, only hybrid has this type of hazard since it uses the same direction for arrivals and departures.

(2) battery swapping/charging of eVTOLs in the area where the passengers embark/disembark. There is a risk of battery explosion during battery swapping. It is safer to charge/swap batteries of the vehicle in a separate station. From the 3 design categories, The Multi-Function Single Pad and the Hybrid design categories have this type of hazard.

(3) landing and taking off in the same place where passengers embark and disembark. From the 3 design categories, Multi-Function Single pad design category has this hazard.

After determining the possible hazards at a vertiport, the probability of an incident occurring, and the severity of the incident were determined to calculate the risk value of each hazard. Then the risk levels were calculated by multiplying the probability and severity values. Table 1 shows the risk values of each hazards.

Table 1. Possible hazard types for vertiports

Hazard #	Hazard Description	Accident Type	Probability of Occurrence	Severity	Hazard Risk
1	Using the same direction for arrivals and departures	eVTOL collision	0.0001	1000	0.1
2	Battery swap in the area where passengers embark/disembark	Battery explosion	0.001	100	0.1
3	Land/take-off in the area where passengers embark/disembark	Crash landing	0.0001	1000	0.1

Finally, the safety score of each vertiport design category were calculated by adding the risk value of each possible hazard. Table 2 shows the safety score of each vertiport category. Since the safety scores were calculated by looking at the number of safety hazards, the best safety score is 0.

Table 2. Safety Score for Each Vertiport Category

	Hazard Type			
Design Alternative	Hazard #1	Hazard #2	Hazard #3	**Safety Score**
Multi-Function Single Pad	0	0.1	0.1	0.2
Hybrid	0.1	0.1	0	0.2
Linear Single Function Pads	0	0	0	0

B. *Noise*

Noise directly impacts the community acceptance of a vertiport. People who live around the vertiport location will be affected by the vertiport even if they are not using the UAM-TS. eVTOLs produce noise at the vertiport when they are flying around and landing/departing. The noise levels around the vertiport are not equally distributed causing some parts of the community to have higher noise levels below the flight path. However, if the vertiport has multiple flight paths, then the noise levels around the vertiport are going to be lower and distributed around the vertiport.

The noise levels around the vertiport were estimated using the flight path noise distribution property. First, the number of flight paths and their directions for each vertiport design were determined. Since each side of the vertiport has a different noise level, the side with the highest noise level was identified to assign the noise score.

The noise score of each side was calculated by multiplying the proportion of the flight paths on the side with the most flight paths by that side's noise level. The noise level of each side was calculated by adding the noise produced by eVTOLs landing and/or taking taking-off from that direction by using equation (2). For this calculation, each eVTOL was estimated to have 70 dB of noise from a distance of 500 feet.

$$L = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\left(L_i/_{10}\right)}\right) \qquad (2)$$

$$L = Total\ Noise\ Level$$

$$L_i = Noise\ Level\ of\ one\ eVTOL$$

$$n = Number\ of\ Flight\ Paths\ on\ Loudest\ Side$$

For the smallest designs included in the simulation, the number of flight paths in each direction was identified and shown in Table 3. Flight path directions were identified by assuming that the eVTOLs cannot fly over the staging areas. The Hybrid design with two staging areas (double tracks) has its staging areas located on one side of the vertiport. The Hybrid design with three staging areas (triple tracks) has its staging pads on three sides of the vertiport. Both Linear Single Function Pad designs have staging pads in between their landing and take-off pads.

Table 3. Number of Flight Paths per Direction

Design Alternative	# of Paths in Direction 1	# of Paths in Direction 2	# of Paths in Direction 3	# of Paths in Direction 4	Total
Multi-Function Single Pad	1	1	1	1	4
Hybrid with Double Tracks	1	0	1	1	3
Hybrid with Triple Tracks	1	0	0	0	1
Linear Single Function Pads	2	2	1	1	6

After the direction with the highest proportion of the flight paths was identified for each design, the below noise scores in the Table 4 were calculated. The designs with a lower noise score are better. The Multi-Functional Single Pad distributes its noise around it, lowering the noise score while the Linear Single Function Pads allows for landing and departing to occur in two places on one side of the vertiport raising the noise score. The Hybrid with Triple Tracks only allows for landing and departing from one side causing all the noise to occur there.

Table 4. Calculation of Noise Score

Design Alternative	Proportion of # of Paths in the Loudest Direction	Noise level of the Loudest Direction	Noise Score of the Design
Multi-Function Single Pad	0.25	70	17.5
Hybrid with Double Tracks	0.333	70	23.31
Hybrid with Triple Tracks	1	70	70
Linear Single Function Pads	0.333	73	24.309

VII. VERIFICATION AND VALIDATION

A. VDT Verification

Vertiport Design Tool (VDT) was verified by using inspection, demonstration and testing. The VDT simulation was run 10 times given a set of different inputs and the results were compared to expected outputs for each design configuration. The expected simulation outputs were determined by doing hand calculation of the each vertiport design category. For the hand calculations, it was assumed that there were an infinite number of batteries. Deterministic process times were used, and arrival time of eVTOLs were created from an exponential distribution with mean interarrival rate of 15 mins. After the verification process, mistakes in the simulation code were identified and fixed.

B. VDT Validation

In order to validate the vertiport design tool (VDT), an Integrated Product Team (IPT) composed of representatives from architecture companies and experts in the field were created. Specific tasks and questions were developed for the experts in the field to walk through the system and complete. The VDT successfully passed the validation tests that the VDT could be used to choose the best vertiport design for a location. In the interview, experts commented that having a vertiport design tool would not be able to eliminate all aspect of architect's jobs such as looking at the air space, wind constraints, direction of vertiport, flight paths, structural integrity and cost analysis on materials based on location.

VIII. CASE STUDY: BETHESDA MALL PARKING LOT

A case study on how to use the Vertiport Design Tool (VDT) to support a DC Region, Rapid Reliable Urban Mobility Systems (RRUMS) was conducted. There are 5 steps on how to use the VDT.

Figure 14. Bethesda, MD Mall Parking lot

(1) Choose the locations for the vertiports and get the dimension. For this example, shown in Figure 14, a mall parking lot in Bethesda, MD was used. The dimensions of width and length were gathered.

Figure 15. VDT Input Information Section

(2) Enter the site information into the VDT. This is shown in Figure 15. VDT Input Information Section. After getting the information, it was input into the VDT. This includes the location name, interarrival rate in mins, the width and the length in meters, and the weights for each of the attribute, noise, safety and wait time, to determine the utility of each design.

Figure 16. VDT Ranking Section

(3) Pick one of each design type to compare. One of each design type are select in the ranking tab to be compared in the next step, shown in Figure 16. VDT Ranking Section. They must be one of each kind of design. They are listed descending based on their utility. These are only stable and feasible options. Some design categorized may not be available.

Figure 17. VDT Design Comparison Section

Figure 18. VDT Website Plot Tabs

(4) Compare each of the designs. The default slider selections are the selected rows on the ranking table (Figure 17). Changing the inputs will show a different picture depending on the selection. At the bottom of the page, the data provided can be viewed about each design selection such as vehicle time at vertiport, vehicle queue length and wait time, battery wait time, utility vs cost, and any other statistics for different design selections. The tabs on the VDT for the plots are shown in Figure 18.

Figure 19. VDT Site Report

(5) Download and review the output. Once the selections have been made for comparisons under design comparison tab, the report can be downloaded from the website. The report of a complete design of experiment for simulation can be downloaded as well. Inside of the VDT site report, there are 9 sections that needed to be looked at when building a vertiport which is the introduction, enterprise process for building a vertiport, design description, vertiport elements, safety discussion, noise discussion, utility calculation, design Comparisons, and minimum design requirements.

IX. TRADE-OFF ON SURFACE AREA, NOISE, SAFTEY AND TRHOUGHPUT

The simulation was run with 1176 configurations by changing the design, the number of pads, the number of staging areas, the interarrival rate of vehicles, and the number of batteries at each vertiport. Of the runs, 1112 of them were stable, and the vehicle wait time did not grow uncontrollably.

A. Trade-off on Surface Area and Throughput

A trade-off exists between the surface area and the throughput. Increasing the number of staging areas or pads results in an increase in the throughput at the vertiport. For example, for a Multi-Functional Single Pad, the throughput increases by 6 operations per hour for each additional pad, or 2,700 m^2 (Figure 20).

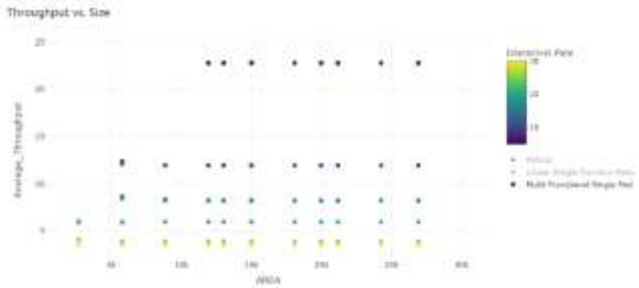

Figure 20. Throughput vs. Vertiport Surface Area of Multi-Functional Single Pad

When all the vertiport designs are compared (Figure 21), the pareto frontier shows an increase in the throughput as the surface area increases: for every 420 m^2 increase in vertiport surface area, the throughput increases by one vehicle per hour. For this, the time between vehicle arrivals also needs to decrease for more arrivals to occur.

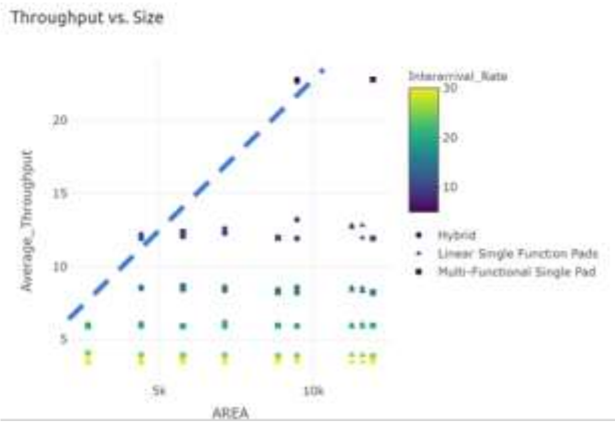

Figure 21. Throughput vs Vertiport Surface Area for all designs

The Pareto Frontier identifies the lowest cost for each level of throughput (Table 5.)

Table 5. Highest Throughput and Smallest Surface Area Designs

Design	Number of Pads/Modules	Number of Double Track (LSFP)/Triple Staging Area (Hybrid)	Number of batteries at each vertiport	Interarrival Rate (minutes between vehicle arrivals)	Length (m)	Width (m)	Throughput (# of Arrivals + Departures per hour)
Hybrid	2	0	3	5	148	64	23
Linear Single Function Pads	2	0	2	5	163	148	23
Linear Single Function Pads	1	0	3	10	163	69	13
Hybrid	1	1	2	10	99	72	13
Multi-Functional Single Pad	1	0	1	20	69	39	6
Multi-Functional Single Pad	2	0	1	10	148	39	12
Hybrid	1	0	3	10	69	64	12

B. Trade-off of Surface Area and Safety

A trade-off between the design configurations for surface area and the safety was conducted. Between the smallest configurations of the three designs, the largest design has the lowest safety risk score while the smallest has the highest (Figure 22). Safety hazards occur where there are passengers in the vicinity of vehicle operations, such as battery swapping. By having these operations on separate pads, risk of injuries or accidents can be mitigated. However, more staging areas require a larger surface area.

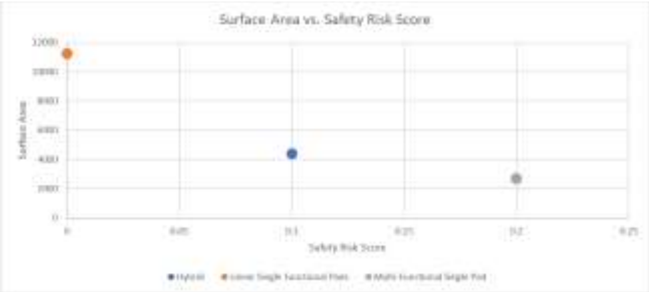

Figure 22. Surface Area vs. Safety Risk Score of Smallest Designs

C. Noise Benifits of Hybrid Design

The noise level of the Hybrid design shows that as the number of flight paths increase, the noise score decreases (Figure 24). This is due to the distribution of the flight paths around the vertiport as more pads are added to the vertiport. However, the Multi-Functional Single Pad Design and the Linear Single Functional Design both concentrate the noise on either side of them as the number of pads increase. This can be seen with green arrows of Figure 23 (left) as the flight paths on the Hybrid design vertiport and the yellow arrows (right) as the flight paths on the Linear Single Functional Pads design, each with three pads.

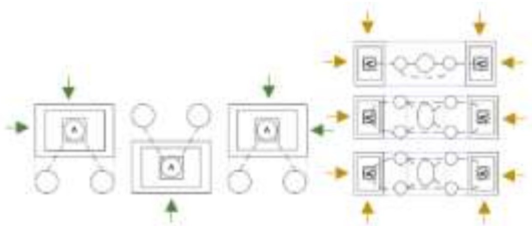

Figure 23. Flight Paths of Vertiport Designs

Figure 24. Noise Score vs. Number of Flight Paths

D. Trade-off of Utility and Cost

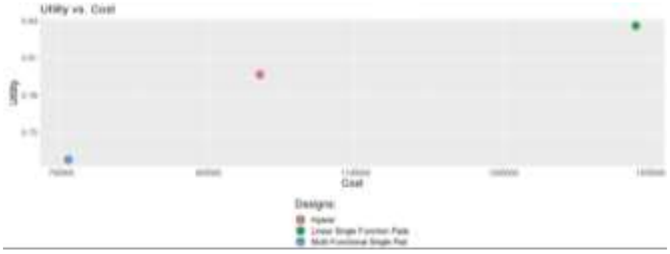

Figure 25. Utility vs Cost

The Single Function Pads has the highest utility and highest cost, and Multi-Functional Single pad has the lowest utility and lowest cost (Figure 25). There is a trade-off between cost and utility because the increase in the cost might not be worth the gain in utility. The difference in the Hybrid and Liner Single Function Pads is the greater cost for the Linear Single Function Pad and a small difference between the utility of the two designs. The marginal cost of utility is about $1,428,500.

X. Business Case

The Vertiport Design Tool (VDT) is for architects and will deliver through a website. In the website, the architect would be able to input the information they have to build a vertiport. The VDT would be able to show which design is the best for that location by looking at the simulation results. Current architects focus on building a helipad which is not a vertiport. They do not look at the dynamic operations to build a vertiport. The Vertiport Design Tool (VDT) will reduce the architecture companies' amount of time and money to research prior to installing a vertiport.

The Vertiport Design Tool (VDT) website will be a subscription-based website where a customer would pay $60,000 initial upfront fee to use the website. In the initial upfront fee, the one-month fee is included. The monthly fee would cost $22,500. When the purchase is made, the key will be provided to the architect to access the website.

The initial cost to start producing the Vertiport Design Tool (VDT) will cost $300,000. The maintenance of this tool will cost $225,000. Twenty-one units of the product are expected to be sold in 5 years which will generate revenue/sales of $6.93 million in 5 years. Creating the Vertiport Design Tool (VDT) and maintenance of VDT will cost $1.35 million in 5 years which will produce a profit of $5.58 million in 5 years. Therefore, the Return on Investment (ROI) would be 413% in 5 years and the breakeven will happen in the 3rd year.

References

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