Project 2122 | May 2023

Land Use Analysis on Vertiports Based on a Case Study of the San Francisco Bay Area

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Mineta Transportation Institute

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Report 23-13

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May 2023

A publication of the
Mineta Transportation Institute
Created by Congress in 1991

College of Business
San José State University
San José, CA 95192-0219

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
23-13

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Land Use Analysis on Vertiports Based on a Case Study of the San Francisco Bay Area

5. Report Date
May 2023

6. Performing Organization Code

7. Authors
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8. Performing Organization Report
CA-MTI-2122

9. Performing Organization Name and Address
Mineta Transportation Institute
College of Business
San José State University
San José, CA 95192-0219

10. Work Unit No.

11. Contract or Grant No.
65A0660

12. Sponsoring Agency Name and Address
California Department of Transportation
1120 N Street Sacramento
CA 95814

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract
Vertiport research and development trails in the emerging commercial air taxi sector known as Advanced Air Mobility (AAM). Published scholarship remains limited as federal, state, and local governments have yet to create or implement policies for the rapidly progressing larger AAM ecosystem, which is designed around autonomous electric vehicle takeoff and landing aircraft. With the potential for frequent low altitude flights, long-range planning must demonstrate awareness, knowledge, and utilization of geographic information science to select safe and just vertiport locations. This study summarizes the AAM literature and offers planners a set of stakeholder-informed parameters to use in a no-cost preliminary GIS analysis when applied to urban, suburban, and exurban site suitability models. Parameters for this case study were identified under the considerations of safety, access, and equity for vertiport placement and given a high, medium, or low priority level to determine site suitability. The goals of this study are to establish a framework for the systematic approach to vertiport site selection and to provide recommendations for how a region might plan its AAM network, regulations, or best practices. The approach established by this framework would ensure general consistency in AAM land use planning for a region while remaining flexible enough to allow for other considerations that may differ between regions, such as local zoning or state regulations. The study also highlights the importance of integrating a focus on land use planning when implementing AAM, especially as it relates to a case study of the San Francisco Bay Area.

17. Key Words
Advanced air mobility (AAM), Land use planning, GIS, Transportation planning

18. Distribution Statement
No restrictions. This document is available to the public through The National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
75

22. Price

Form DOT F 1700.7 (8-72)

DOI: 10.31979/mti.2023.2122

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ACKNOWLEDGMENTS

The authors appreciate the great help, support, and guidance from: Dr. Hilary Nixon, the Mineta Transportation Institute (MTI) Research Director; Mr. Matthew Friedman, Mr. Patrick Miles, and Mr. Tarek Tabshouri, the three Division of Aeronautics Chiefs at the California Department of Transportation (Caltrans); and Mr. Nathan Loebs and Mr. Balwinder Tarlok, two Officials from the Division of Research, Innovation and System Information at Caltrans.

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Executive Summary

Objective

The vertiport case study of the San Francisco Bay Area establishes a framework for a systematic approach to vertiport site selection and recommendations for how a region might plan their Advanced Air Mobility (AAM) network using Geographic Information Systems (GIS). This approach offers consistency in AAM site selection for a region while remaining flexible enough to allow for other local considerations that may differ between regions such as zoning or community preferences.

The study area encompassed the greater San Francisco Bay Area, which for this study included Alameda, Contra Costa, San Francisco, San Mateo, and Santa Clara Counties. This broad region was chosen to ensure the inclusion of a variety of different urban forms and built environments within a region that would likely have broad implementation of AAM where there is an air, rail, and transit network. This airspace already consists of commercial air traffic serving major airports within the region including San Francisco International Airport (SFO), San Jose International Airport (SJC), and Oakland International Airport (OAK), in addition to several smaller regional airports which mainly serve light General Aviation (GA) traffic.

On the landside, San Francisco City and County represents urban areas having compact densities; Santa Clara County, which includes the City of San Jose, represents suburban forms with considerable low-rise single-family residentials, and Alameda County including the City of Livermore, which serves as an exurban employment and tourism destination. Using GIS, the research team conducted a suitability analysis to determine appropriate locations for vertiports in the Bay Area.

Ultimately, the goal is to encourage transportation planners and local governments to start planning for AAM in a simple, cost-effective way. By layering safety, access, and equity features, suitability composite maps are created that inform public engagement and entitlement decision-making in California communities. Analyzing the "where" is a valuable first step for comprehensive plan development and for regulatory zoning amendment considerations that will be needed to permit eVOTL flights and their associated vertiport land use categories.

Scholarly Literature

During this study, key literature was released that helped aid and guide the research process. In August of 2022, the Ohio Department of Transportation released the nation's first advanced air mobility framework; while the study summarized opportunities and challenges for Ohio to embrace AAM, it also served as a guideline for other states. The framework also presented three use cases of AAM including cargo/freight delivery, regional air mobility, and emergency services.

Engineering Brief #105 for Vertiport Design was released by the Federal Aviation Administration (FAA) in September 2022, providing interim guidance for the design of vertiports to serve aircraft having vertical takeoff and landing (VTOL) capabilities. In addition, given the research location, the study considered Caltrans' California Airport Land Use Planning Handbook and the California Aviation System Plan for identifying relevant regulatory requirements appropriate for aviation planning and land use compatibility.

GIS case studies and alternative methodologies were researched to formulate the workflow and process in other literature. Rimjha et al. (2021) is most relevant because it too was a case study for northern California and offers a larger regional context for a suitability analysis. Fadhil (2018) used a weighted linear combination method to locate suitable areas for Urban Air Mobility (UAM) ground infrastructure, including two industry interviews to determine variable considerations for analysis in the metropolitan cities of Los Angeles and Munich. K-means algorithms are also used in numerous analyses to determine site suitability. Jeong, So, and Hwang (2021) applied the K-means algorithm to the Seoul metropolitan area focusing on values related to commuter data. Across these examples, the selection of considerations was based on the type or scale of analysis (such as demand, travel, or region). These studies helped identify parameters used for the GIS analysis methodology in this research.

Methodology & Results

For the suitability analysis, parameters were separated into three categories—safety, access, and equity—for vertiport site placement in the Bay Area. These parameters were identified through literature reviews and discussions with key industry and agency stakeholders. Safety is a paramount consideration in the aviation industry and will be the primary influence in any AAM framework. Access is a major consideration of traditional planning and ensures that facilities can be reached through a mix of transportation modes which can positively impact its use. Equity is an emerging concern of modern planning and considers the equity of impacts that a project might have and unequal impacts may stifle a project or create additional considerations on how to ameliorate those inequities. The parameters were then assigned to a priority level of high, medium, or low, which varied depending on the geographic form at that place (urban, suburban, or exurban). High-priority factors include those which are essentially non-negotiable, and failure to meet any of those factors indicates an unsuitable site. Medium priority factors are more flexible to a degree, and, while not meeting these factors is not ideal, they do not necessarily indicate an unsuitable site. Low priority factors do not factor into the dichotomy of suitability, but are additional considerations for how ideal the site is for vertiport placement.

In a real world setting of site selection, suitability can be determined based on four evaluation outcomes. A site which meets all nine factors in the matrix, all parameter categories at all priority levels, can be considered a "Pass" and is highly suitable. One that meets the criteria in high and medium priorities, but not low priority, can be one that is "Highly Considered." A site that only meets the high priority criteria is further downgraded to "Considered," and a site that does not meet high priority criteria, regardless of the other parameters it may fit, is considered a "Fail" in the suitability analysis. Using geospatial analysis tools, subject parcels that met assigned criteria were identified and summated to determine suitable locations for vertiports.

The compact urban form of San Francisco contains higher population densities and, as a result, has a higher output of suitable parcels, at 1392 meeting the priority features. San Jose in its suburban form contains only 43 resultant parcels that meet high priority standards. This is reduced even more in Livermore in its exurban form, where just three parcels meet high priority standards for the three parameters (safety, access, and equity). Additional parcels meet standards for medium priorities with conditions that could be developed through zoning, economic development, and capital improvements, which would boost more sites into highly suitable conditions.

Recommendations

The following recommendations are based on our research findings, which are not limited to geographic modeling, but also address implications for how local governments and planners can prepare for AAM.

Getting Started:

- Determine the appropriate use case(s) for AAM integration within selected study area boundaries.
- Develop a list of non-negotiable “high priority” parameters for vertiport locations.
- Map existing flight path(s) and engage early with the FAA and local airport authorities.

Data Acquisition:

- Ensure there is easy data access across all agency departments (including engineering, public works, transportation, recreation, urban forestry, and community development).
- Review the metadata for geospatial appropriateness and consistency.
- Maintain a data dictionary and data log to maintain accuracy and currency.

Data Analysis:

- Prioritize locations needing intermodality such as hospitals and transit stations.
- Value proximity to safe pedestrian and bicycle routes, and other micromodal options.
- Understand that suitability varies by community and that preferences change.

Land Use Planning:

- Incorporate GIS site suitability AAM analysis into the Transportation and Land Use sections of comprehensive plans.

- Consider vertiports a form of TOD infill and redevelopment.

- Add vertiport as a land use category in land development codes or zoning codes.

Engagement:

- Add participatory GIS in stakeholder workshops and incorporate virtual reality to lessen fears about eVTOL aircraft noise and their aesthetic impacts.

1. Introduction

1.1 Research Goal

The goals of this study are to establish a framework for a systematic approach to vertiport site selection and to provide recommendations for how a region might plan their AAM network, regulations, or best practices. The approach established by this framework would ensure general consistency in AAM land use planning for a region while remaining flexible enough to allow for other considerations that may differ between regions such as local zoning or state regulations.

This project is based on the case study of vertiport site suitability across five counties in the San Francisco Bay Area region. The objective is to understand what it means to have a new AAM vertiport land use and to create a replicable process for the beginning of geographic planning. By generating a set of prioritized parameters from reputable and free geospatial data, the study outlines a simplistic GIS workflow to identify parcels potentially fitting future vertiport development. Unlike previous models, this study examines safety, access, and equity in urban, suburban, and exurban settings.

Recommendations are based on the research findings, which are not limited to geographic modeling but also address how local governments and planners can prepare for AAM.

1.2 Study Area

The study area, as shown in Figure 1, includes three representative vertiport destinations as the foci of landside GIS analysis including the City of San Jose in Santa Clara County, the City and County of San Francisco, and the City of Livermore in Alameda County. However, GIS analysis was conducted on all parcels across all five counties (Santa Clara, San Mateo, San Francisco, Alameda, and Contra Costa) because the same methodology may be applied to identify suitable ground conditions (below air corridors) connecting these three destinations. It was important to this study to examine different geographic scales since California's metros are multinucleated with varying densities (and in this case, span urban San Francisco through suburban San Jose to exurban Livermore).

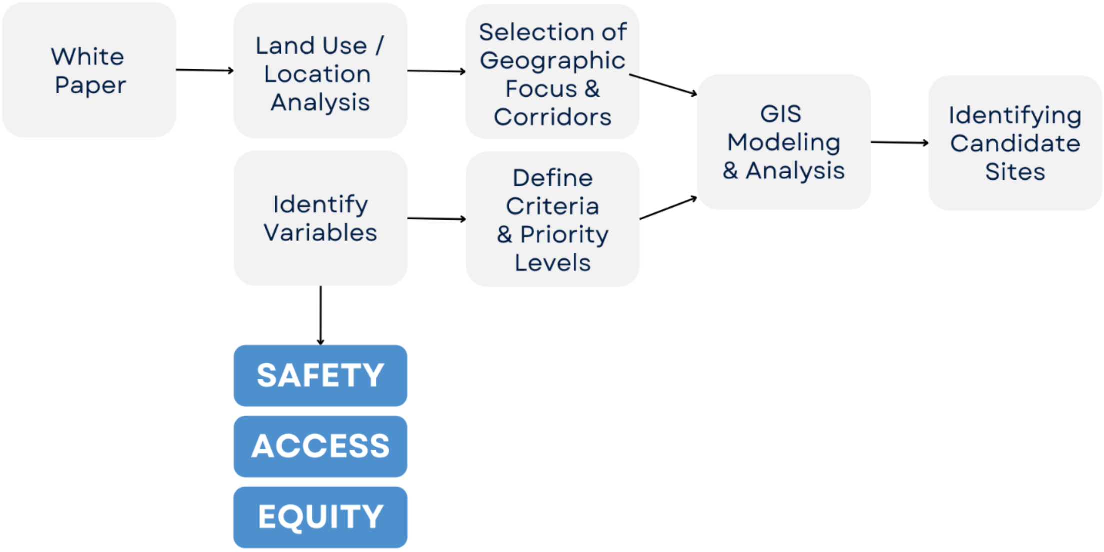
Figure 1. Study Area Map

County of Santa Clara, Bureau of Land Management, Esri, HERE, Garmin, USGS, NGA, EPA, USDA, NPS

1.3 Research Methodology and Approach

Research was conducted over one year and divided into multiple phases. First, a literature review on vertiports is conducted. Second, GIS modeling methods are developed and locational parameters for GIS analysis are generated. Third, data acquisition, storage, and GIS analysis are conducted. Fourth, the results are interpreted and the data is visualized. Lastly, a summary report highlighting a replicable workflow for identifying vertiport parcel (at a site-specific scale) locations and making recommendations is written . This effort required a mixed-methods and largely qualitative approach including a review of existing published scholarship, discussions with key informants, organizing and leading a roundtable style focus group, and GIS analysis. Early on, an overview project workflow was created for ESRI ArcPro GIS software, although the same process could be run using open-source QGIS (Figure 2).

Figure 2. Project Workflow



With industry, and federal and state governments unveiling new aircraft and planning documents frequently during 2022, the study was aided by having two graduate research assistants and one undergraduate research assistant tasked with managing data acquisition while the Principal Investigator and Co-Principal Investigator met with industry and government to formulate location variables and parameters, which is a critical component of this research. Quarterly presentations to the Caltrans Division of Aeronautics Directors served a critical advisory role in completing this project. The research team participated in two NASA AAM Ecosystem Community Integration Working Groups held in October 2021. These early gatherings brought together expertise in transportation, aviation, aerospace, engineering, and planning, and were a great starting point for vertiport location consideration. Combined with existing published peer-reviewed literature on previous GIS methods, a list of appropriate landside location variables was generated and reviewed by Caltrans aviation, planning, and equity officers. Once the variables were prioritized, they were presented to gain scholarly feedback at the American Association of Geographers (AAG), at the California State Chapter American Planning Association (APA) conferences and at the Future of Aviation Tech Transfer Conference. Interestingly, the planning audience was largely ignorant of AAM indicating the need for greater cross-collaboration in transportation and land use planning.

The esearchh team met with two industry leaders currently developing proprietary geospatial modeling software to discuss this study. AirspaceLink has worked with the City of Ontario and the State of North Dakota to create a tool for autonomous flight mission planning that also includes a risk score based on ground location features. EY-Parthenon is a large consulting organization currently building machine learning software for AAM planning that will incorporate real-time weather and congestion data. These advanced models can be useful for planning at a selected site and for ongoing operations.

San Jose State University, in partnership with the California Governor's Office of Planning & Research, hosted the first European Union + California Urban Air Mobility roundtable. This meeting was hosted by State Director Sam Assefa, and European Union Regional Minister Jeroen Olthof. This international focus group gathered experts from federal, state, and local governments, industry, and academia with the purpose of addressing how to govern AAM. Notable participants included Wisk Aero, Joby Aviation, Archer Aviation, Caltrans, City of San Jose Office of Innovation, City of San Jose Department of Planning, and the ministry of the Province of Noord-Holland (Amsterdam). Following this, Joby Aviation included the research team at its Field Day to tour its Marina, and the California research, development, and production facilities.

1.4 Report Organization

Besides this introductory chapter, this report is divided into the following chapters: Literature Review, Research Methodology and Modeling Methods, Case Studies, Results and Recommendations, and a Summary and Conclusions. The literature review provides an overview of the scholarly research on AAM (and the subtopic known as UAM) and vertiports. Research Methodology and Modeling Methods discusses the basis for this analysis including the research design and parameter variables established for geoprocessing. Case Studies includes generated urban, suburban, and exurban parameter matrices and high-value composite site suitability maps identifying urban, suburban, and exurban parcels that may be appropriate vertiport locations. Results and Recommendations interprets the case study findings, and the final chapter discusses project implications and provides a summary of our research and opportunities for future research.

2. Literature Review

2.1 Advanced Air Mobility

Urban Air Mobility (UAM) is a subset of the Advanced Air Mobility (AAM) ecosystem generally referring to a new transportation mode powered by vertical takeoff and landing aircraft (VTOL). Electric versions, known as eVTOLs, can eventually be used as autonomous passenger air taxis that run on highly automated on-demand systems to transport passengers or cargo at low altitudes within 60 miles. UAM aims to transform mobility by alleviating traffic congestion through a reduction in single-occupancy automobile use. This will decrease greenhouse gas emissions and offer the public a new transit alternative at infrastructure buildout. UAM is a quiet sustainable travel mode that efficiently replaces surface transportation, and the typical eVTOL aircraft has been designed to accommodate as many as six passengers, though at onset, flights will require a licensed pilot. The vertiport is a ground hub serving eVTOLs that can be used for passenger boarding and disembarkation, and for aircraft maintenance and charging. Vertiports can be considered as a brand-new land use that operates like a hybrid of an airport and transit station.

In the case of UAM, the industry is advancing faster than policy. Planning for UAM has been slow because critics feel the technology does not apply to most consumers nor does it offer a considerable benefit to other transit services. It is true that UAM will initially serve small populations (especially those in emergency situations), but a well-integrated systems plan for landside vertiports and airside corridors means UAM has the potential to safely and equitably benefit everyone. UAM and its associated infrastructure will start in “low-complexity, low-operational tempo operations and [build] toward an environment of higher operational tempo and the introduction of UAM airspace structure to mitigate an otherwise higher level of complexity” (FAA ConOps 1.0, 2020). Successful implementation of any UAM network requires significant engagement and investment from industry and government at all levels, and extensive stakeholder and public engagement.

To date, the most favorable UAM use case is in emergency and fast-response healthcare services. There are already examples of drone deliveries, i.e., Unmanned Aircraft Systems (UAS), for medical practice. During the coronavirus pandemic, United Parcel Service (UPS) and CVS Pharmacy embarked on a joint effort to airdrop prescription medication to a retirement facility in Florida during shelter-in-place orders. This same practice was applied in Rwanda and Ghana where test kits and medication were air dropped (Goyal & Cohen, 2022). On a larger scale, UAM presents new opportunities for eVTOL vehicles to transport emergency patients and dispatch supplies when timing is critical. However, in its current technological state, UAM applications of aeromedical transport are not expected to be any more cost-effective. It is also believed that these use cases will positively contribute to public acceptance (Goyal & Cohen, 2022). The Ohio AAM framework prepared by the State Department of Transportation expects healthcare providers to be early adopters of AAM with the highest likelihood for small package delivery. Utilizing small UAS vehicles will still bolster logistical support for a statewide approach needed to fully leverage AAM (Ohio DOT, 2022). Assessing demand for UAM infrastructure varies from place to place. UAM is likely to be adopted in dense urban areas where populations earn higher than median incomes and are faced with longer than average commute durations. Regardless of location, widespread adoption, especially in the case of autonomous flight, requires consumer trust in safety—something not yet seen with automobiles.

In 2007, the United Nations released data that more than half of the world's population lives in urban areas with a forecast that the percentage will rise to 60% by 2030 and 67% by 2050 (Swadesir & Cees, 2018). Rapid urbanization will be linked to increased congestion, especially worsening in global cities. In these cities "air-taxis," which are expected to rollout as early as 2024, put pressure on planners to consider significant changes to the built landscape, and to address potential environmental effects of something truly unique. Further, there is the challenge underlying policy to understand future user behavior which can at best be derived from current daily rhythms such as time allocations, activity timing, scheduling, and frequency (de Abreu e Silva & Goulias, 2009; as cited in Chaniotakis et al., 2020). Simply stated, "if people behave the same [with UAM] within clusters of individual behaviors, there is a good basis that they would behave the same when it comes to aspects such as new forms of mobility and new infrastructure," (Chaniotakis, et al., 2020). A key question is whether the degree of consumer demand is similar in autonomous systems since this could change with demographic and economic trends as is the case with aging populations, rising fuel prices, increasing health and environmental concerns, and changing consumer location preferences that tend to increase demand for more accessible multi-modal locations (Litman & Steele, 2017).

Large cities should see greater demand for eVTOL trips—places such as New York City, Los Angeles, and Washington, D.C. have air taxi commuters. More than 33% of all air taxi demand trips predicted in a model completed by Haan et al. occur in three combined statistical areas (CSAs), while 50% of all air taxi demand occurs in the top six CSAs. This suggests air taxi service may be viable only in a handful of places and/or additional port infrastructure investment will be needed for UAM adoption in small cities. That is, the potential market might be concentrated in large cities because smaller cities might not make financial sense (Haan et al., 2021). It is expected that on-demand urban air transportation should be targeted to get people to and from the city core along with options to travel elsewhere, if needed.

Planning for desired travel routes can follow existing major roads and freeways. When comparing travel time for on-demand urban air transportation against three of the most common transport methods in the Melbourne metropolitan area, on-demand urban air transportation was found to be the quickest in 88% of all modeled cases. The only occasion where on-demand urban air transportation was comparable in terms of speed was when the destination was less than 10 kilometers from the point of origin. The largest difference showed a three-hour benefit over driving with all cases being faster than driving (Swadesir & Cees, 2018).

With current eVTOL aircraft, the optimal performance is a mission traveling no farther than 60 miles at a cruising speed of 150 miles per hour, and having a pilot plus four passengers (Uber Elevate). Thus, advancement in batteries will be an enabling technology essential for widespread usage. With this comes new challenges in the aviation industry, challenges defined by capabilities to improve battery strength, achieve full FAA certification, build ground infrastructure, establish Air Traffic Management (ATM) procedures, train pilots, and ensure safety. Proper safety applies to all parties involved—from passengers, to operators, to the public, and to private infrastructure owners (Cokorilo, 2020). Eker et al. (2019) evaluated the feasibility of four security measures for public acceptability including: (a) the use of existing FAA regulations for air traffic control; (b) establishing air-road police forces; (c) detailed profiling and background checks of eVTOL owners and operators; and (d) establishing no-fly zones near sensitive locations, such as military bases, power/energy plants, government facilities, and major transportation hubs (Shahriar et al. 2020). NASA, the University of California, Berkeley, and the City of Los Angeles are also studying airspace operational safety because current ATM systems do not manage low elevation airspace, established air corridors are at a high elevation, there will be increased workload, and UAM will require extensive safety and maintenance training. Several challenges delay integration with existing National Air Service (NAS) operations and urban operations; specifically, there may be a higher frequency of operations than seen in existing commercial aviation, there might be higher density operations at low altitudes, and varying performance differences are yet to be measured. Combined, these factors will stretch current air traffic control system capabilities and drive the need for significant changes (Bauranov & Rakas, 2021). To successfully implement UAM systems, the transportation sector must prepare for a separate Air Traffic Control (ATC) strategy for eVTOL aircraft that pays equal consideration to airsides and landsides. The approach controls near vertiports are essential for service in populated urban areas (Song & Yeo, 2020, p. 1).

Vertiports must be placed throughout a city for easy access to destinations or for transfer transportation modes. Taking this into consideration—along with no-fly zones that are in place due to safety restrictions—it becomes apparent that the air space available for UAM will be quite limited (Eissfeldt, 2020, p. 2). No-fly restrictions limit flight over public buildings, correctional institutions, hospitals, conservation areas, and military lands.

A market study of UAM focused on three potential cases—airport shuttles, air ambulances, and air taxis—presented to NASA in 2018, indicates that the UAM market faces both technological and non-technological challenges (Booz, Allen, & Hamilton, 2018). In terms of non-technological constraints, there is real concern over fast safety and security screenings (Mofolasayo, 2020). This is a risk factor that must be made relatively nonexistent for transit model adoption. Several developed econometric models found that sociodemographic factors, cultural impacts, and affinity to automation (including the enjoyment of technology use) heavily influence adoption. In particular, the presence of in-vehicle cameras and human operators aid confidence in UAM service (Tyrinopoulos & Antoniou, 2020).

The general public perception of UAM is one of caution. This is mainly due to expected noise levels. Aircraft manufacturers, such as Joby Aviation, have reduced noise generation to 40 dBA, mimicking the sound of wind and thus mitigating this issue, but this may still be too noisy in some circumstances, particularly for vertiports located close to residential areas (Swadesir & Cees, 2018). Thus, the primary reason people do not want a vertiport in their community is still noise (Cohen, 1996).

2.2 Vertiport Design

The term vertiport is a general categorization of next generation heliports necessary to enable AAM operations. However, not all takeoff and landing locations have equal capabilities or identical roles in the AAM ecosystem. Based on their function, most 'vertiplaces' will be characterized into one of three categories—vertihubs, vertiports, or vertistops (NASA, 2020). The Heliport Design and Vertiport Design Advisory Circulars published by the U.S. Department of Transportation provide design specifications for heliports and vertiports dating as early as 1991. As defined by the Vertiport Design Guide:

> vertiport landside features such as passenger services (terminal and parking), hangars, employee parking, charging equipment, and storage will vary from site to site. Ground space required for these features is in addition to the ground space required for airside activities. At elevated vertiports, facilities and services may be located on floors one or more levels below the level of the airside surface. Landside facilities should be functional, attractive, and capable of orderly expansion as future needs develop. (FAA AC Vertiport Design, 1991)

Early in 2022, the FAA published an Engineering Brief establishing interim draft guidance for vertiport design and operation that serves UAM aircraft; the FAA further published a revision to this document in September 2022 (FAA EB #105, 2022). The publishing of these subsequent guidelines signals to the aviation industry that UAM implementation is expected in the near future, and therefore the FAA must continue to work with eVTOL manufacturers to establish performance standards. In 2022, the Ohio State Department of Transportation (ODOT) published the first ever state-level AAM framework plan with recommendations for integration based on collaboration with industry partners (ODOT, 2022).

UAM will require dedicated infrastructure that currently does not exist. Even though UAM is initially expected to retool or better utilize existing helicopter infrastructure, there will be a shift to vertiports as a predominant ground land use. The site selection process for vertiports becomes crucial for effective and safe UAM operation. There are several important factors to consider when evaluating vertiport locations, some of which are obvious such as avoiding flight obstructions. ODOT calls for an iterative process for lifecycle management in AAM evaluation, exploring surrounding airspace and land uses. This calls for noise monitoring and approved route planning for on-demand and scheduled trips by aircraft type (ODOT, 2022). Vertiports need transmission interconnection to sufficient electricity to power eVTOL operations and aircraft, though manufacturers are investing in alternative fuels such as hydrogen. Fulton (1969) wrote in *Official Architecture and Planning* how quiet vertiports could act as technological growth points and provide city-centre renewal. Ahead of its time, a 1996 report of vertiport characteristics by Peisen et al. laid out the physical requirements for vertiports to accommodate passenger load, but based standards on airport design. However, for UAM to be successful, the overall travel time must be shorter than conventional road travel during peak congestion hours. One way to decrease the overall travel time is by reducing transfers though this requires multiple vertiports (Park et al., 2020). This potential volume of citywide UAM operations generates a need for standardized design: "Using standard modular components can reduce construction duration but planning is needed to streamline permitting" (NATA, 2019).

Perhaps the most comprehensive review was conducted by Garrow, German, and Leonard who created a database of 800 publications in UAM, EV, and AV literature. A meta-analysis compared the overall research related to demand modeling, operations, and integration with existing infrastructure. Then, comparative analysis identified important factors for design and operation for future AAM systems along with gaps in the research that will be important for future study (Garrow et al., 2021).

A holistic approach to vertiport site selection should not only include technical engineering considerations but also pay mind to the land use implications of access, zoning, and mitigating negative effects. This ensures UAM results in a net community land use analysis, especially when using GIS, which allows for easier identification of specific criteria while also providing for flexibility in changing parameters. As an additional benefit of forethought, careful planning can mitigate future issues leading to community action which might require immense staff time and can result in new ordinances or regulations which restrict the operational levels of a vertiport below its planned design.

2.3 AAM Models

UAM research methodologies range from those that are demand driven and route analysis to K-means algorithm clustering at regional scales. Case studies have examined global metros from the United States, Australia, East Asia, and Europe. In all applications, the variables were predetermined. Knowing UAM demand is of course valuable to the site selection process, but at this point, it can only be forecasted. Goyal et al. used a five-step process for demand modeling, including: (1) trip generation, (2) scoping, (3) trip distribution, (4) mode choice, and (5) market constraints. Alternatively, Winter, Rice, and Lam statistically compared demand modelling to a survey of early adopter willingness. Results range by value, fun, wariness, fear, and happiness, and suggest there is value in extensive consumer marketing.

A northern California sensitivity analysis conducted by Rimjha et al. explored commuter demand when the calculation of UAM demand was integrated with vertiport placement and travel cost per mile. By creating an algorithm for mode choice, the study placed vertiports to maximize UAM demand for any given number of vertiports throughout the region. It considered mode alternatives, drive alone, and transit options. Findings reveal that UAM success depends on popularity among high-income users and operational efficiency. The system would have to be errorless for commuting purposes in order to generate profit. Ultimately, wait times will greatly impact UAM demand, so the

system must have policies that lead to a minimum delay; otherwise, the driving alternative quickly becomes a more attractive mode for commuters. The construction and operation of a future UAM system will be complex and it will require intricate long-term planning. Several policies will be needed to promote the system's success and economic feasibility. Many of these policies are implemented in some form for other transportation systems (e.g., aviation or driving), so the lessons learned in their implementations will be of use to the UAM system. (Rimjha et al., 2021)

Designing UAM aircraft requires knowledge of local conditions where the transportation system will be implemented. The station network, including elevation, architecture, local climate, and demographics strongly influence aircraft type (Ploetner et al., 2020). For this case, a multi-criteria analysis was conducted to evaluate alternatives, and an indicator system was developed to assess proposed UAM scenarios—from environmental, to transport-business related, and to socioeconomic—each having a corresponding desired outcome with defined sub-indicators. To estimate future UAM demand in Munich, a current and future mobility demand per household with detailed origin to destination routes had to be known. Additionally, a specific mode-choice model for both commuters and other users (such as airport passengers) including all other relevant alternative modes of transport (such as autonomous vehicles) had to be set up based on stated preference surveys (Ploetner et al., 2020).

A K-mean algorithm analysis was conducted by Jeong, So, and Hwang (2021) for the Seoul metropolitan area that focused on commuter data. The commuter demand was estimated from a 2015 commuting population census conducted by Statistics Korea. The K-means algorithm used requires enough data for clustering, so allocations can be made to each area and plotted on a dot density map where one point equals 5000 persons. This clustering is repeated many times until optimal vertiport locations are observed (Jeong et al., 2021). The key element is parameter "k" which should be initially specified, and the entire clustering process is repeated until a cluster center location appears. Vertiport locations are then selected using commuter data and the K-means algorithm (Jeong et al., 2021). Another methodology using the K-means algorithm and comparative analysis was conducted from the Zillow Transaction and Assessment Dataset (ZTRAX). This method introduced land use by size and cost constraints for the determination of landing sites. This thesis compares the availability of land, effects from splitting, consolidation, relocation of vertiports, and the cost per passenger-mile (Tarafdar, 2019). GIS was helpful because it analyzed geocoded (latitude and longitude) data with acreage, county name, floor area, and landform type (Tarafdar, 2019). This proved valuable for assessing vertiport suitability based on square footage.

Fadhil (2018) conducted notable GIS research on AAM ground infrastructure. This research applied integrated AHP-Delphi analysis built on weighting various criteria and also used statistical aggregation of judgments made in group decision-making. This benchmarks a consensus among experts engaged in an iterative process (Mu & Pereyra-Rojas, 2017; as cited in Fadhil, 2018). Ground infrastructure is one of the critical issues affecting the implementation of AAM (Vascik & Hansman, 2017; Uber Elevate, 2016; as cited in Fadhil, 2018). Yet, there are only a few published sources on landing equipment. In order to improve the process for factor selection, AHP-Delphi and expert interview methods were conducted jointly resulting in a ranking of weighted factors (Fadhil, 2018).

2.4 AAM Policy

2.4.1 Federal

AAM is an emerging market with no universal framework or public policy. As AAM technology continues to advance, so will FAA regulations. This will spur proactive and reactive policy creation as eVTOLs become further integrated into society. Specific governance should be developed to address air travel and operations including vertiport safety regulations (California DOT, Caltrans). Currently, eVTOL and vertiport standards are based on drones, helicopters, and helipads.

It is expected that the FAA will act as the principal agency responsible for setting AAM standards, especially for safety, as is the case for existing aircraft. The FAA began establishing standards for vertiport design when it published Advisory Circular (AC) 150/5390 in 1991, but this document was eventually cancelled in 2010 (FAA EB#105, 2022). FAA standards are evolving in consultation with manufacturers. These in progress standards are available for public review in the Vertiport Engineering Brief (FAA EB#105, 2022). Due to the anticipated high-tempo operations, the FAA safety standards in 14 CFR Part 135 are akin to those that generally apply to commercial non-scheduled operations typically referred to as private charters or air-taxis. It is important to note that, under the *Heliport Design Guide* Advisory Circular, the FAA cannot regulate private heliports but can provide specifications and constitute proper infrastructure for takeoff and landing sites. While a vertiport may operate as a privately owned private-use facility, it is also possible that the vertiport will be required to comply with federal standards to ensure “adequacy” as defined in the regulatory text of Part 135 (NATA, 2019).

2.4.2 State

In the decade since the 2013 legislative session, state lawmakers have frequently considered bills addressing unmanned aerial systems. State legislatures often debate if and how drone technology should be regulated, considering the benefits of autonomous drone use, the privacy concerns, and their potential economic impact. At least 44 states enacted laws addressing drones and an additional three states adopted resolutions. Common issues include defining UAS, law enforcement limitations, and how operations can be flown safely in public (NCLS 2021). These regulations are applicable to eVTOLs, but need to be refined and/or expanded for human passengers. The FAA's Engineering Brief #105 Vertiport Design specifies that states' departments of transportation, aeronautics commissions, or similar airport authorities grant approval and, in some instances, issue a license to establish and operate landing facilities. Many states have determined to what extent the FAA Heliport Design Guide applies and how the FAA guidelines are subsequently enforced within their jurisdictional boundaries, ranging from very minimal and permissive to intense oversight and restrictive (NATA 2019). In California, the state grants its Department of Transportation (Caltrans) full oversight and authority when it comes to regulating airports within their jurisdictions. Published standards must be met, including sound studies, land use compatibility studies, and California Environmental Quality Act (CEQA) Environmental Impact Reports as defined by the Caltrans Airport Land Use Planning Handbook. In 2022, the ODOT published its own AAM framework introducing plans for statewide AAM in the coming years with an expectation that uncrewed flights will be licensed by Ohio for operations in 2027 (Ohio DOT, 2022). The framework by Ohio's DOT is the first of its kind and does an excellent job explaining AAM use cases including airport shuttles, emergency services, passenger air taxis, and cargo/freight deliveries along with regulatory, industry, and workforce recommendations.

2.4.3 Regional

No regional policies have been adopted for AAM air transportation or connection to surface transportation. However, AAM integration at the regional scale is essential for achieving a safe and accessible multimodal vision. A regional transit network needs efficient flight paths connecting the periphery to the urban core, and to neighboring cities and/or employment hubs. Regional agencies or metropolitan planning organizations, and the federally mandated and funded transportation policy-making organizations foster cross collaboration between local jurisdictions and provide a defining voice in establishing roles and responsibilities: "Even though civil aviation authorities are accustomed to dealing with all airspace issues, the integration of UAM will require city and regional stakeholders to take an active role in shaping some aspect of UAM policy development" (LA DOT, 2022).

2.4.4 Local

Local government policies will depend largely on geography. AAM is novel, making an advisory committee critical for documenting and determining the wants versus needs of communities. Advisors should facilitate focus groups with relevant community advocacy groups representing environmental justice, transit advocacy, pedestrian advocacy, civil rights, economic development, and community leadership (LA DOT, 2022). This outreach and engagement are essential for AAM adoption. Local government is also responsible for California Environmental Quality Act (CEQA) compliance and drafting comprehensive plans and zoning codes not currently addressing AAM. Some communities are more sensitive to noise, growth, and development, and want to feel protected by extensive policies and design guidelines. NASA recommends that local governments considering vertiports should engage early with the FAA, who must assess the safety of any proposed vertiport location and any impacts to the existing National Airspace System. The FAA's current regulations require a vertiport proponent provide timely notice of intent. Interested parties should contact the Airports Regional Office or Airports District Office. Several communities enacted new zoning ordinances, changed building and fire codes, and created conditional use permitting procedures to expand vertiport development permitting (FAA EB #105, 2022).

2.5 Transportation and Land Use

Before building vertiports, as new multidimensional spaces for connecting surface and air transportation, it is essential and beneficial to understand how other new transportation modes affected their surroundings in the past. In most cities, transportation comes in several forms from public transit (including high-speed rail) to on-demand drivers, private automobiles, buses and bus rapid transit, and micromodal bicycles and scooters. To reduce harmful greenhouse gas emissions, cities are investing in ways to reduce single occupancy vehicle trips in favor of Transit Oriented Development (TOD). In this way, land use planning helps achieve sustainable transportation goals. TOD can be expanded to include vertiports which not only builds new infrastructure but also creates new green jobs; however, moving aviation off the airport will pose new questions over land use compatibility (FAA Land Use Compatibility and Airports, 2022). Until AAM is a reality, the most compatible zones are commercial and industrial, vacant lots, and publicly owned sites. Initially, residential communities, even downtown, should be excluded to alleviate community impact.

California's land use and transportation problems are co-dependent; problems in any one arena are reflected in another. Such co-influences call for a more holistic planning approach (Cervero, 2003). This provides a better understanding of the interaction between transportation and location phenomena, and thus greater knowledge of the determinants of urban spatial patterns (Putman, 1983). Understanding this interrelationship is essential. Badoe and Miller (2000) found that land-use policies emphasizing higher urban densities, traditional neighborhood design, and a land-use mix do result in declines of auto ownership and use, while also enhancing transit patronage and walking. The debate concerning residential density in determining urban transportation "efficiency" or "sustainability" is ongoing. A "pro-density" argument is associated with the scholarship of Newman and Kenworthy (1989), among others, in which density seems to be the single most important factor for explaining macro differences in transportation and energy use in cities (Badoe & Miller, 2000). AAM seems fitting in this case; when eVOTLs become a quiet electrified alternative to urban congestion, it can re-center discussion on other environmental or social justice effects.

Environmental equity is of growing concern in planning. Airport development is legally required to consider environmental impacts since the adoption of the National Environmental Policy Act (NEPA) and creation of the Environmental Protection Agency (EPA) in 1970. NEPA adheres mainly to direct impacts on the environment from a proposed action, but the EPA's responsibility is reviewing actions of other federal agencies—this was expanded following the

Department of Transportation's refusal to release agency comments regarding the Environmental Impact Statement (EIS) on supersonic transport (Alm, 1988). The concept of environmental justice entered public discourse in the 1980s following studies over proximity to hazardous waste landfills surrounding communities of racial or ethnic minorities, and low-income backgrounds. Then, in the 1990s, continued evolution of federal policy including the Presidential Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, resulted in a new requirement for specific considerations of environmental justice (McNair, 2020). In the following decades, environmental justice was given progressively higher importance with many studies and actions. Yet, research continues to reveal disparities in environmental justice in the airport context. Correlations exist between environmental concerns and the locations of communities of traditionally disadvantaged racial, ethnic, or socioeconomic backgrounds (McNair, 2020).

There is fear that AAM will disproportionately affect those with unequal access or opportunity. AAM is more likely to cause a negative impact on regions with a lower income due to a lack of access and economic factors which can hinder participation in community planning meetings. While the concept of accessibility is simple to understand, measuring it is often complex and diverse (Kelobonye et al., 2019). Accessibility denotes the ease of reaching destination opportunities such as jobs, stores, schools, and health services. Accessibility could refer to people or places; it could be measured at the neighborhood or regional scale, and in absolute terms (e.g., minutes) or in relative terms (e.g., as indices). While social, economic, and political factors could become barriers to access, spatial accessibility is affected by three spatial factors: attributes on origin (for example, home location when accessibility refers to places, an individual's gender, income, or other characteristics when accessibility refers to people); attributes on destination (for example, number of jobs or size of schools); and spatial separation or transportation linkage between origin and destination (Pan et al., 2018).

Land use patterns affect accessibility because the ability to reach desired services and activities is affected by mobility—the amount and type of travel activity (Duranton & Guerra, 2016; Litman, 2003). Different land-use patterns have different accessibility features. Urban areas have more accessible land use and more diverse transport systems, but slower and more costly automobile travel. Suburban and rural areas have less accessible land use and fewer travel options, but driving is faster and cheaper per mile (Litman & Steele, 2017). There is a significant lack of U.S. data related to the transport disadvantage of specific socio-demographic groups that can support an investigation of transport need and disadvantage (Pyrialakou, Gkritza, & Fricker, 2016). Transportation equity considerations have limitations. First, they only consider a subset of all social equity issues (Litman & Brenman, 2020). For example, the "intangible" transportation outcomes, such as walkability or livability, are frequently overlooked, while "tangible" outcomes, such as reduced traffic congestion and improved transit coverage, are easier to measure and present to the public; thus, they are the focus of social equity considerations and are prioritized over the intangible outcomes (Handy, 2008). For effective decision-making it becomes essential to integrate all factors into a transportation equity analysis framework. Second, consideration of equity issues is challenged by the need to balance the diverse goals of such a project (Guo et al., 2020). As AAM transportation infrastructure is incorporated into cities, planners must be cautious of accessibility and land use when selecting locations. Designing AAM with multimodal transit requires planners and stakeholders to account for accessibility in both physical and ethical senses and for walkability to and from these locations.

Existing research shows that the airport industry is sited in places where communities of traditionally disadvantaged backgrounds tend to have higher risk for exposure to negative environmental impacts. Specific examples include a study showing a higher likelihood of fine particulate matter from aircraft emissions surrounding the study airport in a community having lower income, less education, and non-white ethnic background (Rissman et al., 2013); a noise study which found that ethnicity was an important predictor of exposure to aviation noise pollution (Ogneva-Himmelberger & Cooperman, 2010); and a study of the planning processes which highlighted an inherent power imbalance in the public participation process (McNair, 2020). Planning can benefit greatly from quantitative measurements.

One study focused on NEPA development filings at 19 airports between 2000 and 2010, and identified two shortcomings in the NEPA process for addressing environmental justice. First, the unit of geographical analysis is not prescribed but instead simply directs that it should not artificially dilute or inflate the affected populations. The study found that the effects to so-called protected communities were downplayed due to the large population of those communities in the geographic study area (McNair, 2020). In doing so, the reasons behind *why* these populations were clustered in the affected area were overlooked and might include historically racist practices such as redlining. Additionally, in some cases, the definitions of “low-income communities” were often based on general thresholds rather than local benchmarks which artificially decreased the population of affected communities in the environmentally impacted areas (McNair, 2020). Secondly, there was a tendency to nullify findings from the NEPA process. In two of the airports studied, environmental impacts were identified but written off as mitigated though not actionable measures. There was also a tendency to reference within the NEPA process the need for an impact to be worse than would occur in the no-development scenario, creating an implication that airports are free to continue creating unequal effects so long as there was no change to the status quo in current operations (McNair, 2020).

3. Research Methodology and Modeling Methods

3.1 Introduction

Transportation facility development historically involved site selection from land available for lease or purchase followed by a feasibility analysis during a specified due-diligence period. During the feasibility phase, planning professionals had the arduous task of manually compiling disparate sources to examine which location(s) yields the most desired outcomes. Usually, this process was transformed by web data portals and GIS software. Geoprocessing tools automate the combination of spatial data and identify ideal candidate locations quickly. This digitally replaced the use of translucent overlays on multiple maps needed to add variables or subtract constraints and expanded study areas.

GIS models are powerful tools for exploring regional extents at site scale variability. By modeling parameters, computational processing allows one to test changing conditions or scenarios without making costly real-world errors. The dynamic composite maps are data visualizations made possible by a relatively simple series of GIS steps. This can be for free using open-source GIS platforms for spatial analysis such as QGIS. Therefore, this research not only introduces the general procedure for vertiport site suitability analysis but also links to variable data sources and steps to carry out procedures.

3.2 General Procedure

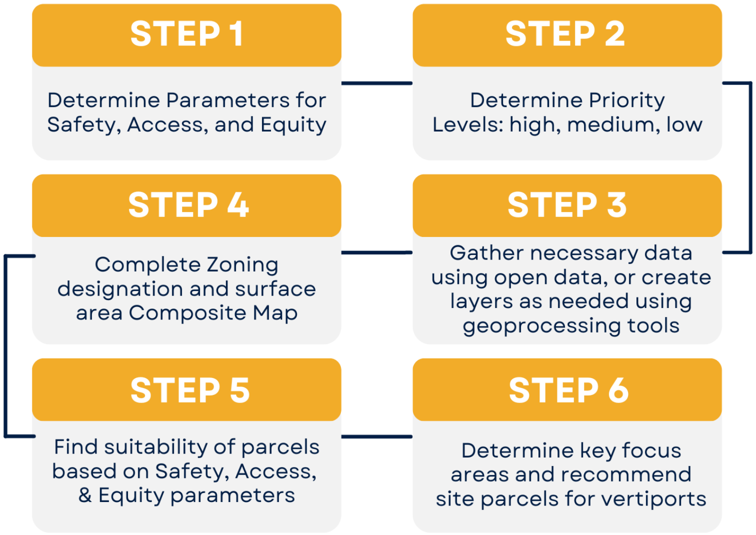
ArcGIS Pro is capable of data storage, advanced analytics, and data analysis in 2D, 3D, and 4D spaces; its maps can be easily shared online, and across devices and operating systems (ESRI). Public agencies are increasingly offering GIS portals where geospatial information is readily available for download and can be processed by an end user. While these resources are great for political and physical features such as zoning or mass transit stations and stop locations, portals might not include demographic data. The US Census demographic and socioeconomic tables and household (travel) behavior information collected in the American Community Survey are available through Census.gov and can be related to locations in GIS. Computational power is needed for analysing an entire regions' vector points, lines, and polygon data, or when creating new continuous raster surfaces.

This research is a vector-based analysis of parcels based on safety, access, and equity variables used to determine vertiport site suitability. New transportation systems are extremely expensive, so using geospatial models and forecasts prior to capital investment is imperative and frequently referred to as a digital twin. The techniques outlined here are purposely unsophisticated because an overarching goal of this research is to reduce barriers and improve standardization in community AAM planning.

The novel contribution of this research is a vetted list of available data prioritized for urban, suburban, or exurban settings. Instead of applying numerical weights to each variable, this study takes an innovative and more flexible, implementable, and realistic approach. Myriad parameters or factors must be considered for vertiport development from different perspectives, and each have a different importance to the decision-makers. Therefore, it is important to bucket priorities of all these considered parameters into high, medium, or low values that can be further refined when AAM is able to be tested in situ. Here, variable priority levels were classified from published literature, NASA-led working groups, industry demonstration, key informant discussions, and focus group insights.

The general procedure and steps to develop the GIS modeling for site suitability analysis is summarized in the roadmap in Figure 3 and is based on the case study of the San Francisco Bay Area.

Figure 3. GIS Modeling Roadmap



Step 1 Establish Parameters. Parameters are based on the Caltrans mission to emphasize transportation safety, access, and equity. This step also involves choosing representative samples for analysis because there is variability across the San Francisco Bay Area.

Step 2 Classify Variables. It is recognized that data layers are in fact variables within each of the three parameters (safety, access, and equity). Decisions on how variables should be prioritized differently in urban, suburban, and exurban places was largely based on the literature review and qualitative inquiry. Each variable was assigned in a table as having either high, medium, or low importance based on geographic form (i.e., urban, suburban, or exurban).

Step 3 Data Organization. This is a huge effort in any regional study. Parcel and zoning information was gathered from five counties and 52 cities in the Bay Area (see Appendices). There are MPO data sources, but it was determined that cities and counties maintain the most up-to-date parcel information within their jurisdictional boundaries. Socioeconomic data at the block group scale was obtained from the U.S. Census website. All data was logged and stored for free on Google Drive; meta-data were reviewed for currency and academic research permission.

Step 4 Data Aggregation. Data aggregation is needed for efficient geoprocessing. Electric eVTOLs are designed to be quiet and without emissions; however, the environmental effects on surrounding land uses are still unknown. To be cautious and conservative, parcels with industrial or commercial zoning were aggregated and used as a proxy for early vertiport development.

Step 5 Data Analysis. Site suitability analysis can be done using ArcGIS Online; however, given the abundance of the five counties' parcel data, this study used the ArcPro2.8.2 Desktop version to minimize processing time when selecting by attribute or using the join, intersect, and clip geoprocessing tools. These basic steps are fundamental but must be replicated for each variable found in each parameter, and conducted in repeated series. Network analysis was also used for connection to transit while buffers were applied to examine proximity to incompatible/sensitive land uses in the vicinity and for distance to points of interest (POI) and employment anchors.[1] Generate Drive Time Areas was used to calculate drive times and walking distances for several variables because it creates a feature class based on travel time and distance. This can include driving distances and walking. When working with around 200,000 zoning parcels across five counties, the researchers chose to use a Boolean output. A parcel which either was scored as having a "high" value or did not meet the criteria was excluded from further study. However, planners recognize that places can change, so a site excluded from GIS study cannot be considered permanently unsuitable for vertiport development.

Step 6: Data Visualization. When a parcel scored "high" across all three parameters, it was included on the resulting site suitability map.

3.3 Variables

As mentioned in Step 4 above, commercial and industrial zoning served as a land-use proxy for vertiport analysis. Each county and city have multiple and often different zoning designations for commercial (GC, C-1, C-2, etc.) and industrial (I, IC, IB, etc.) uses. Figure 4 depicts the process for aggregating zoning data gathered from 57 different agencies. This required extensive data collection and repeated reference to municipal zoning codes to define abbreviations. For data management, a new field was created to categorize parcels as industrial, commercial, or agricultural

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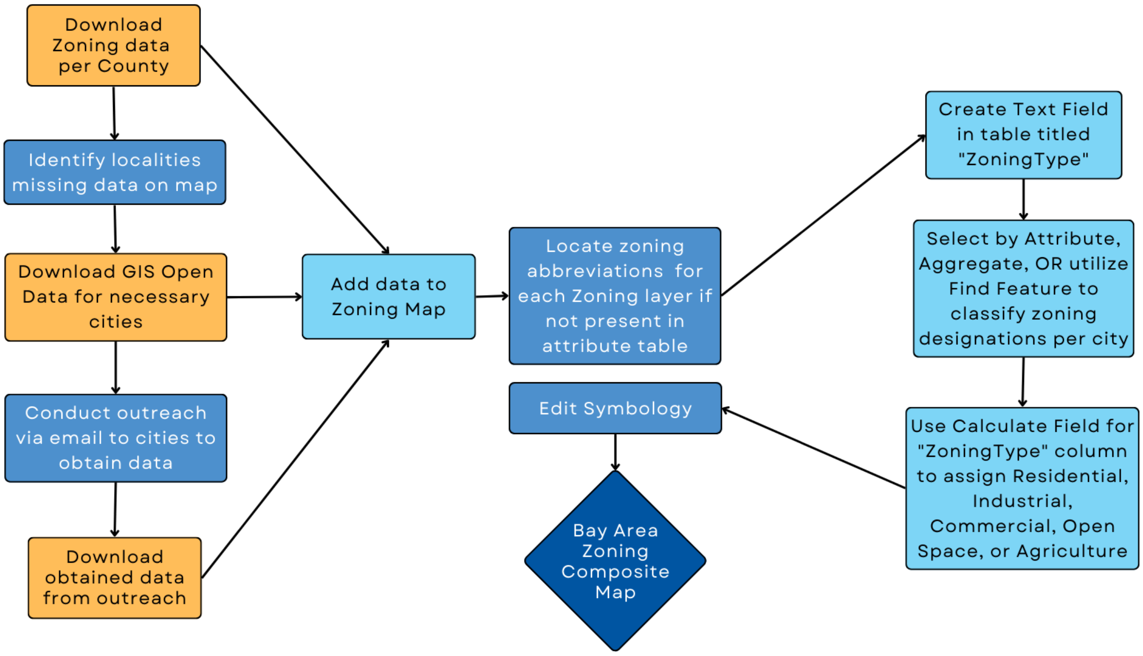
[1] The FAA published guidelines for land use compatibility for airports, in FAR Part 150, which identifies what land uses are normally considered compatible (FAA, VII-6). These include: agricultural, commercial, and industrial uses. Those that are typically considered incompatible are residential areas, schools, and churches.

land (as recommended by the FAA Vertiport Design Circular). This aggregated land use made data manipulation easier and helped improve map clarity.

Figure 4. Zoning Aggregation



Twenty-seven variables were selected for use in the GIS vertiport site suitability analysis and generally included:

- Parcels large enough to support vertiport development and operations
- Final Approach for Takeoff and Landings (FATO) and flight paths
- Location of existing commercial and general aviation airports and heliports
- Presence of incompatible, or sensitive, neighboring land uses
- Employment data on job density, presence of largest employers, and Longitudinal Employer-Household Dynamics (LEHD)
- Multimodality considerations like bicycle and walking distance to major transportation nodes, major employers, or Points of Interest
- Census statistics on median household income, race, ethnicity, head of household, rent versus ownership, and language preference

- Household Transportation Expenditure
- Presence of electricity transmission lines and substations
- Highways and major arterial roads
- Vacant and underutilized properties
- Surface parking lots or parking garages with roof access

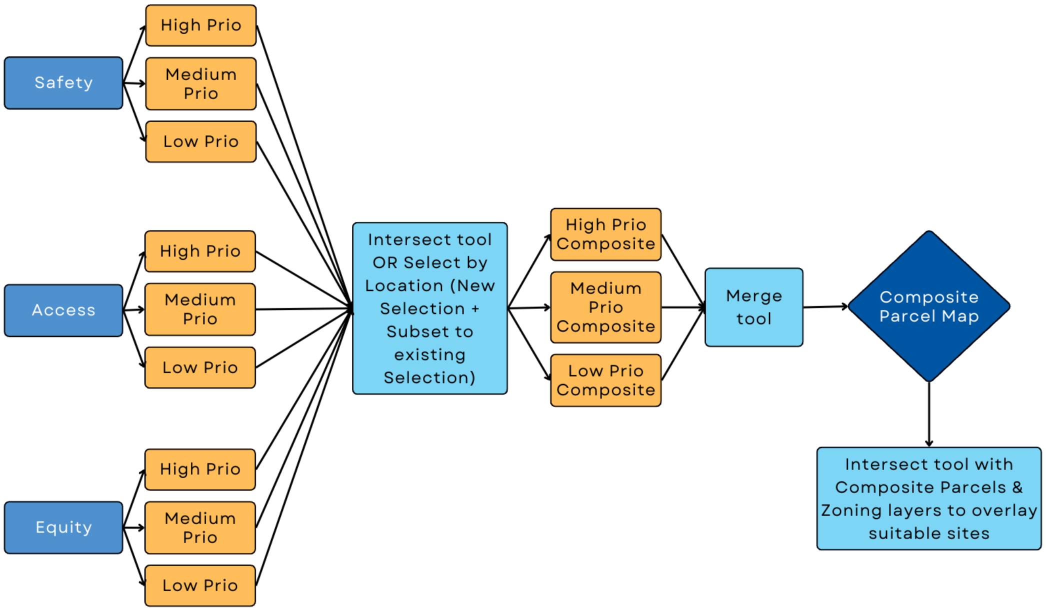
Safety is paramount to AAM adoption. Parcels having greater than 250 ft. by 250 ft. surface area were selected based on FAA vertiport design standards. These 1.5 acres account for takeoff and landing space plus passenger terminal(s) at the vertiport. In the vertiport vicinity, 500 ft. buffers were applied to create a safe space around sensitive land uses (including all schools, daycare, libraries, community centers, assisted living, and parks). Buffers were also created around obstructions such as powerline towers in San Jose and skyscrapers in San Francisco. A 1.5-mile buffer was created around existing airports and heliports.

Access variables were gathered from multiple data sources including LEHD Job Density, Median Household Income, and Transportation Consumer Expenditure. For this analysis, census block groups are preferred. In some cases, block group values ranged, so an average was determined by creating histograms. The Points of Interest (POI) and employment center locations came from market research including crowd-sourced information such as Yelp and TripAdvisor.

The equity variables were gathered using Social Explorer and downloaded at block group scale, but it should be noted that this information ultimately comes from the U.S. Census. The determination of 30% and 50% of household median income depends on location, and in this case came from Bay Area regional housing assessments.

When these variables are combined during spatial analysis, the result is a composite map showing suitability sites across all three parameters (safety, access, and equity). These parcel polygons are merged into a single new output dataset. Figure 5 is a geoprocessing workflow for suitability mapping.

Figure 5. Geoprocessing Workflow



3.4 Data Format and Access

GIS data used to complete this study was obtained from multiple compressed file formats, though information is largely contained as either comma separated value (.csv) spreadsheets or vector shapefiles (.shp, .shx, .dbf, .sbn, .xml, and .dbf). The data files used in this study can be accessed using this link.

4. Case Studies

4.1 Introduction

The San Francisco Bay Area region is selected as a case study. It has a population nearing 7.8 million people that includes the Oakland-San Francisco-Hayward Metropolitan Statistical Area and the nation's 10th largest city, San Jose. The region comprises nine counties, but the five selected for this study morphologically encompass the South Bay. It is recognized that there are significant geographic differences across the region. Therefore, instead of processing a single GIS workflow across the entire area, we have obtained more accurate results by breaking the Bay Area into smaller representative samples, each having a prioritized variable matrix that more precisely models spatial variation.

In this chapter, results based on the GIS modeling and the variables discussed in the previous chapter are mapped by location including urban San Francisco, suburban San Jose, and exurban Livermore, as well as the East Bay and the Peninsula corridor.

4.2 Urban: San Francisco

The Pacific Ocean, San Francisco Bay, Golden Gate Park, and topography naturally shape San Francisco. With limited land, the city has evolved from a historic gold rush seaport into a thriving cosmopolitan tourist destination and global technopole for the high-technology employment sector (the Salesforce Tower is an example). The city represents a grid pattern with desirable population density for a compact form that is desirable in both urban planning and urban design. The predominant land use is mid- to high-rise zero lot line mixed-use buildings having a commercial ground level with residential units above. The city has significant cultural landscapes such as Chinatown and Japantown, but most of the 36 neighborhoods are multicultural destinations for sightseeing, restaurants, and shopping. For this reason, the variables in Table 1 prioritize proximity to transit, walkability, and points of interest; and the pedestrian, cycling, and transit-related variables are regarded as high priority. The choice of these variables and the determination of their priority levels are made in consultation with Caltrans.

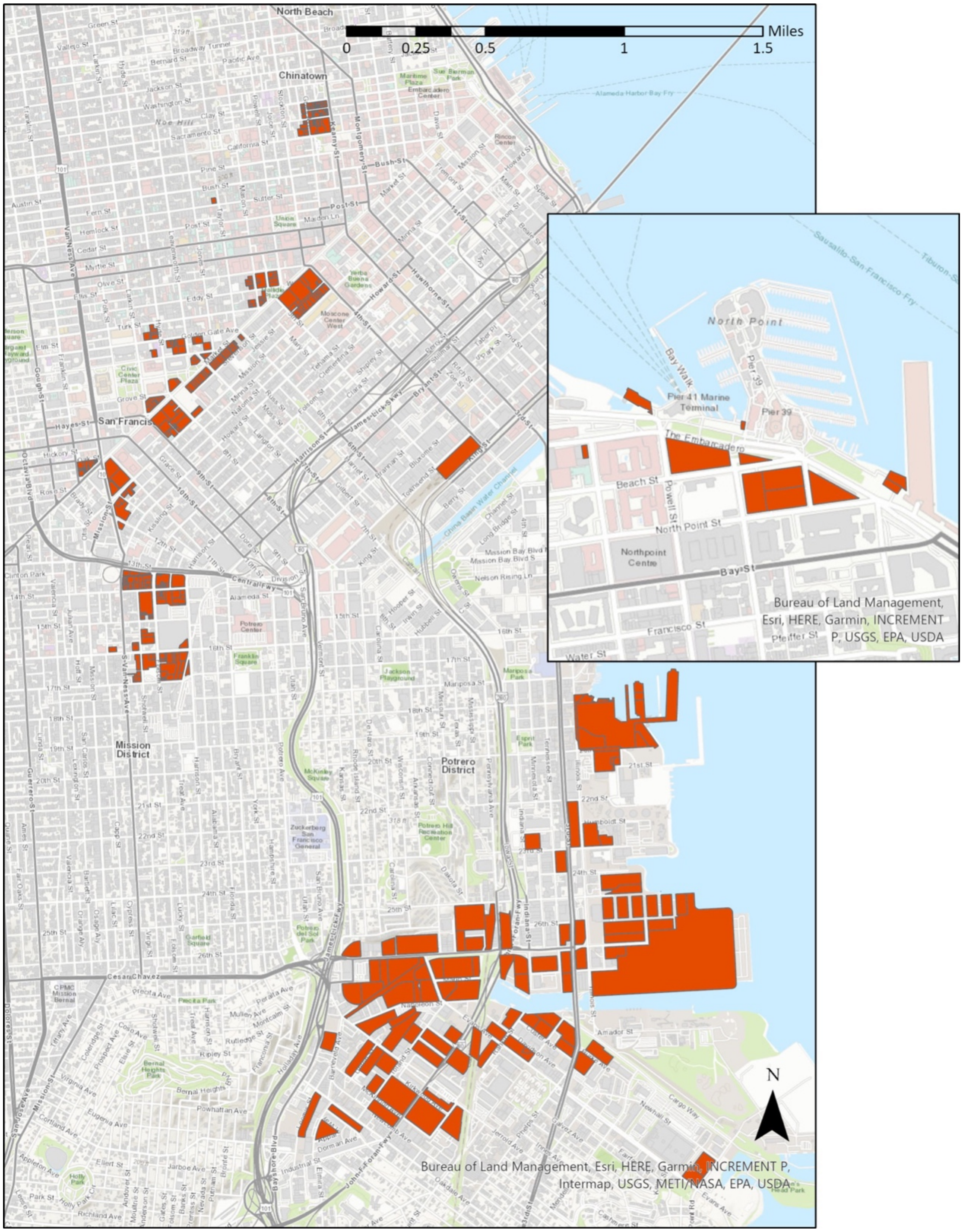
Table 1. Urban GIS Variables

	Safety	**Access**	**Equity**
High Priority	Uses not allowed within a 500 ft. radius of Final Approach for Takeoff and Landing (FATO): • Schools (K12, Community Colleges, Universities) • Parks • Libraries • Gas Stations • Hospitals • Day care • Assisted Living Minimum Parcel 250 ft. x 250 ft	Above average LEHD job density Presence of largest employers in the bay area 2 mile bicycling to at least 1 major transportation node (BART, CalTrain, and/or Airport) 0.25 mile walking distance to at least 1 major transportation node 0.25 mile walking distance to at least 10+ Points of Interest (POI)	Block groups with median household income levels at or below 30% of average Large population of single head of household (apartments can be built in some commercial zones) Block groups having large proportion of the population identifying as Black or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander Block groups having a large proportion of the population identifying as Hispanic, Latinx, Chicanx
Medium Priority	Airports within ½ nm of FATO Heliports within ½ nm of FATO Vertiports within ½ nm of FATO	Block groups with an above average transportation consumer expenditure Existing Power Infrastructure 0.25 mile walking distance to 1 major employer 10 min driving distance to 1 major employer 10 min driving time to at least 10+ POI	Block groups with median household income levels at or below 50% of average Large population of renters (apartments can be built in some commercial zones)
Low Priority		Parking lots or garages with roof access Block groups with above average population density Block groups with above average median household income Proximity to a grand boulevard or arterial 10-minute driving distance to at least 1+ major transportation node	Primary language spoken other than English

Other desirable variables if available are: 4050 ft. from physical obstruction (such as trees, poles, and wires); approach and departure paths; vertical separation based on 8:1 approach and departure surface; above average traffic counts; and above average office lease price

Using the variables above and the workflow described in Chapter Three, as many as 1392 parcels were found to be suitable vertiport locations in the City and County of San Francisco (Figure 6). This is out of 234,693 total parcels; for a complete address list refer to Appendix C.

Figure 6. San Francisco Suitability Map



Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, USGS, EPA, USDA

Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, Intermap, USGS, METI/NASA, EPA, USDA

In San Francisco, any new vertiport must be strategically located for maximum efficiency and demand. It is acknowledged that more than one thousand parcels met suitability criteria based on GIS outputs, however none are ground-truthed. Still, the results are sensible. North Beach by Pier 39 has proximity to the bay and many parking garages that could be repurposed, and it is a popular sight with nearby employers. The Tenderloin and South of Market are also prime locations given their proximity to shopping areas and major employers (including Civic Center Plaza with several museums, events halls, and theaters) with an easy connection to Bay Area Rapid Transit (BART). Surprisingly, Bayview, a neighborhood farther from jobs and points of interest, was selected because of equity variables and adjacency to BART.

4.3 Suburban: San Jose

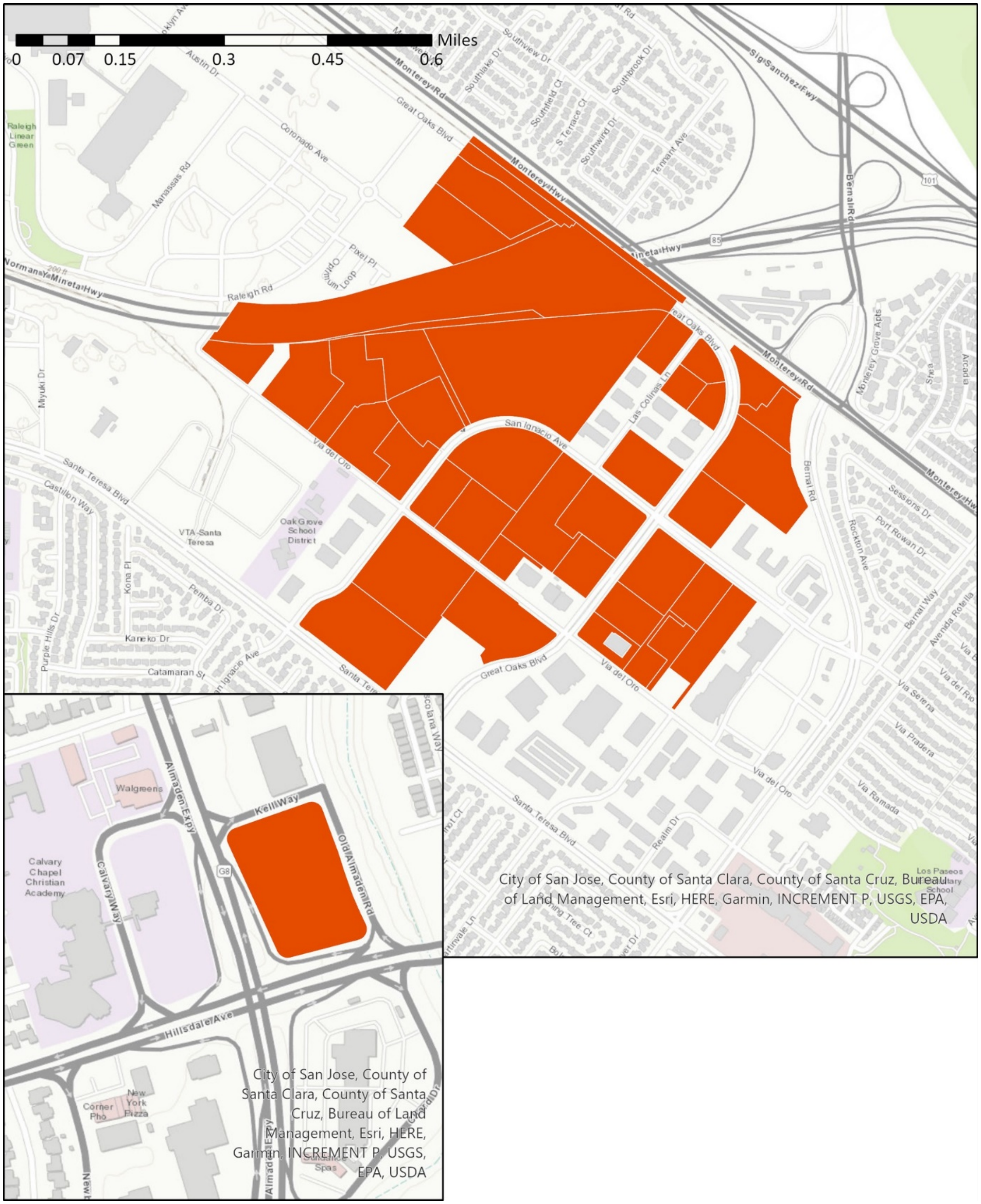
Wide-reaching San Jose is representative of most suburban cities across the American West. The predominant land use is one- or two-story single-family residences which, in this case, stretch to the east, west, and south, with major employers and points of interest (Levi's stadium, a performing arts center; the Mineta-San Jose International Airport; the Great America theme park; a convention center; museums; and San Jose State University) focused in the core and just to the northeast. For this reason, variables in Table 2 prioritize walkability and bikeability plus commuter drive times; the variable for 10-minute drive times to employment and points of interest is considered with high priority, replacing the pedestrian-, cycling-, and transit-related variables considered high priority in the case for San Francisco.

Table 2. Suburban GIS Variables

	Safety	**Access**	**Equity**
High Priority	Uses not allowed within a 500 ft. radius of Final Approach for Takeoff and Landing (FATO): • Schools (K12, Community Colleges, Universities) • Parks • Libraries • Gas Stations • Hospitals • Day care • Assisted Living Minimum Parcel 250 ft. x 250 ft	Above average LEHD job density Presence of largest employers in the bay area Block groups with above average population density Block groups with above average median household income Block groups with above average consumer transportation expenditure Presence of power infrastructure (high voltage, substation) 10-min drive to at least 1+ major transportation node	Block groups with median household income levels at or below 30% of average Large population of single head of household (apartments can be built in some commercial zones) Block groups having large proportion of the population identifying as Black or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander Block groups having a large proportion of the population identifying as Hispanic, Latinx, Chicanx
Medium Priority	Airports within ½ nm of FATO Heliports within ½ nm of FATO Vertiports within ½ nm of FATO	Proximity to a grand boulevard or arterial 0.25 mile walking distance to 1+ major transportation node 0.25 mile walking distance to 1+ major employer 10-min drive time to 1+ major transportation node	Block groups with median household income levels at or below 50% of average Large population of renters (apartments can be built in some commercial zones)
Low Priority		10 min drive time to 10+ POI 0.25-mile walking distance to 10+ POI	Primary language spoken other than English

Other desirable variables if available are: 4050 ft. from physical obstruction (such as trees, poles, wires); approach and departure paths; vertical separation based on 8:1 approach and departure surface; above average traffic counts; and above average office lease price.

Figure 7. San Jose Suitability Map



In the City of San Jose, 43 parcels were found to be suitable vertiport locations (Figure 7) out of 459,282 parcels. San Jose is sprawling but has a global reputation as the heart of Silicon Valley because of an abundance of major employers with large land holdings (such as Cisco, Adobe, NetApp, and PayPal). The city is also linked by the expansive Santa Clara Valley Transit Authority light rail system. Suitable locations for a vertiport include Valley Oak Technology Park near Santa Teresa VTA station due to ample parking adjacent to State Highway 85 and U.S. Highway 101. Redevelopment seems promising, though the San Jose Mineta International Airport flight path may pose airside constraints. Another location, although historically and politically contentious due to environmental effects, is the opportunity for the redevelopment of Reid-Hillview Airport for commercial vertiport use.

4.4 Exurban: Livermore

The City of Livermore is a representative example, because it is a small exurban East Bay commuter city having at least one major regional employer, the Lawrence Livermore National Laboratory, and is a known agritourism destination (including wineries and harvest festivals). Based on its rural-urban interface, the location variables in Table 3 are adjusted to prioritize drive times, which is different from the case in San Francisco, where walkable places with transit are prioritized.

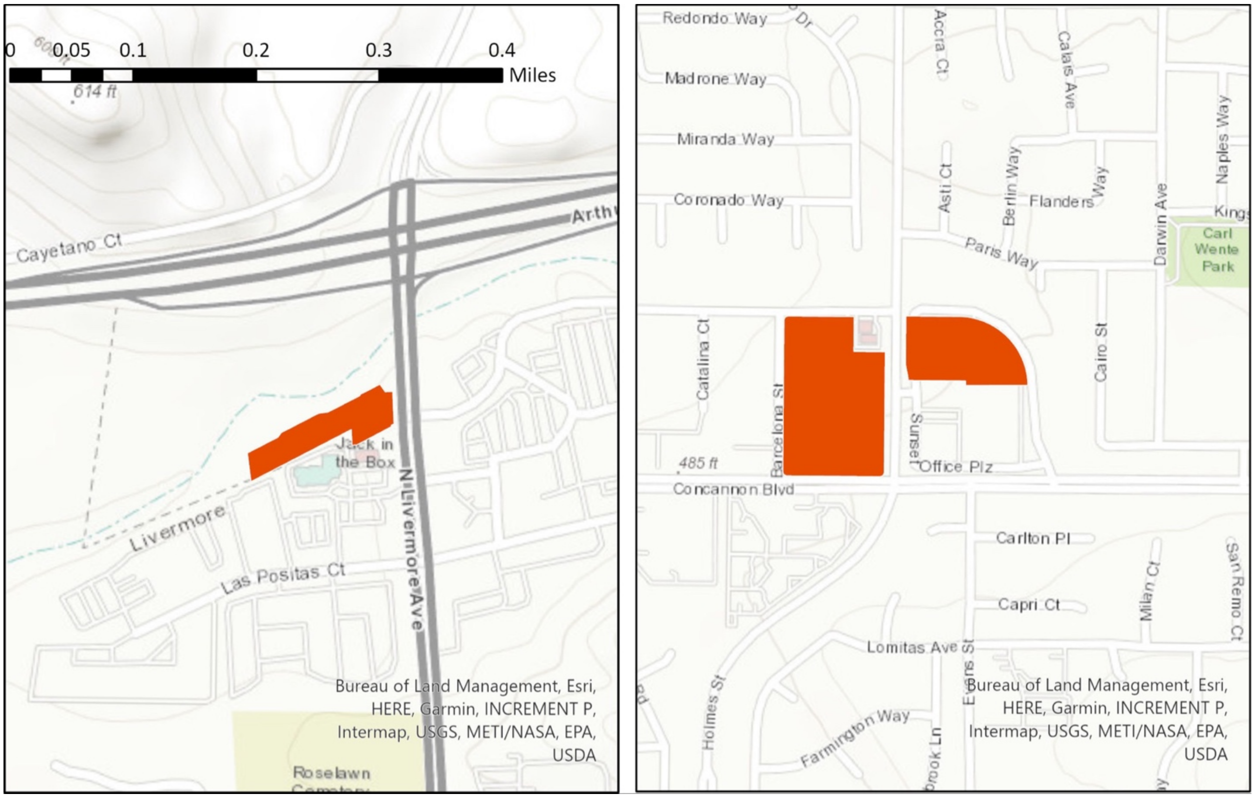
Table 3. Exurban GIS Variables

	Safety	**Access**	**Equity**
High Priority	Uses not allowed within a 500 ft. radius of Final Approach for Takeoff and Landing (FATO): • Schools (K12, Community Colleges, Universities) • Parks • Libraries • Gas Stations • Hospitals • Day care • Assisted Living Minimum Parcel 250 ft. x 250 ft	Above average LEHD job density Presence of largest employers in the bay area Block groups with above average population density Block groups with above average median household income Block groups with above average consumer transportation expenditure Presence of power infrastructure (high voltage, substation) 10-min drive to at least 1+ major transportation node	Block groups with median household income levels at or below 30% of average Large population of single head of household (apartments can be built in some commercial zones) Block groups having large proportion of the population identifying as Black or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander Block groups having a large proportion of the population identifying as Hispanic, Latinx, Chicanx
Medium Priority	Airports within ½ nm of FATO Heliports within ½ nm of FATO Vertiports within ½ nm of FATO	Proximity to a grand boulevard or arterial 10-min drive time to 1+ major employer 10-min drive time to 1+ major transportation node	Block groups with median household income levels at or below 50% of average Large population of renters (apartments can be built in some commercial zones) Primary language spoken other than English
Low Priority		0.25 mile walking distance to 1+ major employer 0.25 mile walking distance to 1+ major transportation node 0.25 mile walking distance to 1+ POI 10-min drive time to 10+ POI	

Other desirable variables if available are: 4050 ft. from physical obstruction (such as trees, poles, wires); approach and departure paths; vertical separation based on 8:1 approach and departure surface; above average traffic counts; and above average office lease price

The same GIS workflow was conducted for Livermore as was used in the previous cases, and in this output just three parcels out of 51,836 met site suitability parameters (Figure 8).

Figure 8. Livermore Suitability Map



Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, Intermap, USGS, METI/NASA, EPA, USDA

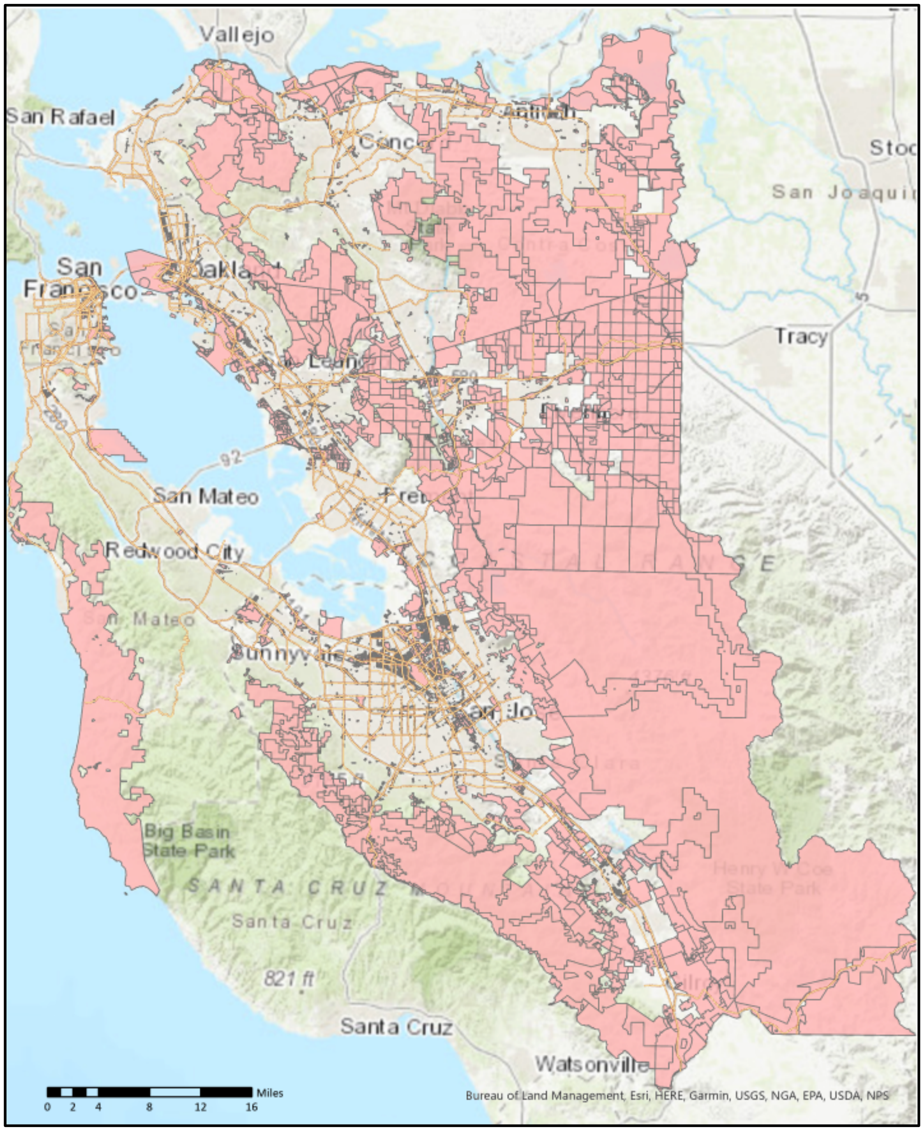
Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, Intermap, USGS, METI/NASA, EPA, USDA

At the urban-rural interface there exists more land area but also farther distances to transportation. Highways and employers are also located beyond the small-town core. Figure 8 identifies the locations suitable for vertiports although visual examination of ESRI aerial imagery shows it under construction. The Livermore sites are found to be closest to single-family and multi-family housing in the study and highlight the importance of integrating vertiports into residential zones, especially for smaller cities.

4.5 East Bay & Peninsula Corridors

Ground hubs for vertiports spaced approximately 40 miles apart mean the space between them could represent corridors in the East Bay (Alameda County) and along the Peninsula (northern Santa Clara County and San Mateo County). If San Francisco, San Jose, and Livermore each had vertiports, then a basic assumption would be that the airspace between these points of origin or destination would be needed for new low-altitude air corridors. For this reason, the same GIS workflow was applied to the landside spanning northern Santa Clara and San Mateo Counties, and in Alameda County resulting in shaded pink suitability areas (Figure 9). GIS outputs reveal ample land is suitable for safe and equitable AAM operations with eVTOLs flying over, largely due to extensive agricultural lands. However, from AAM literature, eVTOLs could follow major highways (US 101, I-280, I-580, I-680, and I-880) or opt to fly above the San Francisco Bay.[2]

Figure 9. Corridor Suitability Map



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[2] When air corridor planning the ground space below, the accessibility parameter is no longer applicable

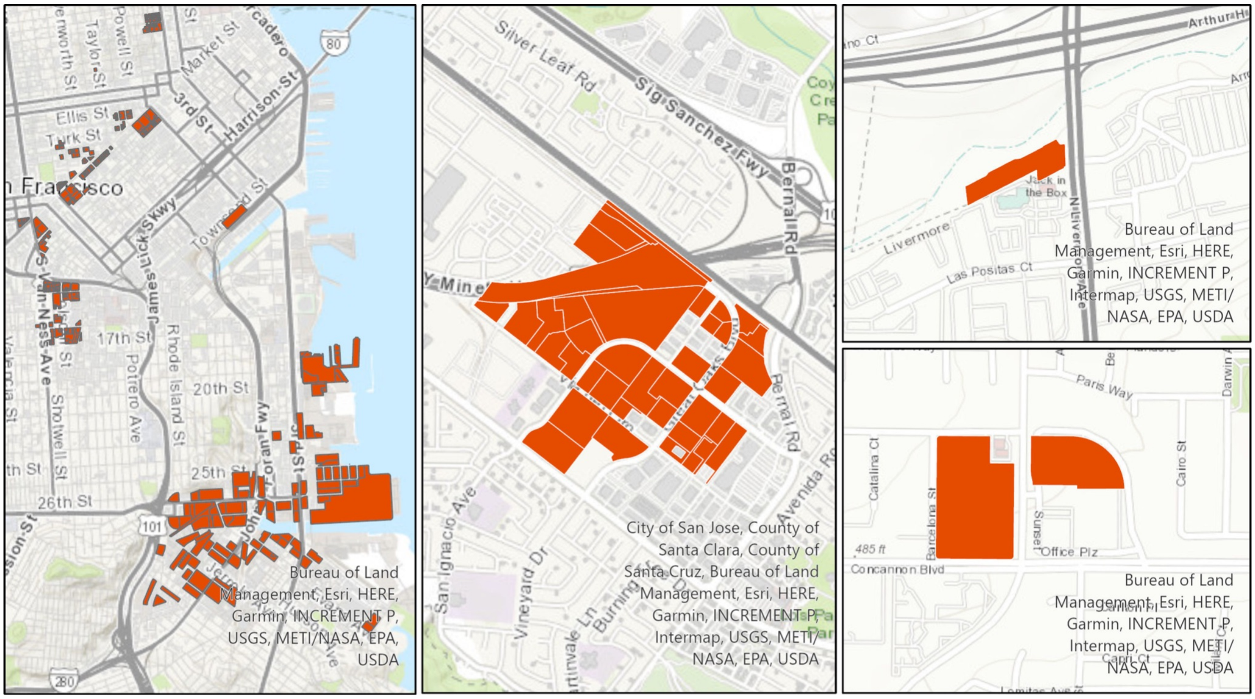
5. Result and Recommendations

5.1 Research Results and Implications

This research demonstrates how GIS can be used to identify safe, accessible, and equitable vertiport locations in urban, suburban, and exurban areas of the San Francisco Bay Area. The results contribute to the limited planning scholarship published on AAM to date. AAM is a rapidly advancing transportation sector, and it is clear from meetings with stakeholders that considerable proprietary geospatial models are currently needed to address the pressing question about where vertiports belong in a region. Advanced approaches and models such as machine learning, neural networks, and real-time three-dimensional spatiotemporal analyses will no doubt prove useful tools for future AAM land and airside operations. However, at this early stage in the AAM ecosystem, it is the public, advocates, communities, and local government (lacking resourced GIS staff) who can benefit most from using a set of urban, suburban, and exurban matrices which, when applied in a simplistic geoprocessing workflow, clearly highlight possible future vertiport locations.

One of the major results of our research are the site suitability maps, shown in Figure 9, which should be used at the start of the long-range planning engagement and can also be used as a rational basis for AAM decision-making.

Figure 10. Summary of Suitability Maps



Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, EPA, USDA

City of San Jose, County of Santa Clara, County of Santa Cruz, Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, Intermap, USGS, METI/NASA, EPA, USDA

Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, Intermap, USGS, METI/NASA, EPA, USDA

Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, Intermap, USGS, METI/NASA, EPA, USDA

San Francisco San Jose Livermore

The results of our case studies clearly validate and strongly support the usefulness of our GIS modeling approach. As indicated in Table 4, our research modeling can effectively narrow large datasets (parcels covering five counties) to less than 19% of all possible vertiport site locations in our case study regions. More suitable sites do not mean more vertiports are needed, just that more parcels met the criteria for the geographic setting. San Jose could, for example, need more vertiports than San Francisco even though fewer parcels met the high priority parameters for safety, access, and equity based on the assumptions and specifications of our current research. As an important feature and advantage of the GIS modeling applied in our research, the site selection results could be easily adjusted with the modification of the variables and their priority levels in the future. In addition to the safety, access, and equity variables considered in this research, we expect that more variables from both the supply and the demand side will be added in the GIS modeling analysis. The final selections of the vertiport location will also depend on other practical issues such as community acceptance, environment concerns, and some special needs.

Table 4. Summary of Suitable Sites

	San Francisco	San Jose	Livermore
Total Parcels	234,693	459,282	51,836
Suitable Parcels	1,392	43	3

This research's case study found that each representative location has at least one underutilized or vacant parcel that could be redeveloped as a future vertiport. However, nowhere are vertiports permitted (yet), and an AAM developer cannot apply for a building permit or zoning map amendment until comprehensive plans and land development ordinances are revised to include vertiport use. This responsibility falls on local government, community development staff, and planning commissions.

5.2 Recommendations

Based on the research experiences and lessons that were learned from this project, the following recommendations are made for vertiport site selection at different stages, from the perspectives of land-use planning, policy, and GIS modeling.

Getting Started:

- Determine the appropriate use case(s) for AAM integration within selected study area boundaries.

- Develop a list of non-negotiable “high priority” parameters for vertiport locations.
- Map existing flight path(s) and engage early with the FAA and local airport authorities.

Data Acquisition:

- Ensure there is easy data access across all agency departments including engineering, public works, transportation, recreation, urban forestry, and community development.
- Review the metadata for geospatial appropriateness and consistency.
- Maintain a data dictionary and data log to maintain accuracy and currency.

Data Analysis:

- Prioritize locations needing intermodality such as hospitals and transit stations.
- Value proximity to safe pedestrian and bicycle routes, and other micromodal options.
- Understand that suitability varies by community and that preferences change.

Land Use Planning:

- Incorporate GIS site suitability AAM analysis into the Transportation and Land Use sections of comprehensive plans.
- Add vertiport as a land use category in land development codes or zoning codes.
- Consider vertiports as a form of TOD infill and redevelopment.

Engagement:

Add participatory GIS in stakeholder workshops and incorporate virtual reality to lessen fears about eVTOL aircraft noise and their aesthetic impacts.

6. Summary and Conclusions

6.1 Research Summary

At present, vertiport research cannot keep pace with the rapidly advancing AAM industry. Aircraft may be available in just a few years, but very few short- or long-range plans show awareness of, or policies to govern, safe, accessible, and equitable vertiport development. This study summarizes AAM literature and offers transportation planners a set of prioritized parameters that assign no cost to urban, suburban, and exurban spatial analysis. This study's goals were to establish a systematic approach to vertiport site selection using GIS and to provide recommendations for how a region might begin planning for AAM. The workflow presented is standard but also flexible enough to allow for regional differences. Our case studies consider land use planning for AAM, especially as it relates to the San Francisco Bay Area, but our research methodology and modeling methods can be adapted and replicated in other places.

The suitability maps constructed in this research serve as a conversation starting point about AAM land use. By creating variable matrices for safety, access, and equity parameters, GIS software can automatically consider access to existing multimodal transportation options and identify areas that may be equitably harmed by vertiport development. This is the basis for participatory GIS which is a powerful tool for effective engagement because the public can visualize vertiports, flight corridors, and these actions' potential consequences. Suitability maps alone cannot sell AAM to communities, but it certainly helps, especially coupled with virtual reality and auralization.

Considerable new knowledge was gained from this research because of the need for qualitative information gathered beyond the original scope of work. After a set of parameters were created and defined, we accomplished a few qualitative investigations including an extensive literature review, participation in industry working groups, meetings with industry professionals, and the hosting of a focus group, in addition to preparing for and conducting regional GIS mapping. The parameters were then assigned to a priority level of high, medium, or low, which varied depending on the geographic form at that place (urban, suburban, or exurban). Using geospatial analysis tools, subject parcels that met assigned criteria were identified and summated to determine suitable locations for vertiports.

Ideally AAM and its vertiports will become a new sustainable mechanism to connect regional areas challenged by vehicular surface traffic and congestion. As is frequently the case in the San Francisco Bay Area, which is separated by water bodies, there are numerous freeways and bridges, and it has transit systems that are not seamlessly integrated making AAM a promising comprehensive transportation solution. With AAM comes new opportunities for public and private partnership to boost business, emergency, and tourism services, and to economically benefit local communities. Despite the initial approach to separate vertiports from housing and largely residential areas, the adoption of vertiports into these areas can meet new housing demands generated by an increased population, and also boost the economic development of these areas. Moreover, by incentivizing redevelopment and vitalization with vertiports, spaces can be transformed and overall benefit the community. However, failure to plan for AAM may lead to inadequate vertiport mitigation or worsen the incompatibilities which led to a history of inaccessible and inequitable airport development. Therefore, our research will not only make a great contribution to scholarly literature and research methodologies, but also provide strong support and practical guidance for vertiport development, land use, and regional planning.

6.2 Further Studies

The most significant challenge to GIS research is the availability and granularity of the geospatial information needed for the desired analysis. In the case study of this research, only free data were used, which precludes the use of potentially valuable information on segmented consumer mobility behaviors typically collected from mobile phone GPS records. With this additional data, planning vertiport locations would benefit greatly from understanding who, when, and where moves in a specific region such as the San Francisco Bay Area.

Also, additional time to intensively ground truth suitable parcels would be useful. For example, Google Street View imagery showed one location under construction which is not suitable for now but could be a candidate location for a vertiport in the future. Site visits would also aid researchers in obstruction identification, since small items such as wires and poles are hard to identify in aerial images, although they occasionally appear as shadows.

The type of landside study presented in this research is obviously needed for safe, accessible, and equitable vertiport placement. However, creating future hubs for ground and air connection requires thorough airside analysis too. It is expected that GIS will be equally helpful, if not more useful, in the airside and integration analysis. Software tools such as ESRI ArcScene and 3D Analyst can be applied to visualize eVTOL movement in corridors and around obstructions where LiDAR or point cloud renderings of the built environment exist.

In the future, more GIS modeling-based research must extend beyond exurban places to examine vertiport site suitability across rural regions. While through this research we have gained extensive insight by working with industry stakeholders, the next phase should position Caltrans in a facilitatory role to liaise research and communications with local governments. For example, a GIS suitability mapping training can be carried out in order to refine and improve the application process around a more intuitive user experience. This could be a best practice that can advance up-to-date knowledge and incorporate future design principles for vertiport and AAM planning in general.

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Appendix A. GIS Data Portal Layers

Below are various data layers used in this GIS case study. Sources are broken down into Zoning, Safety, Access, and Equity.

File Location	File Type	Description	Location	Data Provider
Zoning				
https://data.acgov.org/datasets/0cac9cf8503841d7975fe5471c5815c4_0/explore	Feature Layer (CSV/KML/Shapefile)	Alameda County Zoning	Alameda County	Open Data – Alameda County
https://data.acgov.org/search?collection=Dataset&q=land%20use&sort=name	Feature Layer (CSV/KML/Shapefile)	Alameda Parcels	Alameda County	Open Data – Alameda County
https://data.acgov.org/datasets/7b064a13a9234bfba97654007ccbf8e8_0/explore?location=37.680196%2C-121.906442%2C11.00	Feature Layer (CSV/KML/Shapefile)	Alameda Census Tract Boundaries	Alameda County	Open Data – Alameda County
https://fremont-ca-open-data-cofgis.hub.arcgis.com/datasets/25db2e74c6254091a6f340cf01f8f092_0/explore?location=37.529627%2C-122.012239%2C12.61	Feature Layer (CSV/KML/Shapefile)	Zoning – Fremont	Alameda County, Fremont	City of Fremont Open Data Hub
https://earthworks.stanford.edu/catalog/ark28722-s7w889	Feature Layer (CSV/KML/Shapefile)	Zoning – Hayward	Alameda County, Hayward	Earthworks – Stanford Libraries – City of Hayward (Author)
https://data.oaklandca.gov/dataset/Oakland-Zoning/ngyq-upwh	Feature Layer (CSV/KML/Shapefile)	Zoning – Oakland	Alameda County, Oakland	City of Oakland, Department of Planning and Building, Planning and Zoning Division
https://gis.cccounty.us/Downloads/Planning/	Feature Layer (CSV/KML/Shapefile)	Contra Costa Land Use Element	Contra Costa County	Open Data – Contra Costa County
https://gis.cccounty.us/Downloads/Planning/	Feature Layer (CSV/KML/Shapefile)	Contra Costa Zoning	Contra Costa County	Open Data – Contra Costa County
https://www.cityofconcord.org/737/GIS-Maps-Portal	Feature Layer (CSV/KML/Shapefile)	Zoning – Concord	Contra Costa County, Concord	Open Data – Concord
https://milpitas-gis-milpitas.hub.arcgis.com/datasets/ba1cd9f57c95468	Feature Layer (CSV/KML/Shapefile)	Zoning – Milpitas	Santa Clara County, Milpitas	Open Data – City of Milpitas

File Location	File Type	Description	Location	Data Provider
Zoning				
18ce0451aeebc4d47_0/explore?location=37.429332%2C-121.892600%2C12.47				
https://gis-cupertino.opendata.arcgis.com/datasets/Cupertino::zoning/explore?location=37.309899%2C-122.043900%2C13.85	Feature Layer (CSV/KML/Shapefile)	Zoning – Cupertino	Santa Clara County, Cupertino	Open Data – City of Cupertino
https://data-mountainview.opendata.arcgis.com/datasets/MountainView::zoning-districts/explore?location=37.402550%2C-122.081350%2C13.31	Feature Layer (CSV/KML/Shapefile)	Zoning – Mountain View	Santa Clara County, Mountain View	Open Data – City of Mountain View
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::zoning-districts/about	Feature Layer	Land Use Zoning Districts	Santa Clara County, San Jose	Open Data – City of San Jose
https://www.cityofpleasantonca.gov/gov/depts/gis.asp	Feature Layer (CSV/KML/Shapefile)	Zoning – Pleasanton	Alameda County, Pleasanton	Open Data – City of Pleasanton
https://opengis.cityofpaloalto.org/OpenGisData/	Feature Layer (Shapefile)	Zoning – Palo Alto	Santa Clara County, Palo Alto	Open Data – City of Palo Alto
https://gis-moragatown.opendata.arcgis.com/datasets/c18a51d380c840fd999953f6b8e5dd14_0/about	Feature Layer (Shapefile)	Moraga Zoning (Public)	Moraga, Contra Costa County	Open Data – Moraga, CA
https://www.geosl.org/datasets/sanleandro::zoning-1/about	Feature Layer (Shapefile)	San Leandro Zoning	San Leandro, Alameda County	Open Data – City of San Leandro
https://www.cityofpleasantonca.gov/gov/depts/gis.asp	SHP	Pleasanton Zoning	Pleasanton, Alameda County	Open Data – City of Pleasanton
https://pleasant-hill-spatial-data-mappleasanthill.hub.arcgis.com/maps/726d7292263a4b11baed63b22002ee48/about	Feature Layer (CSV/KML/Shapefile)	Pleasant Hill Zoning	Contra Costa County, Pleasant Hill	Pleasant Hill Open Data

File Location	File Type	Description	Location	Data Provider
Zoning				
https://data.sfgov.org/Geographic-Locations-and-Boundaries/Bay-Area-Counties/s9wg-vcph	Feature Layer (CSV/KML/Shapefile)	Bay Area Counties	San Francisco Bay Area	Open Data – City and County of San Francisco
https://data.sfgov.org/Geographic-Locations-and-Boundaries/Zoning-Map-Zoning-Districts/3i4a-hu95	Feature Layer (CSV/KML/Shapefile)	SF Zoning Counties	San Francisco County	Open Data – City and County of San Francisco
https://data.sfgov.org/Housing-and-Buildings/Land use/us3s-fp9q	Feature Layer (CSV/KML/Shapefile)	SF Land Use	San Francisco County	Open Data – City and County of San Francisco
https://data.sfgov.org/Geographic-Locations-and-Boundaries/Building-Footprints/ynuv-fyni	Feature Layer (CSV/KML/Shapefile)	SF Building footprints	San Francisco County	Open Data – City and County of San Francisco
https://data-smcmaps.opendata.arcgis.com/datasets/coastal-zone/explore?location=37.295496%2C-122.317500%2C10.55	Feature Layer (CSV/KML/Shapefile)	Coastal Zone	San Mateo County	Open Data – San Mateo County
https://data-smcmaps.opendata.arcgis.com/datasets/planning-zones/explore	Feature Layer (CSV/KML/Shapefile)	Planning Zones	San Mateo County	Open Data – San Mateo County
https://data-smcmaps.opendata.arcgis.com/datasets/2014-2022-housing-element-opportunity-sites/explore	Feature Layer (CSV/KML/Shapefile)	Housing Element 2014-2022	San Mateo County	Open Data – San Mateo County
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::updated-demographics-population/about	Feature Layer (CSV/KML/Shapefile)	Updated Demographics – Population: includes current-year estimates and 5-year projections of U.S. demographic data	Santa Clara County	City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::freeway-ramps/about	Feature Layer (CSV/KML/Shapefile)	Freeway Ramps: A representation of the edge of pavement of ramps on or off a freeway, highway, or interstate, to determine the furthest reaches of a	Santa Clara County	City of San Jose

File Location	File Type	Description	Location	Data Provider
Zoning				
		freeway's, highway's, or interstate's width		
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::freeway/about	Feature Layer (CSV/KML/Shapefile)	Freeway*:* A representation of the edge of pavement of freeways to determine the furthest reaches of freeway's width	Santa Clara County	City of San Jose
https://data.sccgov.org/Government/Parcels/b6cf-8q54	Feature Layer (CSV/KML/Shapefile)	Parcels	Santa Clara County	Open Data – Santa Clara County
https://data.sccgov.org/Government/Land-Polygon/24sy-ym6n	Feature Layer (CSV/KML/Shapefile)	Land Polygon	Santa Clara County	Open Data – Santa Clara County
https://gisdata-sccplanning.hub.arcgis.com/datasets/zoning-2/explore	Feature Layer (CSV/KML/Shapefile)	Zoning	Santa Clara County	Open Data – Santa Clara County Planning Office
https://gisdata-sccplanning.hub.arcgis.com/datasets/unincorporated-areas-2/explore?location=37.200000%2C-121.700000%2C9.86	Feature Layer (CSV/KML/Shapefile)	Unincorporated Areas	Santa Clara County	Open Data – Santa Clara County Planning Office
https://gisdata-sccplanning.hub.arcgis.com/datasets/land-cover-2/explore	Feature Layer (CSV/KML/Shapefile)	Land Cover	Santa Clara County	Open Data – Santa Clara County Planning Office
https://gisdata-sccplanning.hub.arcgis.com/datasets/general-plan-2/explore?location=37.339120%2C-121.798050%2C10.00	Feature Layer (CSV/KML/Shapefile)	General Plan	Santa Clara County	Open Data – Santa Clara County
https://gisdata-csj.opendata.arcgis.com/datasets/zoning-districts/explore	Feature Layer (CSV/KML/Shapefile)	Zoning Districts	San Jose, CA	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::high-poverty-rate/about	Feature Layer (CSV/KML/Shapefile)	High Poverty Rate	San Jose, CA	Open Data – City of San Jose
https://data.sfgov.org/Culture-and-Recreation/Recreation-	Feature Layer (CSV/KML/Shapefile)	Recreation and Parks Properties	San Francisco	Open Data – San Francisco

File Location	File Type	Description	Location	Data Provider
Zoning				
and-Parks-Properties/gtr9-ntp6				
https://gisdata-cityofpittsburg.opendata.arcgis.com/datasets/cityofpittsburg::cop-zoning/about	Feature Layer (Shapefile)	City of Pittsburg, Zoning	Pittsburg, Alameda County	City of Pittsburg Open data Hub
https://data.cityofberkeley.info/City-Government/Zoning-Districts/2dtu-vge3	Feature Layer (CSV/KML/Shapefile)	Zoning – Berkeley	Alameda County, Berkeley	Open Data – City of Berkeley
https://public-gis-missioncity.opendata.arcgis.com/datasets/missioncity::city-of-santa-clara-zoning/explore?location=37.389796%2C-121.921390%2C14.74	Feature Layer (CSV/KML/Shapefile)	Zoning – City of Santa Clara	Santa Clara County, Santa Clara	City of Santa Clara Enterprise GIS Public Portal
https://sunnyvale-geohub-cityofsunnyvale.hub.arcgis.com/datasets/81f57ae1ca49400f8a1a322eae53391c_0/explore?location=37.393990%2C-122.023926%2C12.88&showTable=true	Feature Layer (CSV/KML/Shapefile)	Parcels – Zoning	Sunnyvale	Sunnyvale Geohub
https://data.sfgov.org/Housing-and-Buildings/Land use/us3s-fp9q	SHP	SF – land use (for SQ area)	San Francisco, CA	SF Open Data Portal

File Location	File Type	Description	Location	Data Provider
Safety				
https://gis.data.ca.gov/datasets/5a3754e93bb44583903c7025389b8422_0/about	Feature Layer (CSV/KML/Shapefile)	Aviation/AWOS	California	California State Geoportal
https://data.cnra.ca.gov/dataset/nhd-major-features/resource/f7ab90e7-897a-49ff-8bba-98035d8c5015	SHP	Major Rivers and Creeks	California	CA Natural Resources Agency
https://data.cnra.ca.gov/dataset/nhd-major-features/resource/33b8464d-8e03-4301-acb4-0e753c51d0f7	SHP	Major Lakes and Reservoirs	California	CA Natural Resources Agency
https://hub.arcgis.com/datasets/CalEMA::ca-energy-commission-gas-stations/about	Feature Layer (Shapefile)	gas stations – California	California	CA Energy Commission
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::major-private-development-footprints/about	Feature Layer	Major Private Development Footprints	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/school/explore?location=37.247152%2C-121.852629%2C11.40	Feature Layer	School	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/library/explore?location=37.337662%2C-121.864349%2C12.76	Feature Layer	Library	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::hospital/about	Feature Layer (CSV/KML/Shapefile)	Hospitals	Santa Clara County, San Jose	Open Data – City of San Jose

File Location	File Type	Description	Location	Data Provider
Safety				
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::road-noise/about	Feature Layer (CSV/KML/Shapefile)	Road Noise: Boundaries of noise contours from General Plan 2020 update	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::airport-noise/about	Feature Layer (CSV/KML/Shapefile)	Airport Noise: Boundaries of San Jose International airports noise area	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::streets/about	Feature Layer (CSV/KML/Shapefile)	Streets: segments representing centerlines of all roadways within San Jose, CA	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::high-voltage-powerline-towers/about	Feature Layer (CSV/KML/Shapefile)	High Voltage Powerline Towers	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::railroad/about	Feature Layer (CSV/KML/Shapefile)	Railroad	Santa Clara County, San Jose	Open Data – City of San Jose
https://data.acgov.org/datasets/1197af3bbb5e4aa6be187ee428757a9a_0/explore	Feature Layer (CSV/KML/Shapefile)	Airports and heliports in the Bay Area	Bay Area	Open Data – Alameda County
https://www.californiaschoolcampusdatabase.org/#download	GDB	California Schools & Public Universities	CA	California School Campus Database
https://gis.data.ca.gov/datasets/CHHSAgency::oshpd-healthcare-facilities/about	Feature Layer (CSV/KML/Shapefile)	OSHPD Healthcare Facilities	California	CA State Geoportal
https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::child-care-centers/about	Feature Layer (CSV/KML/Shapefile)	Child Care Centers	U.S.	Homeland Infrastructure Foundation
https://www.parks.ca.gov/?page_id=29682	SHP	CA State Parks	California	California State Geoportal

File Location	File Type	Description	Location	Data Provider
Safety				
https://data.sfgov.org/Culture-and-Recreation/Park-Lands-Recreation-and-Parks-Department/42rw-e7xk	SHP	SF parks and rec	San Francisco	San Francisco Open Data
https://gisdata-sccparks.hub.arcgis.com/datasets/SCCParks::santa-clara-county-park/explore?location=37.203842%2C-121.744361%2C10.54	SHP	Santa Clara County Parks	Santa Clara County	Santa Clara County Parks GIS Open Data
https://gis.data.ca.gov/datasets/CDEGIS:: alifornia-schools-2019-20/about	SHP	CA public schools	CA	California State Geoportal
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::park/about	SHP	San Jose local and County Parks	San Jose	City of San Jose Open Data
https://data.acgov.org/datasets/4842a70247ee493eb1d523f176c04483_0/about	CSV	Alameda County Parks	Alameda County	Alameda County GIS portal
https://www.parksforcalifornia.org/parkaccess/?overlays1=parks%2Cnoparkaccess&overlays2=parks%2Cparksper1000	SHP	California parks (local, county, state, federal)	California	California State Parks
https://services5.arcgis.com/bBj6qT5vDKhNkfmk/arcgis/rest/services/Library_Branch_MASTER_WFL1/FeatureServer	SHP	Libraries	California	library.ca.gov
https://data.sfgov.org/Housing-and-Buildings/Tall-Building-Inventory/5kya-mfst	SHP	Tall Building Inventory	San Francisco	SF Open Data Portal

File Location	File Type	Description	Location	Data Provider
Safety				
https://data.acgov.org/datasets/b55c25ae04fc47fc9c188dbbfcd51192_0/about	SHP	Parcels	Alameda County	Alameda County GIS portal
https://gisdata-caltrans.opendata.arcgis.com/datasets/d8833219913c44358f2a9a71bda57f76_0/about		Traffic Volume		Caltrans Open Data
https://www.socialexplorer.com/reports/socialexplorer/en/report/cd771e6e-3d52-11ed-b79a-af6e515729b6	csv	Survey:Market Profile Data 2021 Data set:Original Tables (ORG) Table: MPD_110. Employment by Sector (Employees) [20]	5 counties	Social Explorer
https://www.socialexplorer.com/data/ACS2020_5yr/metadata/?ds=SE&table=A10009	csv	Social Explorer Tables: ACS 2020 (5-Year Estimates) (SE) Table: A10009. Households by Presence of People Under 18 Years by Household Type [19]	6 counties	Social Explorer
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::parcels/about	shp	San Jose Parcels	San Jose, CA	San Jose City Data Portal
https://data.sfgov.org/Geographic-Locations-and-Boundaries/Parcels-Active-and-Retired/acdm-wktn	shp	San Francisco Parcels	San Francisco, CA	SF Open data portal
https://oehha.ca.gov/calenviroscreen/maps-data/download-data	Feature Layer (Shapefile)	Shows the CalEnviroScreen 4.0 results by OEHHA	California	OEHHA

File Location	File Type	Description	Location	Data Provider
Access				
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::transportation-analysis-zones/about	Feature Layer	Transportation Analysis Zones	San Francisco Bay Area	Open Data – City of San Jose
https://data.smcgov.org/Transportation/Caltrain-Routes/upph-wy44	Feature Layer (CSV/KML/Shapefile)	Caltrain Routes	Bay Area	Open Data – San Mateo County
https://data.smcgov.org/Transportation/Caltrain-Stations-and-Stops/jzd3-rqcd	Feature Layer (CSV/KML/Shapefile)	Caltrain Stations and Stops	Bay Area	Open Data – San Mateo County
https://data.smcgov.org/Transportation/BART-Lines/ni6s-89wu	Feature Layer (CSV/KML/Shapefile)	BART Lines	Bay Area	Open Data – San Mateo County
https://data.smcgov.org/Transportation/BART-Stations/pj5k-xgir	Feature Layer (CSV/KML/Shapefile)	BART Stations	Bay Area	Open Data – San Mateo County
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::downtown-parking-lots/about	Feature Layer (CSV/KML/Shapefile)	Downtown Parking Lots	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::average-daily-traffic/about	CSV/KML/Shapefile	Average Daily Traffic collected by travel direction	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/consumer-expenditure/explore?location=37.327185%2C-122.002616%2C12.58&showTable=true	Feature Layer	Consumer Expenditure	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/ aliforn-community-survey-commute-to-work/explore	Feature Layer	American Community Survey – Commute to Work	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ:: aliforn-community-survey-housing/about	Feature Layer	American Community Survey – Housing	Santa Clara County, San Jose	Open Data – City of San Jose

File Location	File Type	Description	Location	Data Provider
Access				
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::updated-demographics-income/about	Feature Layer	Updated Demographics – Income	Santa Clara County, San Jose	Open Data – City of San Jose
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::vacant-land-inventory/about	Feature Layer (CSV/KML/Shapefile)	Vacant Land Inventory	Santa Clara County, San Jose	Open Data – City of San Jose
https://www.eia.gov/maps/layer_info-m.php	SHP	Power Infrastructure (various SHPs)	U.S.	U.S. Energy Information Administration
https://nhts.ornl.gov/	CSV/SAS/DBF	National Household Travel Survey	U.S.	NHTS
https://www.bts.gov/latch/latch-data	CSV/SAS	Local Area Transportation Characteristics for Households Data (NHTS 2017 Transferability Statistics)	U.S.	BTS (Bureau of Transportation Statistics)
https://www.bart.gov/schedules/developers/geo	KML	Stations and Lines	Bay Area	BART Open Data
https://gis.data.ca.gov/datasets/1f71fa512e824ff09d4b9c3f48b6d602_0/about	SHP	National Highway System	California	CA State Geoportal
https://gis.data.ca.gov/datasets/e21246e58c6f46edb39aa5a1639bc2ad_0/about	SHP	Hospital Heliports	California	CA State Geoportal
https://cecgis-caenergy.opendata.arcgis.com/datasets/CAEnergy:: alifornia-electric-substations/about	SHP	California Electric Substations	California	California Energy Commission
https://cecgis-caenergy.opendata.arcgis.com/datasets/CAEnergy:: alifornia-electric-transmission-lines/about	SHP	California Electric Transmission Lines	California	California Energy Commission
https://data.sfgov.org/Transportation/MTA-parkingcensus_offstreet/dkzc-uy8h	SHP	MTA.parkingcensus_offstreet	San Francisco	SF Open Data Portal
https://lehd.ces.census.g	CSV	LEHD Origin-	California	U.S. Census Bureau

File Location	File Type	Description	Location	Data Provider
Access				
ov/data/#lodes		Destination Employment Statistics (LODES)		
https://data.census.gov/cedsci/table?q=population&g=0500000US06001%241500000,06013%241500000,06075%241500000,06081%241500000,06085%241500000&tid=ACSDT5Y2020.B01003	CSV	B01003 TOTAL POPULATION	5 counties BG	U.S. Census Bureau
https://www.socialexplorer.com/tables/ACS2020_5yr/R13188531	CSV	A00002 Population Density – ACS 5YR 2020	5 counties BG	Social Explorer; U.S. Census Bureau
https://www.socialexplorer.com/tables/ACS2020_5yr/R13188546	CSV	A14006. Median Household Income (In 2020 Inflation Adjusted Dollars) – ACS 5YR 2020	5 counties BG	Social Explorer; U.S. Census Bureau
https://www.socialexplorer.com/tables/EASI2021/R13188548	CSV	Market Profile Data 2021: MPD_117. Consumer Expenditures, Transportation	5 counties BG	Social Explorer; U.S. Census Bureau
https://opendata.mtc.ca.gov/datasets/MTC::transportation-analysis-zones/about	SHP	Transportation Analysis Zones	California	MTC
https://opendata.mtc.ca.gov/datasets/MTC::plan-bay-area-2040-forecast-employment/about	CSV	Plan Bay Area 2040 Forecast – Employment	Bay Area	MTC
https://opendata.mtc.ca.gov/datasets/MTC::plan-bay-area-2040-forecast-land use-and-transportation/about	CSV	Plan Bay Area 2040 Forecast – Land Use and Transportation	Bay Area	MTC
https://gisdata-csj.opendata.arcgis.com/datasets/CSJ::average-daily-traffic/about	SHP	Average Daily Traffic	San Jose, CA	City of San Jose open data portal
https://congestion.sfcta.org	CSV	Congestion in SF	San Francisco, CA	San Francisco County Transportation Authority

File Location	File Type	Description	Location	Data Provider
Access				
https://cdn.nar.realtor/sites/default/files/documents/2022-q1-commercial-metro-market-reports-ca-05-09-2022.pdf		Office Lease Pricing	Santa Clara County, San Jose	National Association of Realtors

File Location	File Type	Description	Location	Data Provider
Equity				
https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2021&layergroup=Block+Groups	SHP	2021 Census Block Groups	5 Counties	U.S. Census
https://www.socialexplorer.com/data/ACS2020_5yr/metadata/?ds=SE&table=B04001	CSV	ACS 2020 (5-Year Estimates) Data Source: Social Explorer; U.S. Census Bureau Data set: Social Explorer Tables: ACS 2020 (5-Year Estimates) (SE) Table: B04001. Hispanic or Latino by Race (Collapsed Version)	5 Counties	Social Explorer; U.S. Census Bureau
https://www.socialexplorer.com/data/ACS2020_5yr/metadata/?ds=SE&table=B10040	CSV	Survey: ACS 2020 (5-Year Estimates) Data set: Social Explorer Tables: ACS 2020 (5-Year Estimates) (SE) Table: B10040. Residents Paying More Than 30% or at least 50% of Income on Selected Home Ownership Expenses [3] Universe: Owner-Occupied Housing Units	5 Counties	Social Explorer; U.S. Census Bureau
https://www.socialexplorer.com/data/ACS2020_5yr/metadata/?ds=SE&table=A10009	CSV	Survey: ACS 2020 (5-Year Estimates) Data set: Social Explorer Tables: ACS 2020 (5-Year Estimates) (SE) Table: A10009. Households by Presence of People Under 18 Years by Household Type	5 Counties	Social Explorer; U.S. Census Bureau
https://www.socialexplorer.com/data/ACS2021_5yr/metadata/?ds=ACS21_5yr&var=B25003002	CSV	Survey: ACS 2021 (5-Year Estimates) Data set: American Community Survey 2021 (ACS21_5yr) Table: B25003. Tenure [3] Universe: Occupied housing units	5 Counties	Social Explorer; U.S. Census Bureau

https://data.census.gov/table?tid=ACSST5Y2020.S1101	CSV	American Community Survey 2020: ACS 5-Year Estimates Subject Tables S1101 – HOUSEHOLDS AND FAMILIES	5 Counties – census tracts	U.S. Census
https://data.census.gov/table?q=B04006	CSV	American Community Survey 2021: ACS 1-Year Estimates Detailed Tables B04006 – PEOPLE REPORTING ANCESTRY	5 Counties – census tracts	U.S. Census
https://data.census.gov/table?q=S1601	CSV	American Community Survey 2021: ACS 1-Year Estimates Detailed Tables S1601 – LANGUAGE SPOKEN AT HOME	5 Counties – census tracts	U.S. Census

Appendix B. Requested Data Layers

Some zoning layers were provided via email because agencies require a subject to written agreement for data use form, but this is information still free to anyone who requests it and is permitted for use in GIS location analysis.

File Type	Description	Location	Data Provider/Contact
SHP	Zoning – Dublin	Alameda	jeff.baker@dublin.ca.gov
SHP	Zoning and Parcels – Livermore	Alameda	planning@cityoflivermore.net
SHP	Zoning – Union City	Alameda	planning@unioncity.org
GDB	Zoning – Albany	Alameda	planning@albanyca.org
SHP	Zoning – Alameda	Alameda	planning@alamedaca.gov
SHP	Zoning – San Ramon	Contra Costa	Planning@sanramon.ca.gov
SHP	Zoning – Antioch	Contra Costa	bpeters@ci.antioch.ca.us
SHP	Zoning – Oakley	Contra Costa	ruiz@ci.oakley.ca.us
SHP	Zoning – Pittsburgh	Contra Costa	GISServices@pittsburgca.gov
SHP	Zoning – Brentwood	Contra Costa	engineering@brentwoodca.gov
SHP	Zoning – Martinez	Contra Costa	dutyplanner@cityofmartinez.org
SHP	Zoning – Pleasant Hill	Contra Costa	tfujimoto@pleasanthillca.org
SHP	Zoning – Walnut Creek	Contra Costa	DutyPlanner@walnut-creek.org
SHP	Zoning – Orinda	Contra Costa	orindaplanning@cityoforinda.org
SHP	Zoning – Lafayette	Contra Costa	planner@lovelafayette.org
SHP	Zoning – Hercules	Contra Costa	smatinpour@ci.hercules.ca.us
SHP	Zoning – San Pablo	Contra Costa	planning@sanpabloca.gov
SHP	Zoning – El Cerrito	Contra Costa	planning@ci.el-cerrito.ca.us
SHP	Zoning – Colma	San Mateo	planning@colma.ca.gov
SHP	Zoning – Los Gatos	Santa Clara	planning@losgatosca.gov
SHP	Zoning – Saratoga	Santa Clara	planning@saratoga.ca.us
GDB	Zoning – Morgan Hill	Santa Clara	planning@morganhill.ca.gov
SHP	Zoning – Los Altos	Santa Clara	planning@losaltosca.gov

Appendix C. Suitable Site Locations

The following list is the GIS attribute table for parcels identified as suitable for vertiports in San Francisco, San Jose, and Livermore.

San Francisco
1355 Sansome St, San Francisco, CA 94111
201 Filbert St, San Francisco, CA 94133
2001 The Embarcadero, San Francisco, CA 94133
1 Beach St, San Francisco, CA 94133
100–172 Beach St, San Francisco, CA 94133
709 Taylor St, San Francisco, CA 94108
626 Grant Ave, San Francisco, CA 94108
650 California St, San Francisco, CA 94108
600 California St, San Francisco, CA 94108
725 Sacramento St, San Francisco, CA 94108
731 Commercial St, San Francisco, CA 94108
710 Grant Ave, San Francisco, CA 94108
631 Kearny St, San Francisco, CA 94108
779 Clay St, San Francisco, CA 94108
720 California St, San Francisco, CA 94108
1180 Evans Ave, San Francisco, CA 94124
401 Cesar Chavez St, San Francisco, CA 94124
20th St, San Francisco, CA 94107
1270 Missouri St, San Francisco, CA 94107
2000 McKinnon Ave, San Francisco, CA 94124
1800 Folsom St, San Francisco, CA 94103
1750 Harrison St, San Francisco, CA 94103
2550 Cesar Chavez St, San Francisco, CA 94124
2525 Marin St, San Francisco, CA 94124

San Jose

80 Great Oaks Blvd, San Jose, CA, 95119
30 Las Colinas Ln, San Jose, CA, 95119
6203 San Ignacio Ave, San Jose, CA, 95119
6150 San Ignacio Ave, San Jose, CA, 95119
6626-6650 Santa Teresa Blvd, San Jose, CA, 95119
6601-6645 Via del Oro, San Jose, CA, 9511
6659-6673 Via del Oro, San Jose, CA, 95119
79 Great Oaks Blvd, San Jose, CA, 95119
6340-6358 San Ignacio Ave, San Jose, CA, 95119
30 Great Oaks Blvd, San Jose, CA, 95119
9 Great Oaks Blvd, San Jose, CA, 95119
100 Great Oaks Blvd, San Jose, CA, 95119
6480 Via del Oro, San Jose, CA, 95119
3150 Almaden Expy, San Jose, CA, 95118

Livermore

1510 Holmes St, Livermore, CA, 94550
1706-1754 N Livermore Ave, Livermore, CA, 94551
Granada Shopping Center, 1951 Holmes St, Livermore, CA 94550

About the Authors

Wenbin Wei

Dr. Wenbin Wei is a Professor in the Department of Aviation and Technology in the College of Engineering at San Jose State University. He is also an Affiliated Professor in the Department of Industrial and System Engineering as well as Director of the Human Automation Integration Lab (HAIL). Before joining the faculty at San Jose State University, Dr. Wei was a research analyst in the Department of Operation Research and Decision Support at American Airlines. He earned a Ph.D. from the University of California, Berkeley in transportation engineering and management. Dr. Wei has conducted research spanning transportation planning, traffic control and management, multimodal transportation systems, rail and high-speed rail transportation, airport and airline management, unmanned aerial vehicles (UAV), Advanced Air Mobility (AAM), logistics, and supply chain management. Dr. Wei has obtained more than $2 million in research grants from FAA, NASA, and Caltrans. His research was published in over 40 articles in peer-reviewed journals and conference proceedings.

Kerry Rohrmeier

Dr. Kerry Rohrmeier, AICP, is an Assistant Professor in the Department of Urban and Regional Planning at San Jose State University and a former practicing land planner. Dr. Rohrmeier earned a doctorate at the University of Nevada, Reno in Geography in 2013 and has since taught GIS to hundreds of California State University students. Her funded research focus covers Bay Area geographies scaling from sites to regions and is published in prestigious geography and planning journals.

Tiffany Martinez

Tiffany Martinez worked as a graduate research assistant for the entire project and was hired as a Transportation Planner at Caltrans following the completion of this study and her MA in Geography from San Jose State University. Ms. Martinez also earned her BA in Global Studies from San Jose State University.

Michael Winans

Michael Winans worked as a graduate research assistant toward the end of this project and brought considerable expertise from his role in Airport Operations at San Jose's Mineta International Airport. Mr. Winans is completing his MS in Urban Planning at San Jose State University and previously earned a BS in Aviation from San Jose State University.

Heungseok Park

Heungseok Park worked as an undergraduate research assistant at the beginning of this project before being hired as a Transportation Planner at Kimley-Horn consulting. Mr. Park earned a BS in Aviation from San Jose State University during which he won first place on a student team in a national vertiport design challenge sponsored by NASA.

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