

On Demand Mobility Cargo Demand Estimation

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute
and State University in partial fulfillment of the requirements for the
degree of

Master of Science

In

Civil Engineering

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September 28, 2018

Blacksburg, Virginia

Keywords: On-Demand Mobility, Cargo Demand Estimation, Northern
California

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Academic Abstract

Recent developments in the shipping industry have opened some unprecedented trade opportunities on various levels. Be it individual consumption or business needs, the thought of receiving a package on the same day or within 4-hour from some other business or industry in the urban area is worth appreciating. The congestion on ground transportation modes is higher than ever. Since currently the same-day delivery in urban areas is carried mainly by ground modes, the catchment area of this delivery service is limited.

The On-Demand Mobility for cargo can elevate the concept of express shipping in revolutionary ways. It will not only increase the catchment area thereby encompassing more business and consumers but will also expedite the delivery as these vehicles will fly over the ground traffic.

The objective of this study was to estimate the total demand for ODM Cargo operations and study its effect on ODM passenger operations. The area of interest for this study was Northern California (17 counties). Annual cargo flows in the study area were rigorously analyzed through databases like Transearch, Freight Analysis Framework-4, and T-100 International for freight. The results of this study are presented through a parametric analysis of market share. The end product also includes the flight trajectories (with flight plan) of daily ODM cargo flights in the study region.

The effect of ODM cargo operations on the passenger ODM operations was also analyzed in this study. The major challenge faced in this study was the unavailability of datasets with the desired level of details and refinements. Since the movement of cargo is mostly done by private companies, the detailed records of shipments are often not public knowledge.

On Demand Mobility Cargo Demand Estimation

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General Audience Abstract

The recent advancements in shipping industry has made transfer of goods both domestic and international, swifter and more reliable. Nowadays, some business and consumers in urban areas have the options of few-hours or same day delivery. Currently the same-day delivery in urban areas is carried mainly by ground modes (trucks) and hence the catchment area of this delivery service is limited. Adding to it, the traffic congestion on the urban roads is a major hinderance in growth of such services.

The On-Demand Mobility for cargo can reform express shipping in revolutionary ways. The concept vehicle can fly over the ground traffic. Therefore, it will increase the catchment area thereby encompassing more business and consumers, along with faster delivery options in currently serviced areas.

For the study, we analyzed different databases for annual cargo flows in the region. Seventeen counties in the Northern California were chosen as the study area (or region). The study was focused on estimating the potential market (demand) for the On-Demand Mobility Cargo operations. Multiple set of results were calculated for different market shares that On-Demand Mobility can potentially capture in cargo operations. Flight trajectories (with flight plan) for daily ODM cargo flights were the final product.

The On-Demand Mobility cargo operations are expected to complement passenger ODM operations. Therefore, the effect of ODM cargo operations on the passenger ODM operations was also analyzed in this study. The major challenge faced in this study was the unavailability of datasets with the desired level of details and refinements.

Acknowledgments

I would like to thank Dr. Antonio Trani for his guidance throughout the project. I would like to extend my gratitude to Dr. Susan Hotle, and Dr. Kevin Heaslip for participating in my committee and providing the required support and guidance.

I would like to thank Jeremy Smith and Ty V. Marien of the National Aeronautics and Space Administration (NASA) for their technical and financial support of this work.

Additionally, I would like to thank Maninder Ade, Nick Hinze and Swingle Howard for valuable input and support during the project. I thank my family and friends for encouragement and help.

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CHAPTER 1: INTRODUCTION

The state of California contributes 13.3% to the economy of the United States, highest among all the states in the nation (McPhate, Mike 2017). The two major contributors are; the San Francisco Bay area and the Los Angeles metropolitan area. It cannot be denied that development of transportation systems is crucial for region's economic competitiveness. According to San Francisco Bay Area Freight Mobility Study done by California Department of Transportation, the nature of freight movement in the region, i.e., types of commodity, modes of transportation used, origin-destination patterns and the level of demand is a function of characteristics of economic activity in the region (Cambridge Systematics 2014). The Bay area freight flows support both global supply chains and regional industries. The Northern California Mega-Region Goods Movement Study mentioned that an estimated \$1 trillion worth of goods originated and passed through mega-region's ports, warehouses and industrial districts (Metropolitan Transportation Commission 2016). This figure is expected to be \$2.6 trillion by the year 2040. The expansive economy of northern California region is sensitive to the movement of goods. The mode of transportation for freight movement is a crucial factor.

Urban Goods Movement System

It refers to transportation networks in urban areas used to move freight to the final destination (National Academies of Sciences 2012). Currently, this system is dominated by ground transportation modes, i.e., truck, pick-up vans, etc. The increase in e-commerce is influencing the patterns in traditional urban goods movement system. Parcel delivery systems have boosted the deliveries in the residential area.

Moreover, with increasing consumers in the region, the demand for urban goods movement will also increase. This would further put pressure on the system using already congested infrastructure (arterial and city roads). In some counties of Northern California, the average commute time have risen to more than an hour due to congestion (Brinklow, Adam 2018). Every second lost due to congestion makes the whole system inefficient and contributes to the loss of productivity.

On Demand Mobility Concept

The On-Demand Mobility is an innovative concept in development to address the transportation problems in urban areas. The concept vehicle involved in these operations offers travels from an origin to a destination using a vertical-takeoff-and-landing (VTOL) aircraft that traversing above the ground transportation network avoiding heavy congestions on roads. The aircraft is powered by distributed electrical propulsion and has a maximum range of 150-300 statute miles, depending on the vehicle used (Trani, 2015).

The concept will provide on-demand transportation to minimize long commutes due to heavy traffic in urban areas. The basic infrastructure requires a vertiport for operation (landing and take-off) and apron area for passenger boarding and vehicle servicing (battery recharge). The concept aircraft comprise multiple lift rotors for vertical takeoff and cruise propeller and wing to transition into cruise mode. Complete electric operation eliminates vehicular emission and decreases noise pollution.

The concept aircraft chosen by Uber in the ‘Uber Elevate’ program (Heather Caliendo 2017) is an eVTOL aircraft by Aurora Flight Sciences (a Boeing company). Figure 1 and Figure 2 shows the concept design of the aircraft.



Figure 1: Aurora eVTOL Concept Vehicle at Vertiport. Source: (Aurora Flight Sciences 2018)



Figure 2: Aurora eVTOL Concept Vehicle in Cruise. Source: (Aurora Flight Sciences 2018)

The concept aircraft used in this study is Joby S4 aircraft (see Figure 3) by Joby Aviation Ltd (N. Syed 2017). It is a four-passenger sized ODM vehicle can potentially carry up to 800 lbs. of cargo (Vertical Flight Society 2017) .

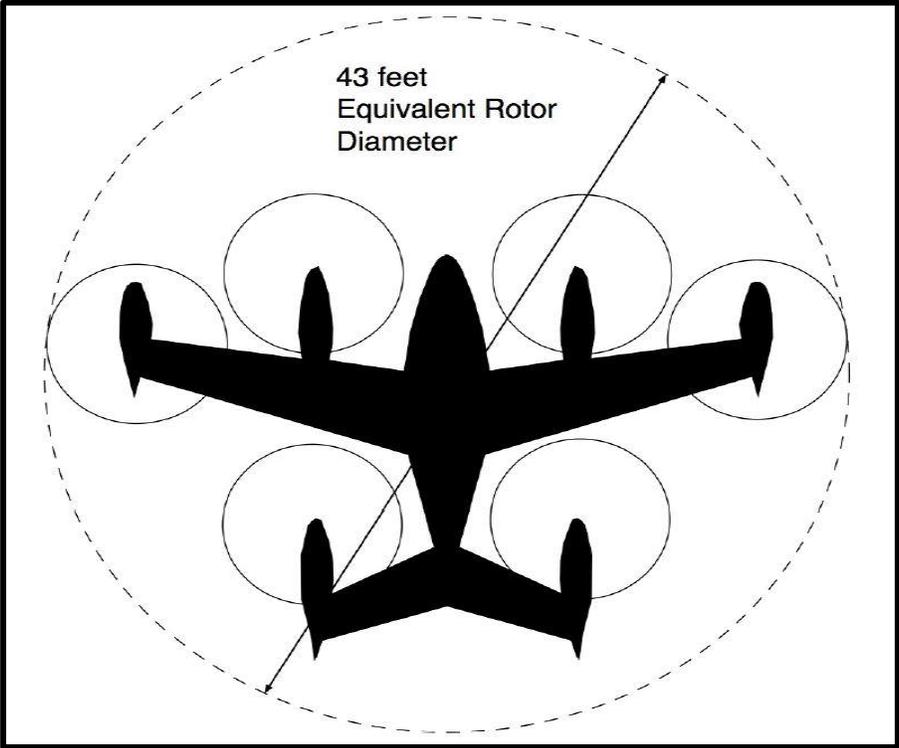


Figure 3: Joby S4 Aircraft Top View. Source: (N. Syed 2017)

The utilization of On-demand mobility concept for cargo in Urban Goods Movement system will not only address some of the current inefficiencies in the system but will also benefit the whole system by providing a faster alternative. The On-demand Mobility service could be revolutionary in the shipping industry. The same-day delivery concept is gaining popularity in the last couple of years. However, the logistics involved rendered it highly expensive and limited to certain regions and business. The On-demand mobility could support express delivery practice to encompass more

businesses and consumers. It will also make it more efficient by saving travel times or delivery time in congested urban areas.

Objective

The objective of this study is to determine potential demand for On-Demand Mobility Cargo in Northern California. Furthermore, studying its effect on passenger ODM operations. This study is a first-order analysis which uses county-level data for cargo flows. The results and recommendations of this study can be either used for further analysis on network level cargo demand or can be used for On-Demand Mobility network development. This analysis was performed with the guidance from the NASA Langley Research Center, and thus the study's workflow is influenced by their recommendations.

Thesis Outline

The thesis begins with *Chapter I: Introduction* which included information about cargo flows and urban goods movement system. It also discusses in brief about On-Demand Mobility Concept and concept vehicle. This section (introduction) ends with defining the research objectives.

The *Chapter II: Literature Review* includes previous work performed in this domain or related to this study. A summary of information extracted from various sources which supported several assumptions and concepts in this study is included in this chapter.

Chapter III: Potential Demand for ODM Cargo includes the concept development and methodology used in various sections of this study. It also introduces the Life-cycle cost model used in this study. It discusses in detail about the methodology and assumptions in each step of the analysis. Furthermore, it incorporates the primary result of this analysis, i.e., Daily number of cargo-ODM flights in Northern California. It also contains the effect of ODM cargo operations of passenger ODM service.

Chapter IV: Extended Results and Findings, this chapter contains the results of parametric analysis of cargo ODM market share, i.e., results for a set of scenarios generated for different market share assumptions.

The ultimate chapter; *Chapter V: Conclusion and Recommendations* includes the qualitative findings of this study and scope for future research.

CHAPTER 2: LITERATURE REVIEW

Recently, considerable efforts have been put in the development of On-Demand Mobility concept. A major part of which is focused on the development of concept vehicle and relatively fewer studies have been done in the systems of On-Demand Mobility concept. This study relates to previous research works with two different perspectives; one being the cargo or freight transportation and another being the On-Demand mobility concept. The On-Demand mobility sub-mode is considered more sensitive to characteristics of cargo than other competing sub-modes (such as truck, rail, pipeline, etc.). Therefore, previous works on the influence of commodity on freight transportation were explored.

Since this study will complement the passenger ODM study, a significant part of On-Demand Mobility concept was adopted from that. To calculate potential ODM cargo flows, the literature on cargo flows were explored. Some studies were reviewed to understand the critical factors in cargo distribution which were conducive to developing second order distribution of cargo flows.

The cargo distribution in freight transportation network is a bit different from passenger trip distribution. The Quick Response Freight Manual II (by Freight Management and Operations, FHWA) helped in understanding the controlling factors in Freight Demand. The summary of controlling factors from the literature (Daniel Beagan 2007) is included in Figure 4.

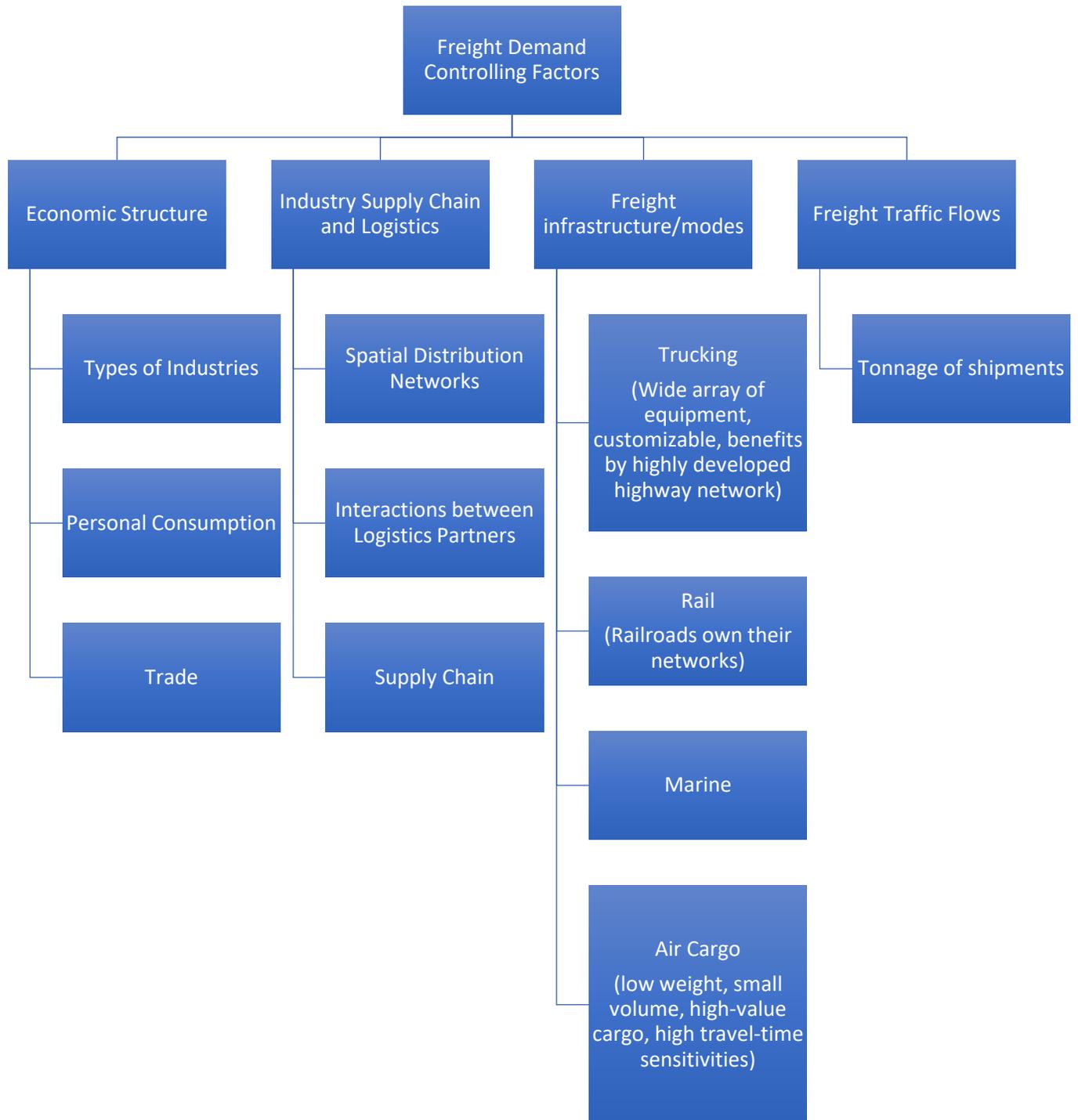


Figure 4: Controlling Factors in Freight Demand from Quick Response Freight Manual II.
 Source: (Daniel Beagan 2007)

The ODM Commuter Aircraft Demand Estimation investigated the potential market for On-Demand Mobility Concept for passengers (N. Syed 2017). The study calibrated a Conditional Logit Model to predict the demand. It also includes a life-cycle cost analysis which has been inherited into this study. The On-Demand Mobility Cargo study is a follow-up to the On-Demand Mobility passenger study. Both studies share the common study area and several fundamental concepts.

Jun. Duanmu developed a commodity-based gravity model to assess the distribution of freight in 31 counties of Virginia (Jun Duanmu 2012). Modeling in transportation using gravity models is a common phenomenon, but not many have been specific to freight transportation. The impact of commodities on the accuracy of the gravity model was analyzed in this study. This helped in developing the insight on commodity-specific freight distribution model for the ODM Cargo study.

The market share is critical for developing the On-Demand Mobility Cargo model. The analysis of present and previously deployed modes in urban cargo transportation is important for understanding the market share ODM could capture. In the *Behavioral Analysis of Decisions in Choice of Commercial Vehicular Mode in Urban Areas*, Q. Wang studied travel activities such as pickup and delivery of cargo from travel diary data of large-scale commercial vehicles in the Denver, Colorado (Hu 2012). The cargo-related attributes recorded the impact of commodity types (characteristic of cargo transportation) in determining cargo mode choice. This study contributed to understanding the behavior of commodities across modes in On-Demand Mobility Cargo (an urban exclusive mode).

For every choice model, the selection of parameters is important. The parameters influencing the choice most and which can either be generated or easily available in the data are selected. The common parameters in passenger choice model are cost, time (in-vehicle time, out-of-vehicle

time), etc. The freight transportation characteristics are different from the passenger transportation characteristics. The Moschovou's *Investigation of Inland Freight Transport Modal Choice in Greece* studied the parameters and attributes, influencing freight mode choice (Giannopoulos 2010). They performed a statistical analysis of a large-scale survey of freight transport actors in Greece. The results of this study have universal applicability, i.e. it can be applied to the United States too. The study concluded with following top-10 criteria for mode choice in freight transportation: Reliability and quality of transport services, Transport cost, Probability for load damage or loss, Customer service quality, Size of load and characteristics of packaging, Service frequency, Cargo value, Lifetime of cargo, Cargo value, Service frequency, Capability for tracking and tracing of the shipment, and Availability of loading or unloading equipment. The information is not usually available for all the parameters during analysis. However, the study provided insight for influencing capability of characteristics in freight transportation modeling.

Table 1 summarizes the literature referred to this study.

Table 1: Literature Review Summary.

| Title | Author | Journal | Year | Results/Conclusion (relevant) |
|--|----------------------------|--|------|--|
| ODM Commuter Aircraft Demand Estimation | Trani et al. | AIAA AVIATION Forum, (AIAA 2017-3082) | 2017 | An integrated approach to estimate passenger ODM demand considering socio-economic information, life cycle cost, diverse fare structures, route constraints, and ODM landing site requirements |
| Distribution Analysis of Freight Transportation with Gravity Model and Genetic Algorithm | Duanmu et al. | Journal of the Transportation Research Board, No. 2269 | 2012 | Freight transportation behavior is sensitive to the interchanged commodities |
| Investigation of Inland Freight Transport Modal Choice in Greece | Moschovou and Giannopoulos | Journal of the Transportation Research Board, No. 2168 | 2010 | Ten significant criteria for mode choice (freight) in Greece; Cargo value, size of load and characteristics of packaging, etc. |
| Behavioral Analysis of Decisions in Choice of Commercial Vehicular Mode in Urban Areas | Wang and Hu | Journal of the Transportation Research Board, No. 2269 | 2012 | Mode choice decisions are made by the commercial sector within a complex context that considers many factors, such as travel attributes, characteristics, and diversity of areas visited, travel purpose, cargo types, and company characteristics |
| A Freight Mode Choice Analysis Using a Binary Logit Model and GIS: The Case of Cereal Grains Transportation in the United States | Guoqiang Shen et al. | Journal of Transportation Technologies, 2012, 2, 175-188 | 2012 | This paper concisely reviewed relevant literature on mode splits for freight movement, developed a binary logit model for truck and rail, tested the model for cereal grains movement in the United States in 2002 and compared the model results with those from a comparable linear regression model |

CHAPTER 3: POTENTIAL ODM CARGO DEMAND

ESTIMATION

Introduction

The ODM operations are expected to capture a fraction in future cargo or freight flows in urban regions. Although the fraction would be small compared to other sub-modes in the market (Truck, Rail, etc.), the enormous amount of cargo flows makes it considerable and promising in the future. In this study, the cargo flows in the Northern California region were analyzed to estimate the potential ODM cargo demand. Urban freight activity mainly consists of two types: freight related to local supply or demand, and freight related to national or international trade (Genevieve Giuliano 2015). As mentioned in Chapter I, the characteristics of consumers dictate the cargo demand generation (both productions and attractions) in the region. In this study, we have considered certain characteristics such as the location of warehouses (for example Walmart, Target, Walgreens, etc.) in the area of interest as these warehouses would be critical components in a developed cargo ODM network. Another characteristic related to households is demographics. The cargo demand in the region is assumed to depend on demographics such as population, household income level, household size, and location of industries.

The factors controlling the feasibility of cargo shipments by ODM sub-modes are slightly different from 'Truck', 'Rail', and 'Air' mode. In general, flying cargo for short distances is considered inefficient over ground modes. However, sometimes the nature of the shipment, i.e., the characteristics of contents could render ODM cargo operation beneficial over traditional modes. The value of contents in the shipments determines the significance of extra shipping cost the customer pays for ODM operation against truck mode. If the commodity being shipped is highly

valuable such as jewelry, semiconductors, etc., it wouldn't be that sensitive to extra cost in ODM shipment whereas lower valued shipments are more sensitive to that extra cost and hence are less likely to be shifted to ODM sub-mode in general. Another characteristic of shipment which makes them a more promising candidate for ODM operations is the urgency associated with it. In such shipments, the value extends beyond the monetary worth of contents. No doubt the ODM operations are faster. Therefore they can elevate the present express shipping to another stage. While most users prefer the cheapest delivery methods today (~70%), fast delivery services are more popular among the younger population. For example, a recent study suggests that 23% of the household surveyed in China, Germany, and the United States prefer same-day delivery options for small packages (McKinsey&Company 2016). According to 2017 Digital Commerce Survey by BRP, same-day delivery has tripled in past three years (51% from 16%) and more growth to come (BRP 2017) which is promising for ODM cargo operations. Similarly, the variety of goods transported using small packages is very diverse. High to moderate-price commodities delivered in small packages to landing site lockers or retailers from warehouses are some of the cargo delivery concepts for ODM vehicles.

There are also limitations to ODM operation concept due to vehicle characteristics and rudimentary network which would make it harder to be a ubiquitous competitor against present ground mode. Network limitations at this moment mean the relatively inferior network infrastructure for ODM operations in primary stages and vehicle limitations are directed by short range (150 miles), relatively smaller capacity (800 pounds), and space constraints which makes bulky items more unlikely to be shifted over ODM.

Modeling urban freight demand (as a whole or for a sub-mode) is relatively difficult than passenger demand modeling. The accuracy of a model's prediction depends on the datasets ground in the

background for the generation of results. The lack of equivalent resources in freight as opposed to ODM passenger travel: NHTS data, LODES data, ACS data, makes it harder to predict with similar accuracy. Moreover, the prediction of freight demand is more uncertain than passenger demand as freight flows are relatively more sensitive to economic conditions.

This study analyzed Transearch data (IHS-Markit 2016), T-100 International data (Bureau of Transportation Statistics 2017) for cargo flows in the study area, i.e., Northern California. The daily number of ODM cargo flights in the study area were estimated based on these datasets.

This chapter is organized into the following sections: Section II describes the study area used in this analysis. Section III elaborates on the data sources used in this study. Section IV includes the extended results and findings. The final section, Section V consists of the conclusion and recommendations.

ODM Cargo Study Area

The study area for this analysis was Northern California which includes seventeen counties. The study area is same as that of ODM passenger study to analyze the effect of cargo operations on passenger model precisely. The study region includes 2,377 census tracts (7106 census block groups) and covers around 20,900 square miles. It includes major players in international and national cargo movement in Bay area namely San Francisco, Oakland, Sacramento, and San Jose.

These counties include:

Alameda, Contra Costa, Marin, Merced, Monterey, Napa, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Stanislaus, Yolo

Table 2: Study Area Characteristics

| Item | Northern California |
|-------------------------|---------------------|
| Area (square miles) | 20,899 |
| Number of Counties | 17 |
| Number of Census Tracts | 2,377 |

The map of the study area is included in Figure 5.



Figure 5: Scope of Study (17 counties).

Since the ODM cargo model is complementary to the previously developed ODM passenger model, the landing sites set from passenger model was refined to accommodate the dual purpose of ODM vehicles: passenger and cargo transport. In the previous study conducted by Virginia Tech for NASA Langley (N. Syed 2017), passenger ODM service was offered from 1000 landing sites in Northern California (study area). Landing sites represented idealized locations near home residences and work locations to intermodal times to each landing site.

For the ODM cargo study, the landing sites from passenger study were inspected and moved to areas where a landing site was considered feasible. Moreover, the number of landing sites was reduced from the original 1000 sites to 375 (six major airports), based on a first-order economic analysis (done by Maninder Ade). The following section explains the rationale of moving the original passenger landing sites to serve in cargo role as well.

Relocation of Passenger ODM landing sites (work done by Maninder Ade, assisted by me)

- ⇒ The concept of ODM operations is to use the ODM vehicle for passenger service during the peak hour times and during off-peak hour operations for cargo transportation.
- ⇒ First, the cargo warehouses and retail spaces with significant cargo flow activity were identified. Furthermore, using Google API, the cargo facility locations were extracted from publicly available data. Facility locations include warehouses, postal offices, and large retailers. The 745 facility locations in the study area are represented in Figure 6.

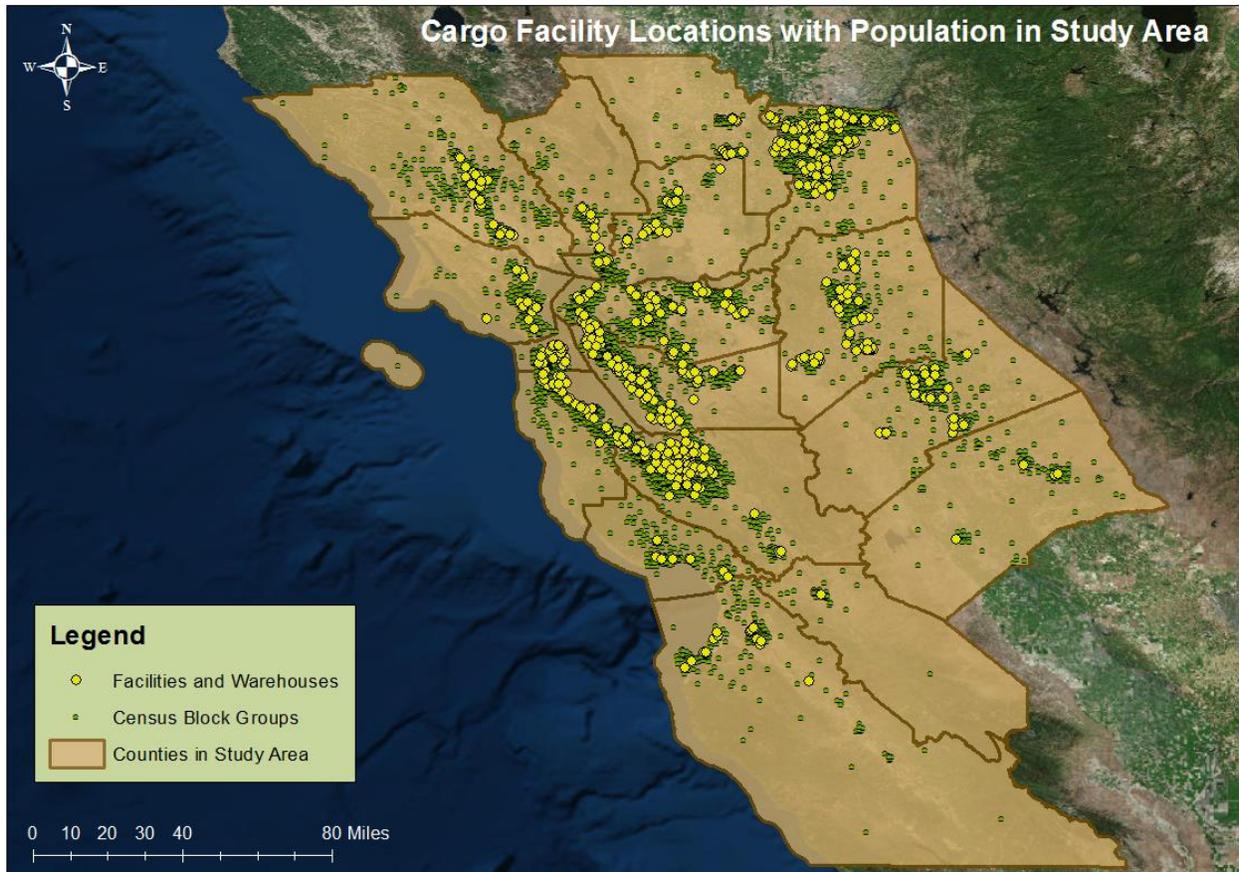


Figure 6: Cargo Facility Location in the Study Area.

- ⇒ Using K-means algorithm, Maninder further relocated the landing sites to entertain the presence of these cargo facility locations. This way importance is given to passenger and cargo demands in the selection of final landing sites.
- ⇒ Primary landing site set was further trimmed for minimum passenger demand (16 passenger roundtrips per day) and simultaneously weighted the landing sets associated with cargo facilities (i.e., one-mile distance or less).
- ⇒ The final step involved the manual relocation of each landing site to feasible surfaces such as facility rooftops, parking places, open surfaces without obstructions using satellite

imagery. The landing sites falling inside the approach surface polygons of commercial airports were moved by minimum distances (performed by the author).

⇒ The relocated landing site surface was checked for minimum surface area required for operation. The FAA standards for heliport requirements demands at least 4,225 sq. ft. of FATO (final approach and take-off) area for Joby S4 (rotor diameter= 43 ft.). The safety area should be cleared of any kinds of obstacle. The safety area is square around FATO with the side of 105 ft ((Ade 2017). The landing site requirements are included in Figure 8.

⇒ The final set of landing sites used in the ODM cargo study is included in Figure 7.

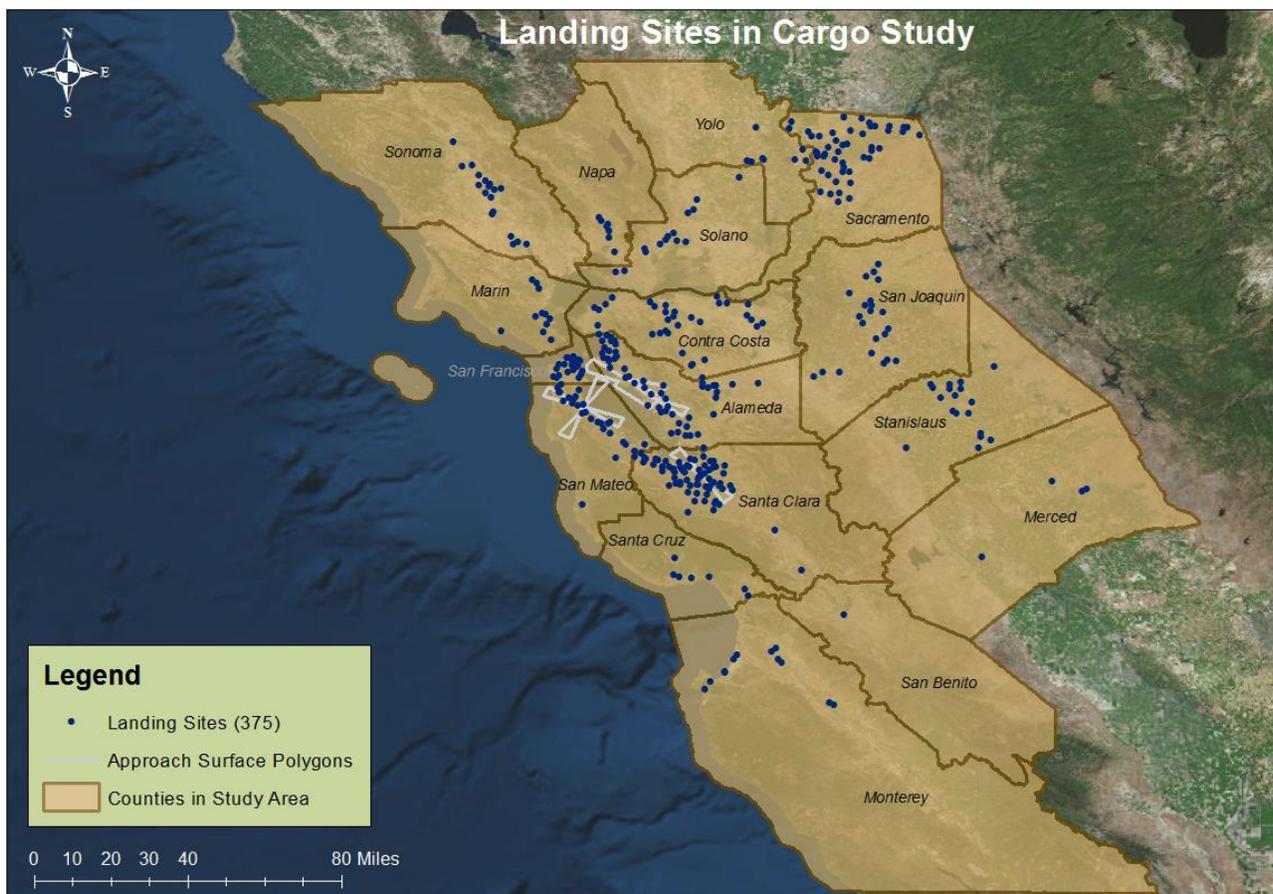


Figure 7: Landing Sites in Cargo Study.

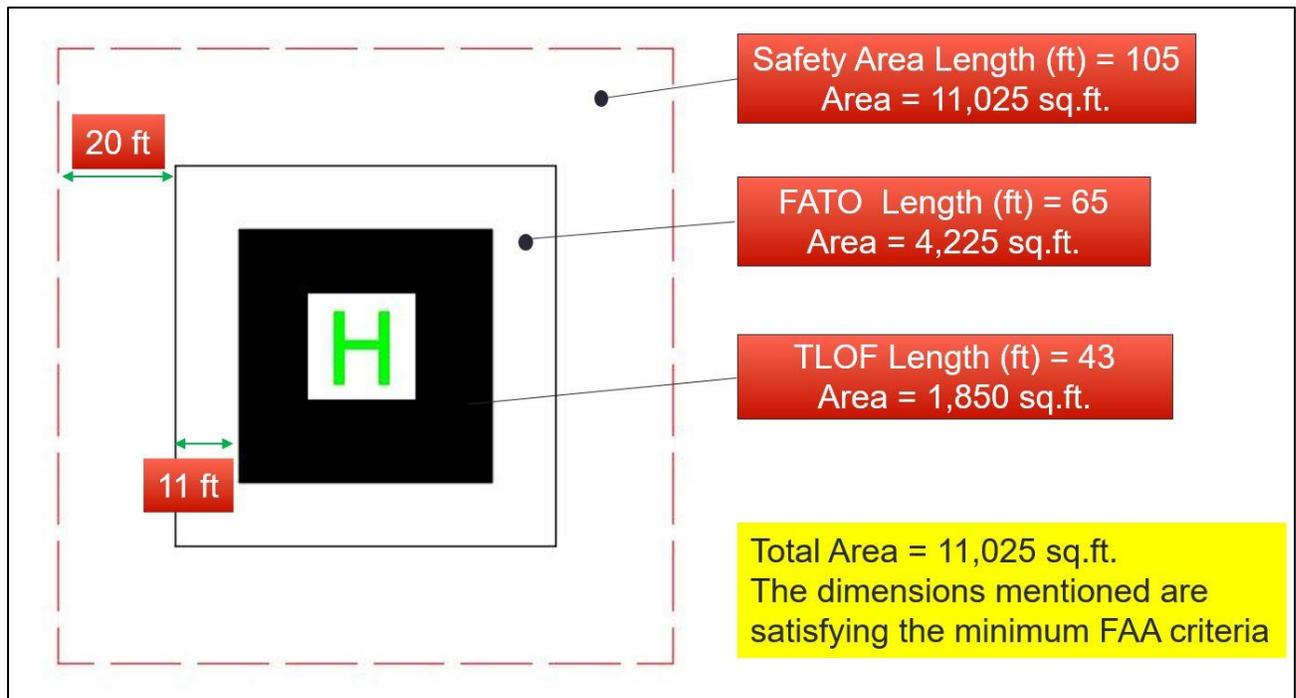


Figure 8: Basic Single Landing Path Design. Source: (Ade 2017)

Transearch Database and T-100 International Database

Transearch Database: It is the database that contains information on cargo shipments inside the United States. The data is compiled by IHS-Markit International and includes shipments by mode, quantity and commodity types.

This study used a subset of Transearch database which includes county-level trade flows focused primarily on seventeen counties comprising study area. Initially, the study was carried out using the Freight Analysis Framework-4 dataset developed by Federal Highway Administration. The ODM cargo operations are sensitive to contents carried in the shipments, i.e., not all commodities can make ODM cargo operation feasible. Transearch database has the edge over FAF-4 data because it has better information about commodity being transferred. Therefore, further analysis was carried out using the Transearch database. The baseline data was cargo flows in the year 2016.

A summary of county-level cargo flows of all commodities in the Transearch database can be observed in Figure 9 and Figure 10.

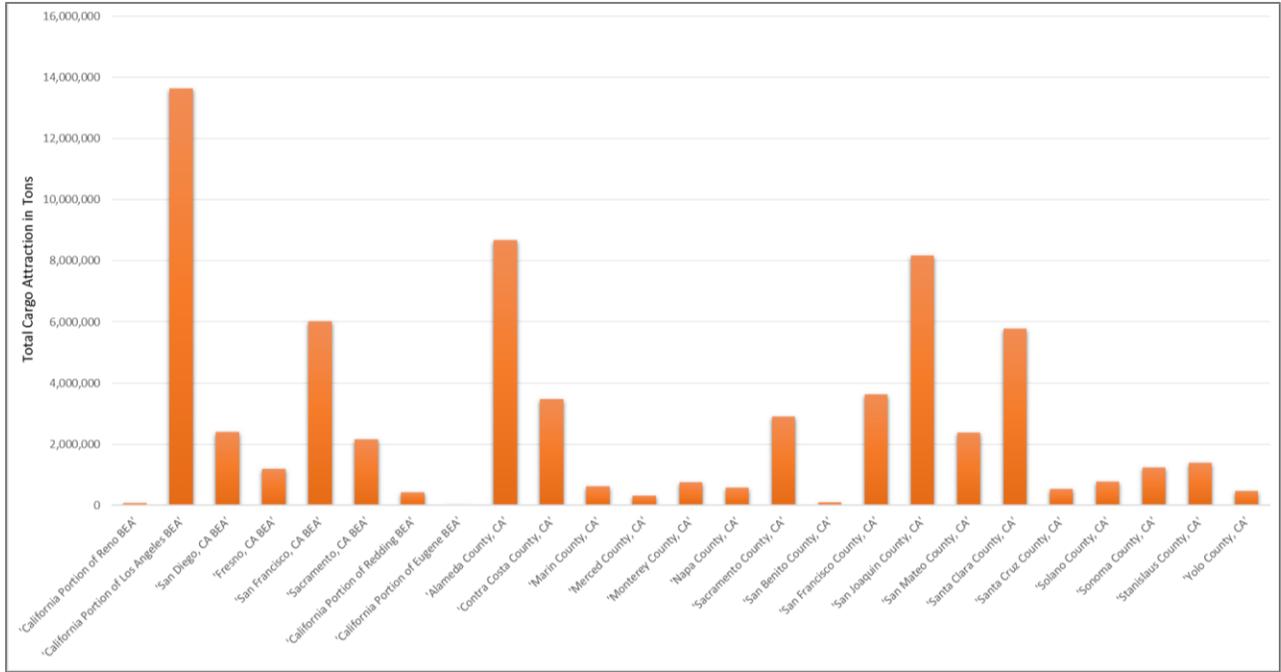


Figure 9: County-Level Attraction from Transearch 2016 (resulting in inflows).

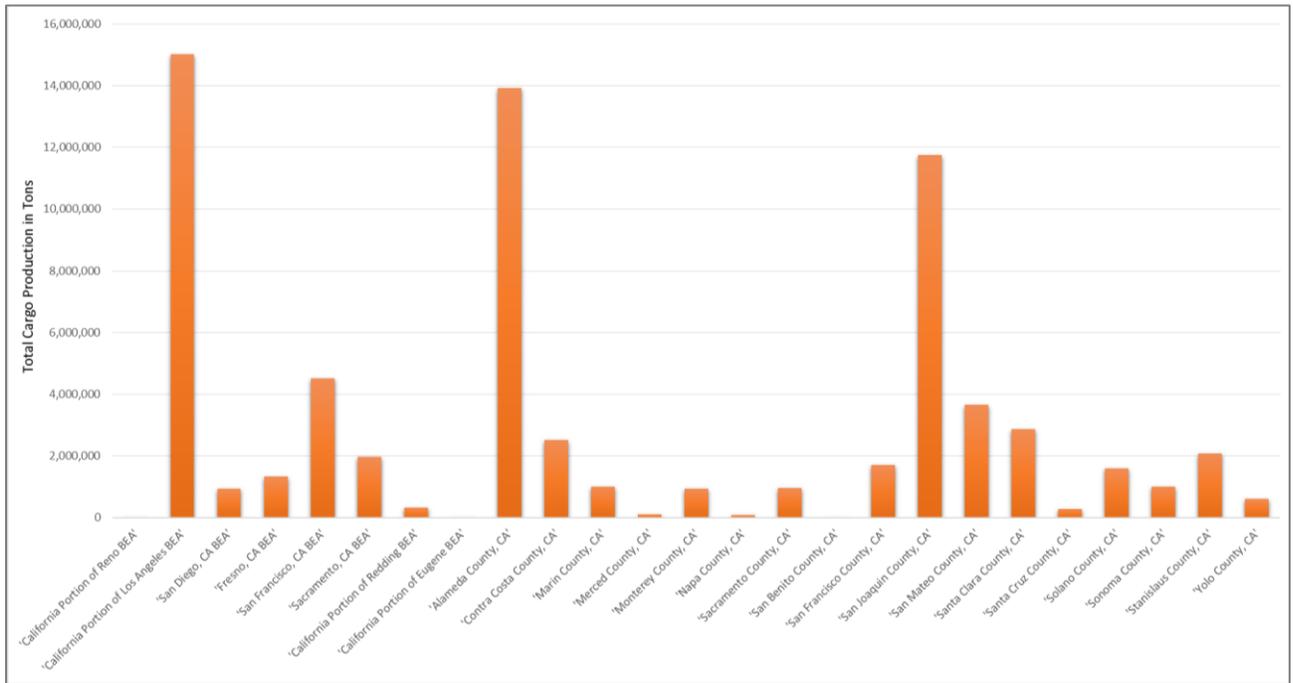


Figure 10: County-Level Production from Transearch 2016 (resulting in outflows).

T-100 International Database: It contains international cargo flows to and from US airports. The data was used to complement Transearch data to estimate cargo flows into major international airports in the study region.

Potential ODM Cargo Demand Methodology

Figure 11 shows a flowchart of the methodology used to predict potential ODM cargo demand in Northern California. The figure shows two databases used to generate cargo and freight flows in and out of the Northern California region: a) Transearch and b) International T-100 air freight data. Both datasets are identified in Figure 11 in blue color. The Transearch database includes details of tonnage, value and commodity types transported by air, ground (truck and rail) and ship in and out of the study area. For this study, we only use the air and truck modes of transportation in the Transearch database. Rail cargo is too bulky and has low value per unit weight to be a candidate for cargo ODM vehicles. ODM vehicles have limited internal volume and an 800-pound maximum payload capability. The Transearch data includes spatial information to estimate county-level attraction and production cargo flows. The T-100 International air freight data provide complementary information to Transearch by reporting airfreight flows in and out of major airports in Northern California. The T-100 International data is airport specific and does not include details about commodity types or value of the cargo. In this study, we assume that most of the air freight shipments in the T-100 are valuable because they are being transported via cargo aircraft – a more expensive alternative to container ship transportation. The analysis still recognizes that even if a large fraction of the air shipments in the international T-100 air freight data arrive in large airports

in the region, only a small fraction of them may be transported by ODM to the final destination points (landing sites).

Three sub-models are identified in Figure 11 by three large red boxes:

- 1) Cargo distribution model: The cargo distribution model handles three distinct cargo flow streams labeled Cargo Flow from Truck Mode (Source: Transearch), Cargo Flow from Air Mode (Source: Transearch) and International Air Freight into Main Cargo Airports (Source: T-100 International). These modules are shown in orange in Figure 11. The cargo distribution model handles the distribution of these flows into airports if the cargo arrives by air into the region. Similarly, the model handles the distribution of cargo from originating points inside the region (i.e., warehouses) to destination points (i.e., other counties). Finally, the model distributes the cargo flows to individual landing sites using population-weighted distribution factors.
- 2) Cargo flight generator model: The input for the cargo flight generator is the amount of cargo shifted to ODM at each landing site (production and attraction). The cargo flight generator then estimates the number of flights at each landing site by ODM vehicles considering ODM vehicle load carrying capacity, typical load factors and the landing site cargo flows produced by the cargo distribution model. The output from this model is the number of daily flights between origin-destination pairs of landing sites using Monte-Carlo simulation.
- 3) ODM flight path generator model: The output of the ODM flight path generator model generates detailed flight tracks to be flown by cargo ODM vehicles considering airspace constraints that avoid runway approach and departure surfaces at major commercial airports.

The ODM flight generator constructs a network of routes in the study region, using the location of landing sites as waypoints to “anchor” these routes. The ODM flight generator uses the shortest path algorithm to identify the minimum travel distance route between an origin and a destination landing site. The ODM flight path generator produces files that can be visualized in Geographic Information System software and files in a format that can be used as input in the NASA ACES simulation model.

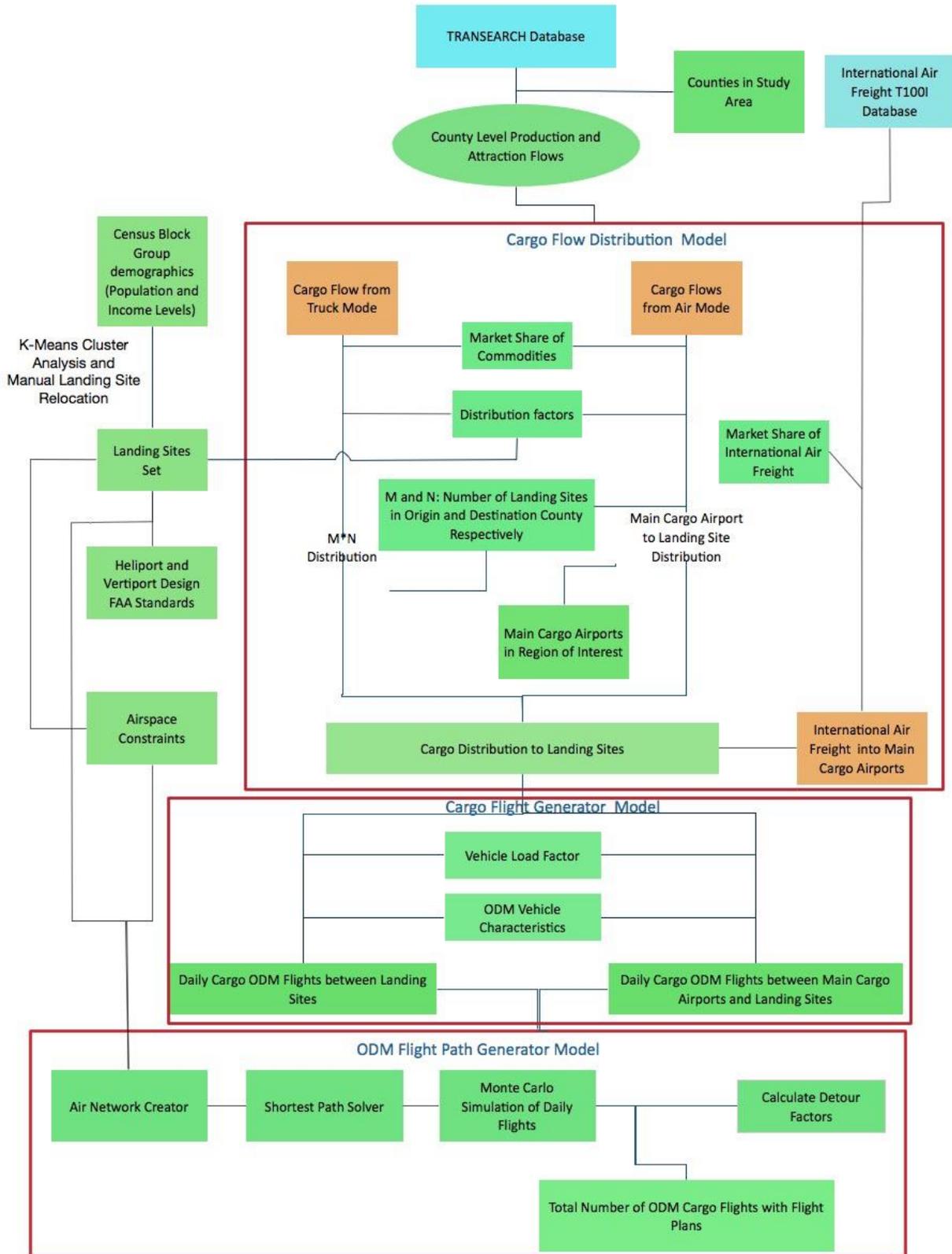


Figure 11: Potential Cargo ODM Demand Methodology Flowchart.

Figure 13 shows details in the analysis of “Truck” and “Air” mode flows contained in the Transearch database. Based on the given origin and destination of shipments, Transearch cargo flows are divided into two branches for each of the two modes of transportation considered:

- a) Internal flows: The cargo flows between 17 counties as included in Transearch are known internal flows. These flows generally use Truck mode. The internal flows analyzed in this study are those within the design range of ODM cargo vehicle. Therefore, these internal flows are those that can be “flown” using an ODM vehicle because the distance between the origin and destination counties is less than the design range of the ODM aircraft. In this study, we assumed a 150-nautical mile range. The internal flows which are greater than ODM vehicle range were treated as pseudo-external, eventually added to external flows.

- b) External flows: These flows are cargo shipments that originate at other regions in the United States located outside the study area and also outside the range of ODM vehicle. For example, fish products from Maine are flown to Northern California via cargo aircraft and handled at one of six cargo airports designated in the area of interest. This particular shipment is handled as an external cargo flow labeled “air” mode in Figure 13. If the final destination of the shipment is San Mateo County, the closest cargo airport assigned to the shipment is San Francisco International Airport (SFO). From that airport, fish products will be distributed to the neighboring counties using distribution attraction factors based on population demographics. For example, the large population density of San Francisco Central Business District will “attract” more fish products than a sparsely populated area like Sonoma County. The process of estimating ODM cargo demand involves ten steps according to Figure 11, and Figure 13 is explained in detail in the following section.

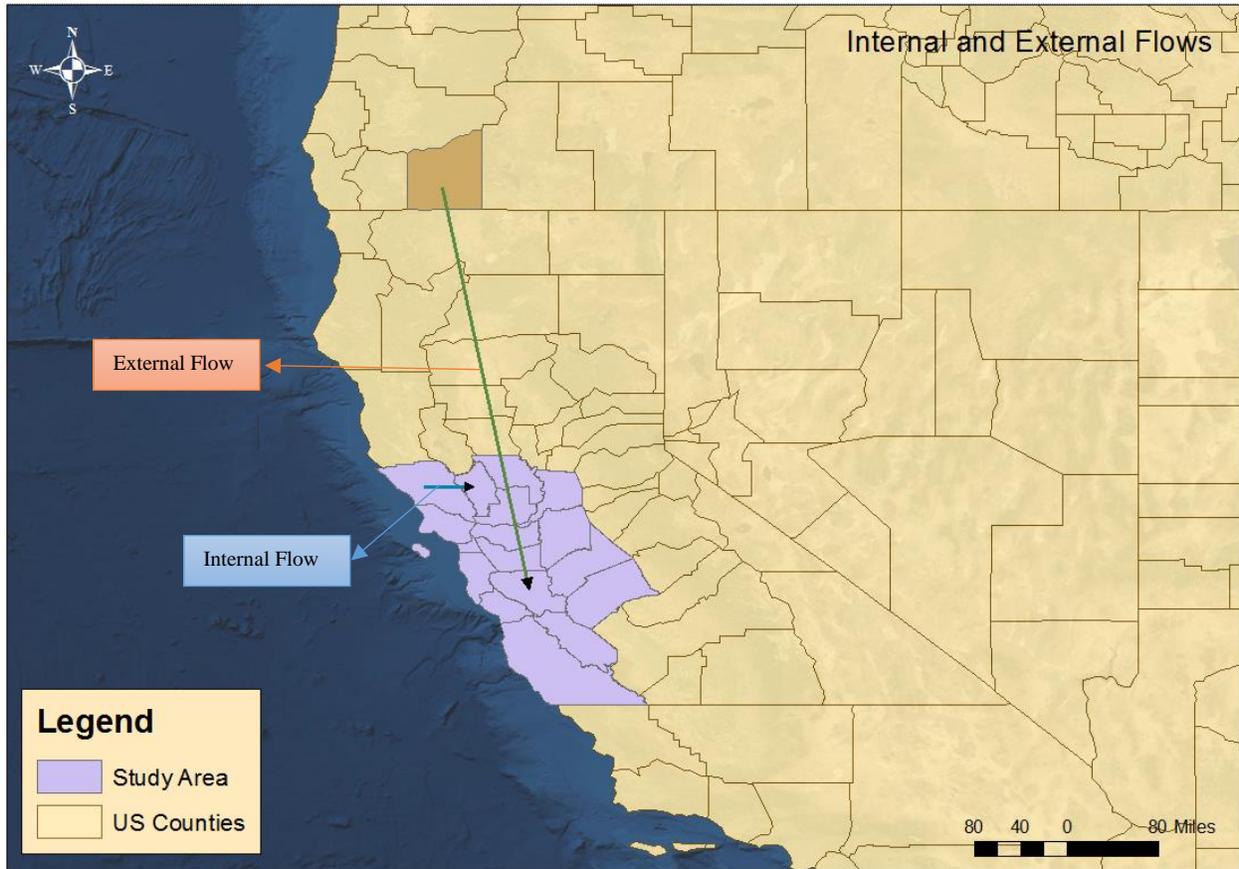


Figure 12: Example of Internal and External Flows.

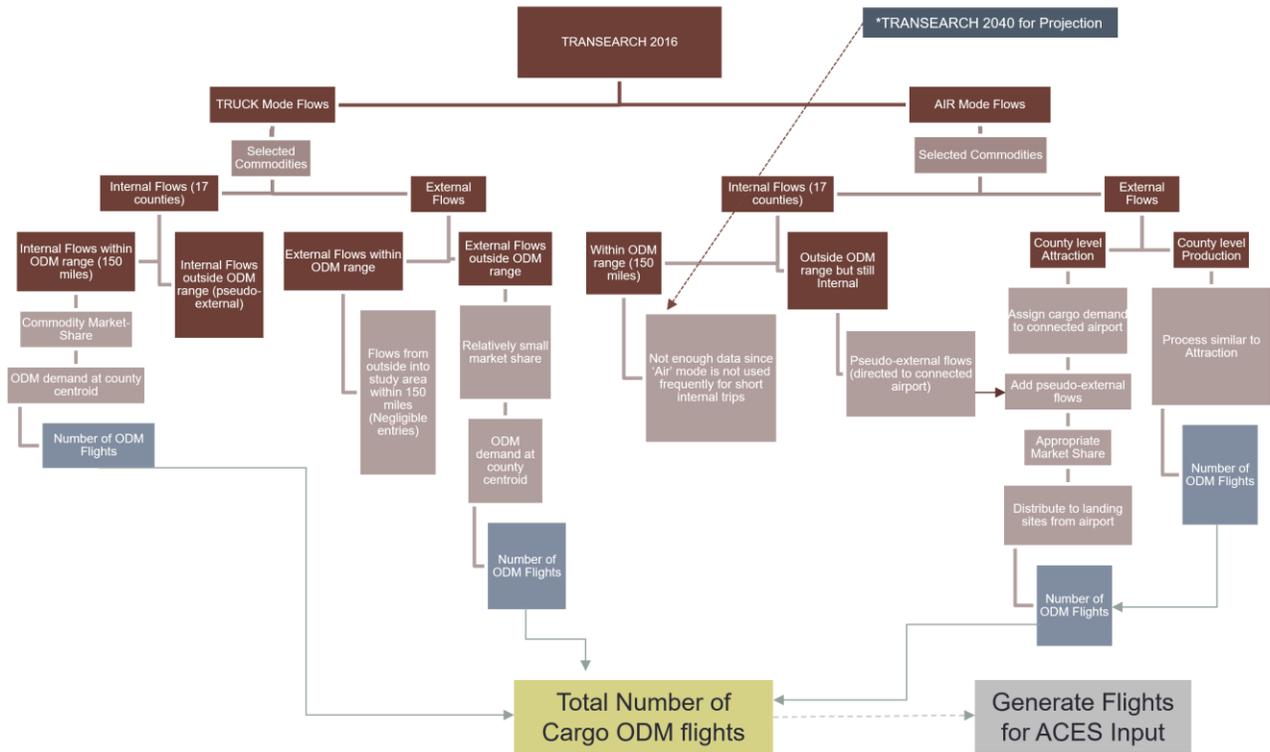


Figure 13: Handling of Various Cargo Flows in the Transearch Database.

Step 1: Identification of ODM Cargo Competing Modes

The Transearch database includes fifteen transportation sub-modes categorized into five major mode groups. In the initial step, we segregated the data for two major modes of shipments namely ‘Truck’ and ‘Air’. These two transportation modes account for 98.49% of the cargo shipment records in the Transearch 2016 database. All modes in the Transearch database are described in Figure 14.

| TRUCK | RAIL | WATER | OTHER | PIPE | AIR |
|--|---|---|--|--|---|
| <ul style="list-style-type: none"> • Truck Truckload • Truck L-T-L • Truck PVT • Truck NEC | <ul style="list-style-type: none"> • Rail Carload • Rail Intermodal • Rail NEC | <ul style="list-style-type: none"> • Water • Water containerized • Water Non-Container | <ul style="list-style-type: none"> • Mail • Foreign Trade Zones • Other | <ul style="list-style-type: none"> • Pipeline | <ul style="list-style-type: none"> • Air |

Figure 14: Mode Groups and Classification in the Transearch Database.

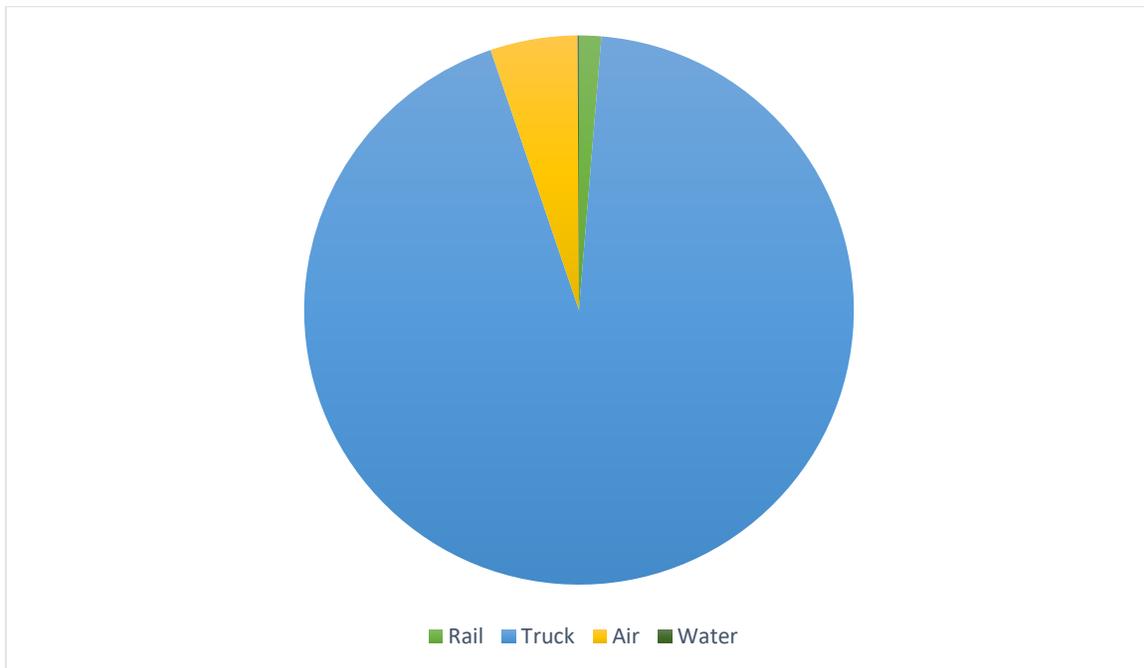


Figure 15: Share of Transearch Records by Mode.

The characteristics of an ODM vehicle renders it to be considered as competition (or complement) to only two mode groups in the Northern California region: ‘Truck’ and ‘Air’. The shipments from ‘Rail’ and ‘Water’ are bulky or low-valued. Hence, it is believed that they won’t have the potential for ODM cargo operations. Therefore, the analysis breaks down the data for these two mode groups for both internal and external flows.

The Transearch database has thirty different commodity groups which could have some potential for ODM cargo shipments. These commodities were selected among 430+ commodities included in the Freight Analysis Framework database (FAF4) based on their value per unit weight. As mentioned before, the FAF4 database was used earlier in the project before switching to the Transearch database. Transearch includes more detailed information compared to FAF4 and includes more than 700 commodity types. Figure 16 illustrates the final set of 30 commodities considered in the cargo ODM demand analysis.

| Commodity Group | Commodity Name | Commodity Group | Commodity Name |
|-----------------|--|-----------------|---|
| 1 | Fresh Fish or Marine Products | 16 | MUSICAL INSTRUMENTS OR PARTS |
| 2 | Clothing and Apparel | 17 | SPORTING OR ATHLETIC GOODS |
| 3 | Paper Products | 18 | COSTUME JEWELRY OR NOVELTIES |
| 4 | DRUGS | 19 | SEMI-TRAILERS RETURNED EMPTY |
| 5 | COSMETICS,PERFUMES, ETC. | 20 | EMPTY EQUIPMENT, REVERSE ROUTE |
| 6 | Leather Products | 21 | MAIL AND EXPRESS TRAFFIC |
| 7 | ELECTRIC MEASURING INSTRMNTS | 22 | OTHER CONTRACT TRAFFIC |
| 8 | PHONOGRAPH RECORDS TELEPHONE OR TELEGRAPH | 23 | FREIGHT FORWARDER TRAFFIC |
| 9 | EQUIPMENT | 24 | SHIPPER ASSOCIATION TRAFFIC |
| 10 | ELECTRONIC TUBES | 25 | FAK SHIPMENTS |
| 11 | SOLID STATE SEMICONDUCTS | 26 | MIXED SHIPMENTS, MULTI-STCC SMALL PACKAGED FREIGHT |
| 12 | MISC ELECTRONIC COMPONENTS | 27 | SHIPMENTS |
| 13 | Pharmaceutical Equipment | 28 | WAREHOUSE & DISTRIBUTION CENTER |
| 14 | JEWELRY, PRECIOUS METAL, ETC. | 29 | RAIL INTERMODAL DRAYAGE |
| 15 | SILVERWARE OR PLATED WARE | 30 | AIR FREIGHT DRAYAGE |

Figure 16: Commodity Groups in Transearch Database Identified for Potential ODM Use.

Step 2: Commodity Value Analysis

All thirty commodity groups contained in the subset of the Transearch database were analyzed for their potential to be shipped via ODM sub-mode in the future. Different parameters were examined and calculated in the analysis for different mode groups. For ‘Truck’ mode, a new parameter was generated from given data called ‘Value per Ton’. As the name suggests, this parameter predicts the shipment’s value per English ton. Under same commodity group, different ‘Value per Ton’ numbers were tabulated. Using the mean and median of ‘Value per Ton’ associated with each commodity group, six commodity groups were selected as potential competitors to ‘Truck’ mode shipments and used in the analysis (see Table 3). The values of the six commodities considered ranging from \$22,964 to \$256,752 per ton (\$10.4 to \$116.7 per pound in 2016. In another part of this study, Sayantan Tarafdar studied current parcel costs for various delivery methods to support some of the assumptions made later in this section about potential market share for ODM cargo shipments. For example, a five-pound parcel shipped “next day air” (with delivery before 8:30 AM of the following day) over distances less than 150 miles costs 51 dollars on average.

Table 3: Selected Commodities for ‘Truck’ Mode. Values in the Table are Dollars per Ton.

| Commodity | Mean (\$) | Median (\$) |
|----------------------------------|-----------|-------------|
| Jewelry, Precious Metals etc. | 190,515 | 193,562 |
| Solid State Semiconductors | 27,248 | 29,172 |
| Electric Measuring Instruments | 256,752 | 286,671 |
| Pharmaceutical Equipment | 27,350 | 14,761 |
| Drugs | 22,964 | 22,212 |
| Telephone or Telegraph equipment | 34,210 | 29,584 |
| Phonograph Records | 24,694 | 24,871 |

Similarly, ‘Air’ mode commodity groups were analyzed but, from a different perspective. It is believed that shipments being flown into the region via ‘Air’ mode have a clearly defined ‘urgency’ factor associated with them, i.e. the value of these shipments extends beyond their monetary value of the contents. There must be a value attached to the shipment generated by time constraint (overnight shipment) or nature of the content (perishable). To quantify this criterion and estimate market shares in the parametric study, all commodity groups shipped via ‘Air’ mode in Transearch were analyzed to determine how often shipments of one commodity are shipped via ‘Air’ mode against other modes of transportation. Table 4 shows the top six clearly defined commodity groups shipped more frequently via ‘Air’ mode in the Transearch database (2016). The Table 4 shows that 99% of the mail and express traffic (regarding tons) was shipped by ‘Air’. Similarly, small packaged freight shipments which generally corresponds to online shopping orders were mostly shipped by “Air”.

Table 4: Selected Commodities for 'Air' Mode.

| Commodity | Percent of 'Air' mode entries |
|----------------------------------|-------------------------------|
| Small Packaged Freight Shipments | 98 |
| Mail and Express Traffic | 99 |
| Fresh Fish or Marine Products | 92 |
| Pharmaceutical Equipment | 12 |
| Drugs | 11 |
| Electric Measuring Instruments | 5 |

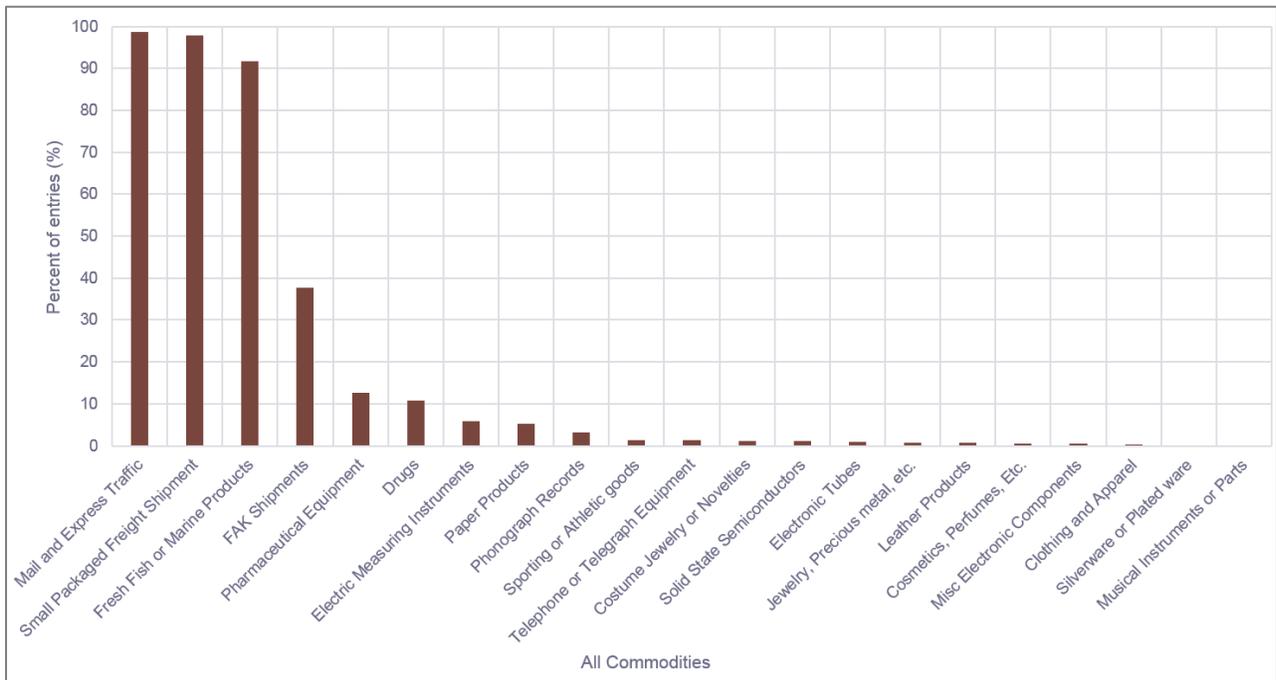


Figure 17: Commodity-wise Percent of Shipments by 'Air' Mode.

Step 3: Internal and External Flow Analysis

The Transearch dataset offers some level of detail concerning the location of where the shipment originates and its delivery point. Transearch has county-level information for the study region (i.e., 17 counties in Northern California) and regional level information for areas outside the study region. The regions are defined as a collection of county Federal Information Processing Standard (FIPS) which together represent a Business Economic Area (BEA). The regional level information is coarser than the county level. Therefore, shipments originating in the study area have county-level information for the origin and regional level for the destination. The opposite is true for shipments originating outside the study area but having a destination inside the study area. For this study, the Transearch dataset was segregated into internal and external flows for both ‘Truck’ and ‘Air’ modes. ‘Internal’ flows are shipments having both origin and destination inside the study region, whereas external flows are shipments having either origin or destination outside study region.

Step 4: Analysis of Internal/External Cargo Flows by Mode

In this step, internal and external flows are analyzed independently for both modes (‘Truck’ and ‘Air’).

For ‘Truck’ mode we adopted the following concept of operation rules:

- a) Internal cargo flows for the ‘Truck’ mode, were divided into two categories based on the distance traveled: i) cargo flows with trip distance less than 150 miles and ii) cargo flows with a trip distance greater than or equal to 150 miles. The ODM vehicle range is assumed to be 150 miles, and multi-legged trips were not considered. Internal flows within 150 miles are believed to have significant potential for ODM applications if the economics of the

shipment via ODM can compete in price and speed with ‘Truck’ mode for selected high-value commodities. For internal cargo flows traveling more than 150 miles via truck were considered as pseudo-external flows as they will rely on the ‘Truck’ mode for a large portion of the trip. These flows were added to the external flows analysis.

- b) In the case of external flows, it is unlikely that shifting shipments from the ‘Truck’ mode to relatively costlier ODM sub-mode for the final part of the trip. For this reason, we expect a very small market share for ODM sub-mode. The analysis estimated a negligible number of flights which were ultimately removed from the analysis. The pseudo-external flows associated with internal flows by ‘Truck’ mode, were also eliminated because it is not plausible to shift cargo shipments to an ODM vehicle after they have traveled by truck over a large portion of the trip.

For the ‘Air’ mode we adopted the following concept of operation rules:

- a) Similar segregation was applied to ‘Air’ mode shipments also, but with a modified perspective. The internal flows were separated into two categories based to trip distance. Transearch did not have enough records for internal shipments traveling less than 150 miles via ‘Air’ mode as expected. It is unlikely that traditional ‘Air’ mode would be selected for such short distances. The internal flows with travel distance greater than the ODM aircraft range (150 miles) were considered as pseudo-external flows and thereby added to the external flows.
- b) The Transearch data methodology indicates that shipments under ‘Air’ mode were shipped from an airport nearest to the origin region to the airport nearest to the destination region. Further information on airport assignment is included in the following sections. External

flows were divided into two categories namely attraction and production based on whether the shipment originates or ends in the study region. The pseudo-external flows were added to external flows before proceeding for further analysis. Further investigation of the Transearch database shows that **international “Air” shipments** are not included in the Transearch database. A procedure to account for such trips is explained in Step 9 of this workflow explanation.

Step 5: Airport Assignment Methodology

With the internal methodology in Transearch database development and records from cargo, flows are airports in the United States; it is safe to assume that commercial airports are the hubs for all the 'Air' cargo flowing in and out the study region. All shipments via 'Air' mode must go through a commercial airport that normally has cargo facilities. Using the domestic T-100 database from the Bureau of Transportation Statistics and reports from Caltrans on California air cargo studies, the top six commercial airports were chosen as potential cargo hubs for 'Air' mode shipments. These airports are shown in Figure 18. The figure shows that while the region encompasses seventeen counties, the number of cargo hub airports is more limited. There are large sections in the southern part of the study area without a cargo hub airport that can process 'Air' mode shipments contained in the Transearch data. According to domestic T-100 data, Monterey airport has few cargo flights per-week, but their share of cargo flows into the area are very small and not mature enough for ODM operations.

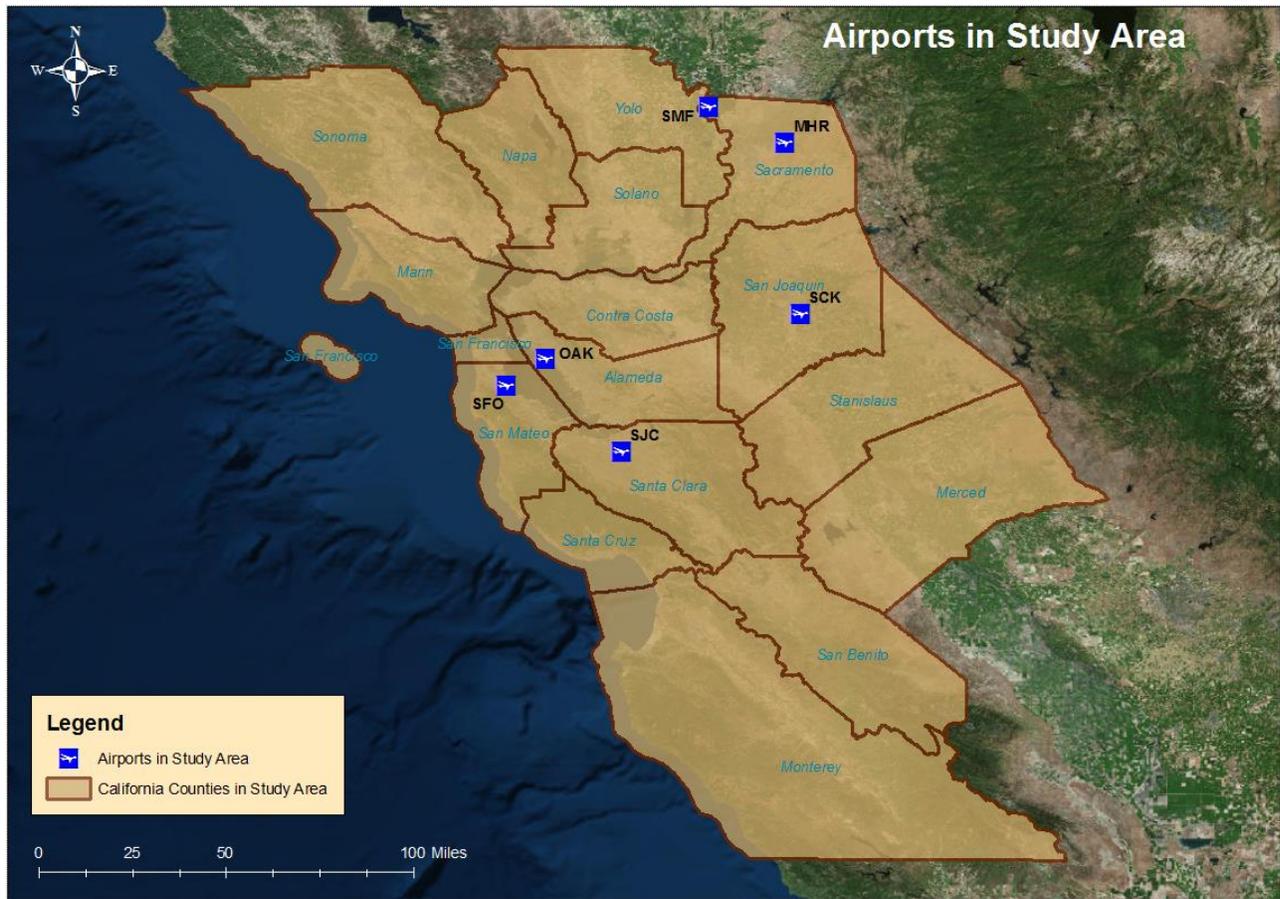


Figure 18: Selected Airports for Domestic Cargo Transfer in the Study Area.

The hub cargo airports were connected to counties via direct routes when possible or with the smallest detour to avoid commercial airport operations. For example, cargo ODM are subject to the same airspace operational restrictions used in the passenger ODM study (N. Syed 2017). In that study, ODM aircraft avoid arrival and departure surfaces of runways at large commercial airports. Avoidance of the approach and departure surfaces will de-conflict ODM from commercial traffic (an assumption in the concept of operation of ODM vehicles) and more importantly, steer ODM aircraft away from wake turbulence effects of commercial operations.

Table 5 shows the counties in Northern California and their assigned hub airports. The basis for the assignment is the distance between the population centroid of the county and the location of

the airport. Every county is assigned the nearest hub cargo airport to its population centroid. Since there are fewer commercial airports receiving cargo compared to the number of counties, each commercial airport in the area is assigned to multiple counties. For example, Oakland Airport (OAK) is connected to four counties, i.e., all the cargo (with six selected commodities) attracted or produced in these four counties shipped via ‘Air’ mode will move through OAK airport.

Table 5: Northern California Counties and Connected Airports.

| County | Airport ID |
|---------------|------------|
| Alameda | OAK |
| Contra Costa | OAK |
| Marin | OAK |
| Merced | SCK |
| Monterey | SJC |
| Napa | OAK |
| Sacramento | MHR |
| San Benito | SJC |
| San Francisco | SFO |
| San Joaquin | SCK |
| San Mateo | SFO |
| Santa Clara | SJC |
| Santa Cruz | SJC |
| Solano | OAK |
| Sonoma | OAK |
| Stanislaus | SCK |
| Yolo | SMF |

Landing Site Network

The landing site network used in this study consists of 375 landing sites - 369 regular landing sites plus six commercial airports with dedicated facilities to land ODM aircraft. The landing sites were originally generated by k-means clustering. They were further modified for passenger demand according to Scenario 1 using the process described in Section 2 of this report. After that, they were manually modified to locations near warehouses which are major cargo producers and attractors. Some landing site locations were modified in order to move them outside the approach and departure surfaces of runways at commercial airports. The final 375 landing sites that will serve both passenger and cargo are shown in Figure 7: Landing Sites in Cargo Study.

Step 6: Cargo Distribution Methodology

The Transearch database is limited to county-level flows. The data does not contain information about flows inside each county. Therefore, to determine the cargo flows at the landing site network level a distribution methodology was developed.

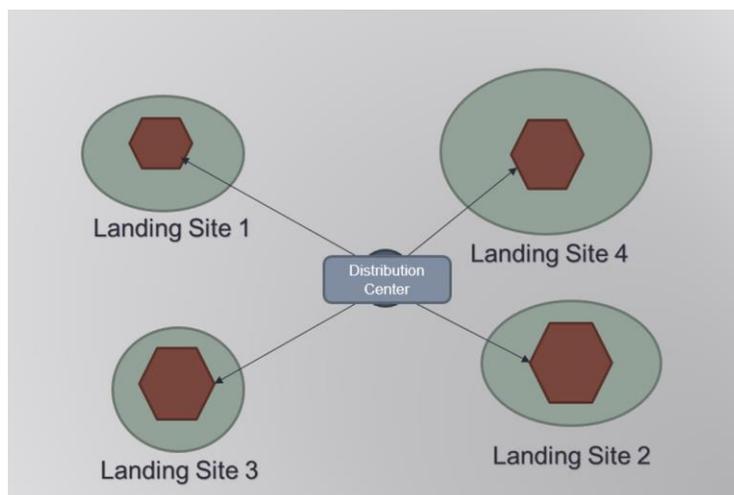


Figure 19: ODM Cargo Distribution Methodology.

The initial step involved is the calculation of ‘distribution factor’ for each landing site in the study area. Using Census-2010 data at the block group level, we studied the demographics surrounding landing sites. It is assumed that ODM cargo demand at a landing site is proportional to the combined population of the surrounding area. For example, landing sites located in densely populated areas will receive or produce relatively more cargo than a landing site located in a sparsely populated area. Distribution centers can be a connected airport or a population centroid. The hypothesis of the analysis is that people are the ultimate recipients of the cargo flowing into the area of interest. The population surrounding each landing site is used as a landing site “catchment” area. Information about catchment areas of warehouses and retail spaces could have refined this part of the analysis, but unfortunately, it was not publicly available.

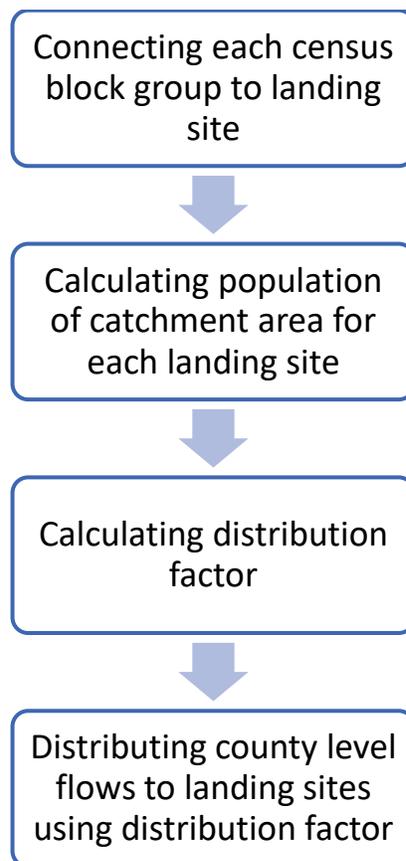


Figure 20: Distribution Factor Calculation Process.

- ⇒ Each census block group in the study area will be connected to the nearest landing site as it believed that shipment would be shipped to nearest port (landing site) via ODM vehicle.
- ⇒ As mentioned before, the characteristics of the catchment area determine the share from county-level flows for each landing site. Therefore, cumulative population is calculated for each landing site, i.e. aggregated population of census block groups connected to it.
- ⇒ Furthermore, the distribution factor is calculated for each landing site using the following equations:

$$Population_{LS} = \sum_{i=1}^n Population_{BG}$$

Where n is the number of census block groups connected to the landing site and $Population_{LS}$ is cumulative population of landing site's catchment area.

$$D_f \text{ for } LS_i = [Population_i / Population_{county}]$$

Where D_f is the distribution factor for the Landing site ' i ' and $Population_i$ is the aggregated population of the catchment area.

- ⇒ Ultimately the distribution factor is used to distribute the county level flows to the landing sites.

Step 7: Application of Appropriate Market Share

The ODM sub-mode is a concept whose potential cargo demand depends on the market share it can capture in future i.e., the percentage of shipments shift from other sub-modes to ODM. This study does not involve the direct calculation of market share for the ODM sub-mode using a cargo choice model. Calibration of such a model requires information that is either not publicly available or documented well enough.

Nevertheless, the effect of varying market share on final cargo ODM demand is estimated by parametric analysis. Different scenarios of market shares were developed from low to high demand to understand their influence on cargo ODM demand across the Northern California region. The initial market share for each commodity was selected concerning the nature of the commodity, i.e., high priority shipments like ‘Mail and Express Traffic’ and perishable commodity like ‘Fish and Marine Products’ were assigned higher market share compared to others. Furthermore, the market share was varied parametrically according to the values shown in Table 6.

It is important to note that there is little publicly available data that explains the details on how customers select among shipping alternatives across commodities. In other words, there are macro-level databases like Transearch that aggregate cargo shipments across regions. Nevertheless, there is no data on the actual choices that customers or retailers considered before making a specific shipment. Such data will have to be derived synthetically.

The initial assumptions for market share were based on the cost function analysis performed in another part of this study (Rimjha 2018). The current shipment costs as a function of weight and distance were studied by Sayantan Tarafdar. The cost function for the FedEx (a multi-national courier service company) was derived from the publicly available cost matrices. The analysis

provides insight on the price point required by the UAS VTOL concept to compete with the existing courier service market. Analysis was limited to express service such as ‘First Overnight’ and ‘Priority Overnight’, which are similar to proposed ODM cargo service. A rudimentary analysis of the cost of such services was performed to understand how cargo ODM could compete with in future. It helped in deciding the market share assumptions.

Table 6: Market Share Assumptions for ODM Cargo Scenarios Modeled.

| Commodity | Scenario 1 | | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|-------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|
| | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) |
| Fish and Marine products | - | 5 | - | 5 | - | 2.5 | - | 2 |
| Drugs | 2.5 | 2.5 | 2.5 | 2.5 | 1.25 | 1.25 | 1 | 1 |
| Pharmaceutical Equipment | 2.5 | 2.5 | 2.5 | 2.5 | 1.25 | 1.25 | 1 | 1 |
| Electric Measuring Instrument | 5 | 2.5 | 2.5 | 2.5 | 1.25 | 1.25 | 1 | 1 |
| Mail and Express Traffic | - | 10 | - | 10 | - | 8 | - | 5 |
| Small Freight Shipments | - | 10 | - | 10 | - | 8 | - | 5 |
| Solid State Semiconductors | 5 | - | 2.5 | - | 1.25 | - | 1 | - |
| Telephone Equipment | 5 | - | 2.5 | - | 1.25 | - | 1 | - |
| Jewelry and precious metals | 2.5 | - | 2.5 | - | 1.25 | - | 1 | - |
| International Air Freight | | 10.0 | | 5.0 | | 3.0 | | 2.5 |

Using the respective market share values, cargo demand for ODM sub-mode at the county level is calculated for each phase of analysis, i.e., internal flows from ‘Truck’ mode traveling less than 150 miles and external flows (including pseudo-external) from ‘Air’ mode.

Step 8: Landing Site Cargo ODM flights Calculation

Certain ODM vehicle characteristics are assumed to calculate the number of daily cargo ODM flights. The number of flights for cargo ODM involves separate analysis for ‘Truck’ and ‘Air’ mode which eventually adds up to find ‘Total Number of Cargo ODM Flights’ (on a daily basis). The following ODM vehicle characteristics are assumed in this analysis: a) 800 lb. ODM vehicle capacity, b) 250 working days per year (with uniform demand) and 0.6-0.75 load factor of the ODM aircraft.

Different load factors were assumed for commodities chosen in the analysis. A higher load factor was selected for commodities in the ‘Truck’ mode due to the slower transportation speeds of the ‘Truck’ mode. This implies that when ODM aircraft compete with trucks, there are greater opportunities to wait a longer period before the shipment and hence improve the chance to reach higher load factors. For commodities in the ‘Air’ mode, we expect lower load factors because ODM will compete with a faster mode of transportation. Table 7 and Table 8 shows the assumed load factors for ‘Truck’ and ‘Air’ modes, respectively.

Table 7: Load Factors for 'Truck' Mode Commodities.

| Commodity | Load Factor (%) |
|-----------------------------------|-----------------|
| Drugs | 80 |
| Pharmaceutical Equipment | 80 |
| Electric Measuring Instrument | 80 |
| Solid State Semiconductors | 80 |
| Telephone and Telegraph Equipment | 80 |
| Jewelry and precious metals | 80 |

Table 8: Load Factors for 'Air' Mode Commodities.

| Commodity | Load Factor (%) |
|-------------------------------|-----------------|
| Fish and Marine products | 60 |
| Drugs | 60 |
| Pharmaceutical Equipment | 65 |
| Electric Measuring Instrument | 65 |
| Mail and Express Traffic | 50 |
| Small Freight Shipments | 50 |

Cargo Distribution Methodology:

‘Truck’ Mode Analysis

- a) The county-level cargo demand follows a two-stage distribution model. Internal flows are first distributed using distribution factors in the origin county followed by distribution of the county share among landing sites in destination county. This generates a m by n matrix where ‘ m ’ is the number of landing sites at the origin county and ‘ n ’ is the number of landing sites at the destination county.
- b) The number of potential daily cargo ODM flights are determined between these landing site pairs using the assumptions stated above. In the next paragraphs, we describe other assumptions in the assumed cargo ODM operational concept.

‘Air’ Mode Analysis

- a) All the cargo attracted or produced at the county level is assumed to move through a hub cargo airport. The last-mile trip from and to the connected airport is the potential market for ODM sub-mode as it provides a time-advantage for shipments with delivery priority (e.g., next-day overnight). For this study, we ran a parametric analysis of the potential cargo ODM demand assuming various market share values for each commodity. The cargo ODM demand is calculated after the application of a market share value to a commodity (see Table 6).
- b) The cargo ODM demand is distributed from the cargo hub airport to individual landing sites based on distribution factor estimated from population demographics.
- c) The number of daily, cargo ODM flights is determined between airports and respective landing sites for each county in the study region.

Step 9: International Air Freight into the Region

The Transearch database does not account for two important additional cargo flows that could play an important role in this analysis: a) international air cargo to and from the study area and b) internal cargo flows between private warehouses (e.g., Amazon shipments between warehouses). International cargo arriving or departing the study area is shipped by air using one of the few international airports in the study area. Using the T-100I (Bureau of Transportation Statistics 2017) we found the total international cargo inflows and outflows into four major airports: a) San Francisco International (SFO), b) Oakland (OAK), c) San Jose (SJC) and d) Sacramento (MHR). Figure 21 shows the freight entering (inflow) the region of interest via four international airports. Figure 22 shows the freight leaving (outflow) the region of interest via four international airports. Both figures show that there is no significant international freight into Sacramento International. Both figures indicate that a large fraction of the international freight is routed through SFO. Figure 21 and Figure 22 demonstrate that in the year 2017, international air freight is well balanced between inflows and outflows at SFO International airports. SFO handles 94.4% of the total air freight arriving at the study area.

Similarly, SFO handles 83% of the air freight departing the study area. For this reason, the results presented in this report considers SFO air freight as the only additional contribution to ODM cargo flights for now. It is important to recognize that international air freight statistics lack commodity type information. An important recommendation of the study is to investigate the types and value of commodities that make the bulk of international air freight shipments to and from this region. The proximity of Silicon Valley and the tech industry could boost the projections made in this analysis.



Figure 21: International Air Freight Arriving at the Region of Analysis (Cargo Inflows).

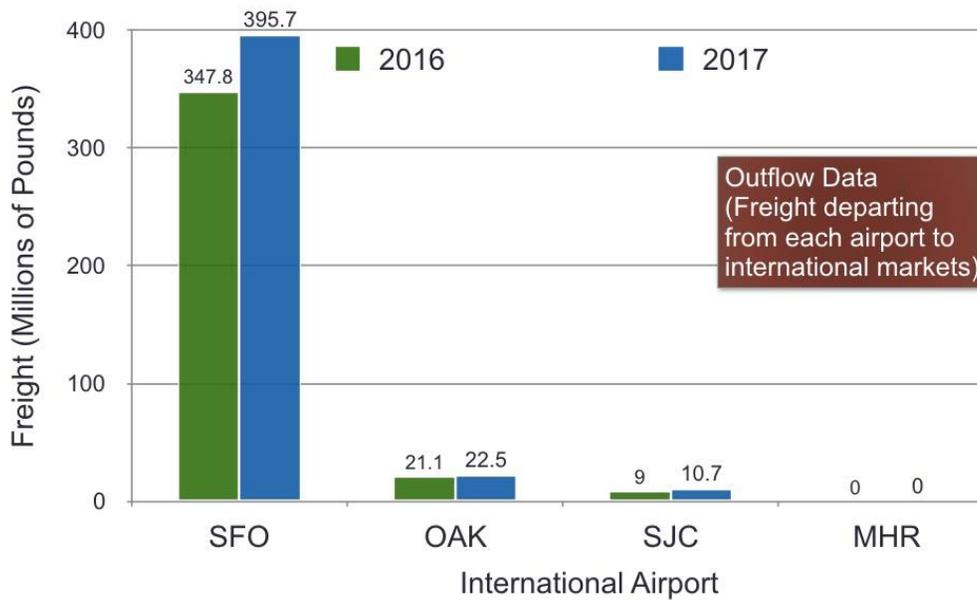


Figure 22: International Air Freight Departing at the Region of Analysis (i.e., Outflows).

Estimation of ODM cargo flights from international air cargo:

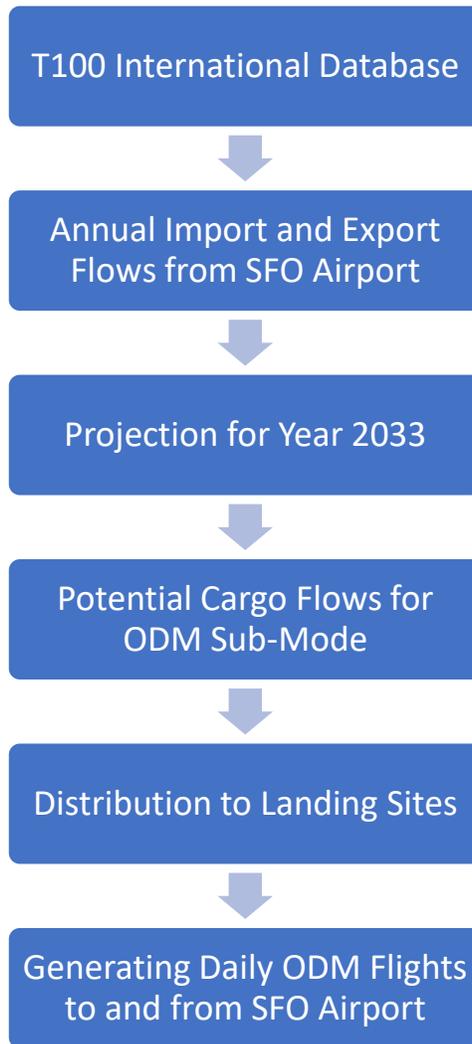


Figure 23: Workflow for Estimation of ODM Cargo Flights from International Air Cargo.

The distribution of international air cargo was similar to cargo distribution model applied to Transearch data. According to the Caltrans report on air cargo in California, the average annual growth was observed between 3.7% to 4.4% (CDOT, Division of Aeronautics 2017). Therefore, for the projection of international air cargo flows, an annual growth rate of 4% was assumed. As mentioned before, only cargo moving through SFO was considered in this analysis.

Among all the 17 counties, only three of them were assumed to be receiving this international air cargo through SFO airport namely San Francisco, San Mateo, and Santa Clara. All the landing sites in these counties were selected to receive fractions of this international cargo. The fractions were calculated by studying the surroundings of each landing site. Every census block group in these counties were consolidated and connected to the nearest landing sites. A new distribution factor was calculated for these landing sites (118) in selected counties.

Using the new distribution factor, the potential share of ODM sub-mode in international air cargo was distributed among selected landing sites. Further using the same parameters for ODM vehicle, daily cargo ODM flights were generated from SFO airport to selected landing sites and back. These flights were added to the cargo ODM flights from other commodities.

Step 10: Generating Origin-Destination Pairs

After calculating the daily number of flights between landing sites from both the modes, Origin-Destination pairs are generated using Monte-Carlo simulation. The Monte-Carlo simulation incorporates a random number generator to decide the fractional part of the demand. If the fractional part of the number of trips between OD pairs is greater than the random number generated; flight exists on that day. For example there are 6.23 flights between landing site '45' and landing site '446'. If the random number generated between 0 and 1 is smaller than 0.23, number of flights would be 7, otherwise 6. This results in a set of daily flights between Origin-Destination pairs.

Step 11: Generating Flight Trajectories

The final step in the analysis consists of generating flight tracks and schedule in ACES (NASA's flight simulator) input format for the set of daily flights from the penultimate set. It includes

Unique Flight ID, Aircraft Type, Departure Airport ID, Arrival Airport ID, Scheduled Departure Time, Cruise Altitude, Cruise Speed, and Flight plan.

The cruise altitude of flight is determined by a table lookup-function of trip distance and cruise altitude. A long-distance flight is assigned higher altitude than a shorter distance flight. The cruise speed varies between 150-200 mph and randomly assigned to each flight.

The flight plan of each flight consists of waypoint point information at every thirty seconds along the route. The flight trajectories are modeled to avoid approach and departure surfaces of commercial airports in the study area. If a flight confronts an approach or a departure surface along the trajectory, it takes the shortest path detour. The waypoint information includes coordinates (latitude and longitude) of waypoint and time stamp of when the flight reaches the waypoint. The detour points are also included in waypoints as they are critical in rerouting the flight. This results in flight plans of all the cargo flights in ACES input format.

Results and Findings

The steps described in Section IV are applied to estimate ODM cargo flights for seventeen counties in the Northern California region. The ODM cargo demand is developed parametrically according to the market share assumptions presented in Table 9.

Table 9: Market Share Assumptions of ODM Cargo Scenarios Modeled.

| Commodity | Scenario 1 | | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|-------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------------------|
| | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) |
| Fish and Marine products | - | 5 | - | 5 | - | 2.5 | - | 2 |
| Drugs | 2.5 | 2.5 | 2.5 | 2.5 | 1.25 | 1.25 | 1 | 1 |
| Pharmaceutical Equipment | 2.5 | 2.5 | 2.5 | 2.5 | 1.25 | 1.25 | 1 | 1 |
| Electric Measuring Instrument | 5 | 2.5 | 2.5 | 2.5 | 1.25 | 1.25 | 1 | 1 |
| Mail and Express Traffic | - | 10 | - | 10 | - | 8 | - | 5 |
| Small Freight Shipments | - | 10 | - | 10 | - | 8 | - | 5 |
| Solid State Semiconductors | 5 | - | 2.5 | - | 1.25 | - | 1 | - |
| Telephone Equipment | 5 | - | 2.5 | - | 1.25 | - | 1 | - |
| Jewelry and precious metals | 2.5 | - | 2.5 | - | 1.25 | - | 1 | - |
| International Air Freight | | 10.0 | | 5.0 | | 3.0 | | 2.5 |

Baseline Year Results (2016)

The results for the scenario I (market share) are included in for the baseline year (2016). The table contains commodity-wise results. It has value-per-ton and includes the daily tonnage shifted from ‘Truck’ and ‘Air’ to ODM. Furthermore, it includes the number of daily ODM flights needed to transport the cargo shifted from ‘Air’ and ‘Truck’ modes. The table also includes additional ODM flights required to transport a small fraction (10%) of the international air cargo arriving in large cargo airports in the region. According to this scenario, in the year 2016, there is a potential demand for 884 ODM cargo flights in the region associated with nine commodities contained in the Transearch data. There could be an additional 535 ODM cargo flights associated with international air freight (reported in the last row in Table 10). Overall, according to the market share assumptions made in Scenario 1, there could be 1,419 daily cargo ODM flights in the region. Note that small freight shipments account for almost 33% (one-third) of the total ODM flights. Figure 24 shows the spatial distribution of ODM cargo flights in the Northern California region. The graphic shows prominently three airports (SFO, OAK, and MHR) as having a substantial share of the cargo ODM flights. SFO receives 94.6% of the international air freight traffic. OAK receives a large share of the domestic “AIR” market due to its strategic proximity to six of the seventeen counties in the region. Domestic air cargo shipments are routed through Oakland International airport and then distributed to landing sites across six counties that represent the catchment area for the airport. Figure 40 shows a summary of daily cargo ODM flights in the Northern California region for all four scenarios.

Table 10: Scenario 1 Results ODM Cargo Modeled (Year 2016 Demand).

| Commodity | Value per Ton for Commodity (\$ 2033) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Daily Tonnage from Truck Market (US Tons) | Daily Tonnage from Air Market (US Tons) | Total Tonnage Carried by ODM Cargo (US Tons) | Rounded Daily ODM Flights |
|-------------------------------|---------------------------------------|-------------------------------------|-----------------------------------|---|---|--|---------------------------|
| Fish and Marine products | 2,664 | 0 | 5 | 0.0 | 1.2 | 1.2 | 5 |
| Drugs | 22,964 | 2.5 | 2.5 | 84.0 | 4.16 | 88.16 | 160 |
| Electric Measuring Instrument | 256,752 | 5 | 2.5 | 1.7 | 0.0 | 1.7 | 3 |
| Pharmaceutical Equipment | 27,350 | 2.5 | 2.5 | 32.1 | 7.3 | 39.4 | 67 |
| Mail and Express Traffic | * | 0 | 10 | 0.0 | 21.3 | 21.3 | 77 |
| Small Freight Shipments | * | 0 | 10 | 0.0 | 154.7 | 154.7 | 486 |
| Telephone Equipment | 34,210 | 5 | 0 | 7.6 | 0.0 | 7.6 | 8 |
| Solid State Semiconductors | 27,248 | 5 | 0 | 63.0 | 0.0 | 63.0 | 81 |
| Jewelry and precious metals | 190,515 | 2.5 | 0 | 0.1 | 0.0 | 0.1 | 1 |
| International Air Cargo | * | 0 | 10 | 0 | 157.8 | 157.8 | 575 |

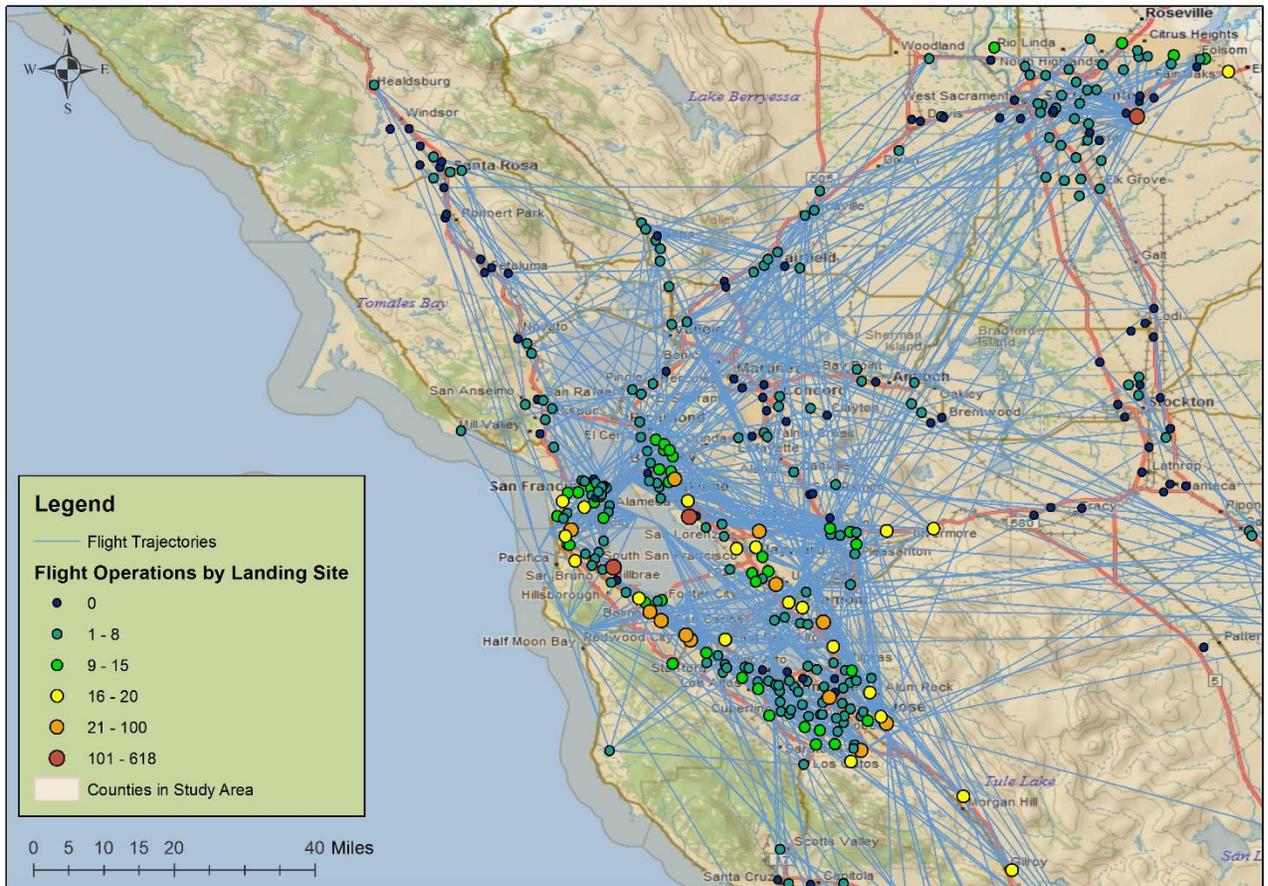


Figure 24: Spatial Distribution of ODM Cargo Flights (in blue) in Northern California for Scenario 1. The High-Demand Scenario Generated 1,419 Daily Cargo ODM Flights in the Region.

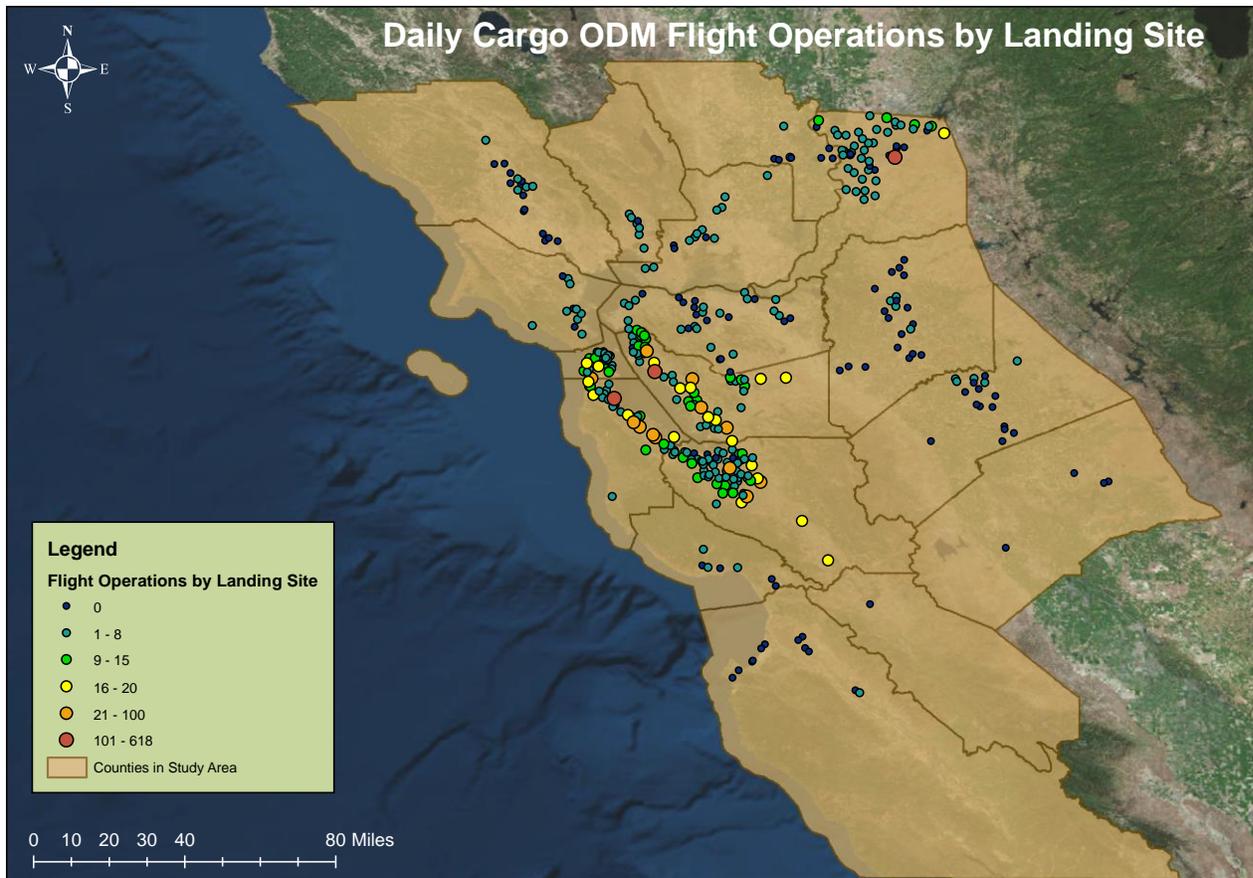


Figure 25: Flight Operations by Landing Sites for Scenario I (2016).

Projection Year Results (2033)

The Transearch data used in this study also contains the forecast of cargo flows in the year 2040. Using the above-explained methodology on this data, we projected the ODM cargo flights in the year 2033 when the cargo ODM services are expected to be ‘mature’. According to the market share assumptions made in Scenario 1, there could be 2,357 daily cargo ODM flights in the region. Note that small freight shipments account for almost 25% of the total ODM flights. Figure 27 shows the spatial distribution of ODM cargo flights in the Northern California region.

Table 11: Scenario I Results Modeled (Projection Year 2033).

| Commodity | Value per Ton for Commodity (\$ 2033) | Percent Market Share from Truck (%) | Percent Market Share from Air (%) | Daily Tonnage from Truck Market (US Tons) | Daily Tonnage from Air Market (US Tons) | Total Tonnage Carried by ODM Cargo (US Tons) | Rounded Daily ODM Flights |
|-------------------------------|---------------------------------------|-------------------------------------|-----------------------------------|---|---|--|---------------------------|
| Fish and Marine products | 7,580 | 0 | 5 | 0.0 | 1.2 | 1.2 | 5 |
| Drugs | 68,725 | 2.5 | 2.5 | 84.0 | 4.16 | 88.16 | 276 |
| Electric Measuring Instrument | 272,138 | 5 | 2.5 | 1.7 | 0.0 | 1.7 | 6 |
| Pharmaceutical Equipment | 45,799 | 2.5 | 2.5 | 32.1 | 7.3 | 39.4 | 128 |
| Mail and Express Traffic | * | 0 | 10 | 0.0 | 21.3 | 21.3 | 85 |
| Small Freight Shipments | * | 0 | 10 | 0.0 | 154.7 | 154.7 | 621 |
| Telephone Equipment | 35,608 | 5 | 0 | 7.6 | 0.0 | 7.6 | 24 |
| Solid State Semiconductors | 42,460 | 5 | 0 | 63.0 | 0.0 | 63.0 | 195 |
| Jewelry and precious metals | 255,900 | 2.5 | 0 | 0.1 | 0.0 | 0.1 | 1 |
| International Air Cargo | * | 0 | 10 | 0 | 295.5 | 295.5 | 1067 |

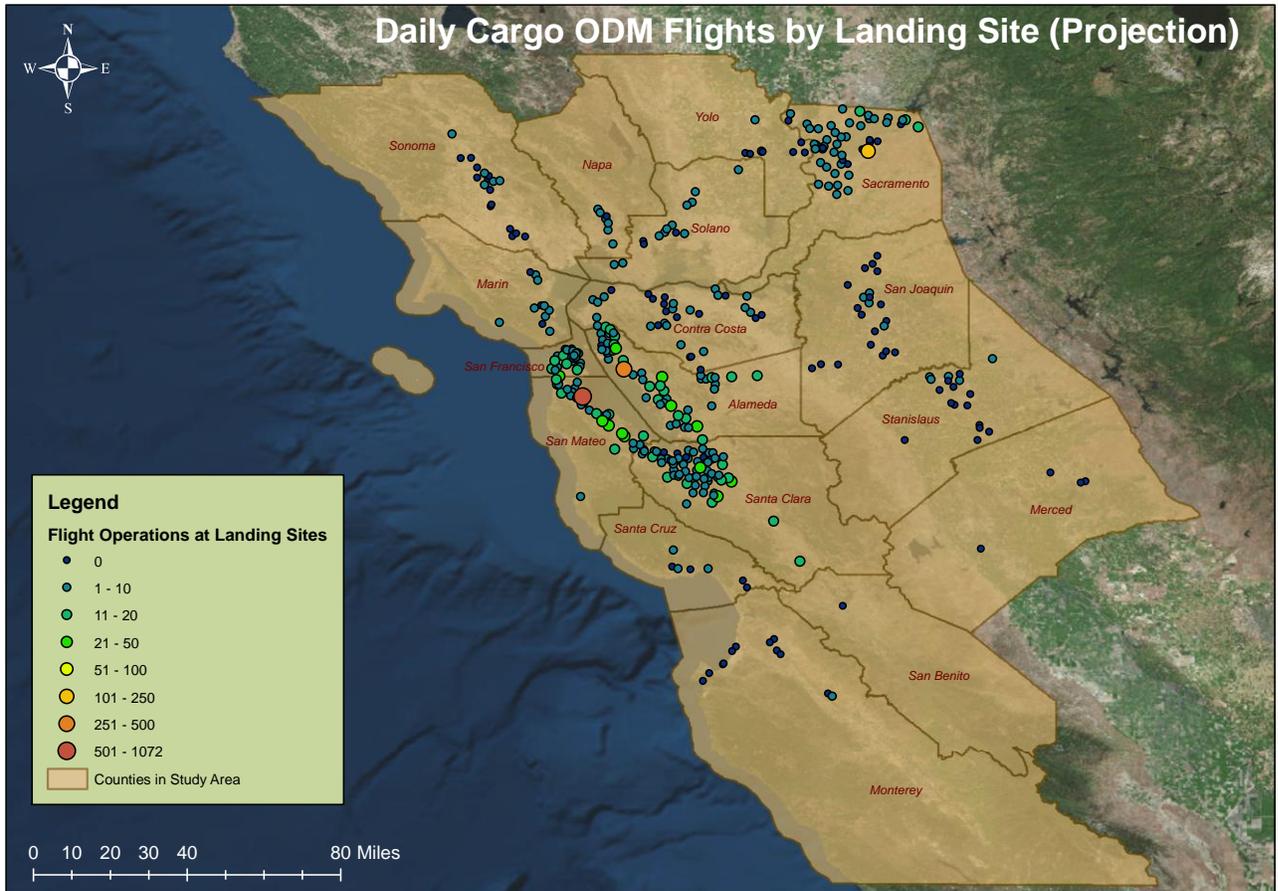


Figure 26: Flight Operations by Landing Site for Scenario I (Projection Year 2033).

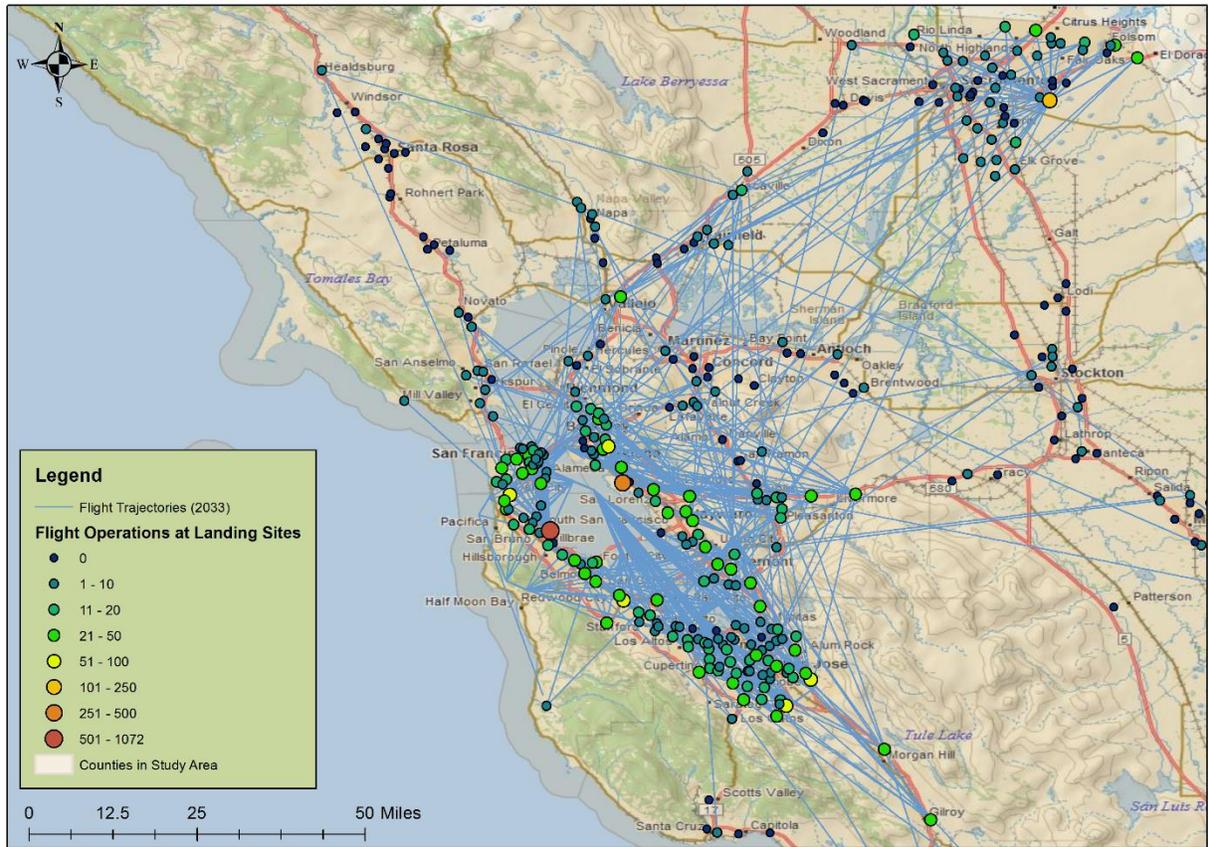


Figure 27: Spatial Distribution of ODM Cargo Flights (in blue) in Northern California for Scenario 1 (Projection Year 2033). The High-Demand Scenario Generated 2,357 Daily Cargo ODM Flights in the Region.

CHAPTER 4: EXTENDED RESULTS

In this section, we will include the results for remaining scenarios from market share parametric analysis. Furthermore, we will briefly describe the life-cycle cost model used to study the effect of cargo ODM operations in passenger demand.

Scenario II

The market share assumptions for scenario II are included in Table 12. The scenario II results for the baseline year (2016) are included in Figure 28 and Figure 29. Similarly, the results for projection year (2033) are included in Figure 30 and Figure 31.

The total number of daily ODM cargo flights in the baseline year (2016) is 1,049 and 1,573 in the projected year (2033).

Please note that flight operations comprise both landings and departures. Therefore, they are usually twice the daily number of flights.

Table 12: Market Share Assumptions in Scenario II.

| Commodity | Truck (%) | Air (%) |
|-----------------------------------|-----------|---------|
| Fish and Marine products | - | 5 |
| Drugs | 2.5 | 2.5 |
| Pharmaceutical Equipment | 2.5 | 2.5 |
| Electric Measuring Instrument | 2.5 | 2.5 |
| Mail and Express Traffic | - | 10 |
| Small Freight Shipments | - | 10 |
| Solid State Semiconductors | 2.5 | - |
| Telephone and Telegraph Equipment | 2.5 | - |
| Jewelry and precious metals | 2.5 | - |

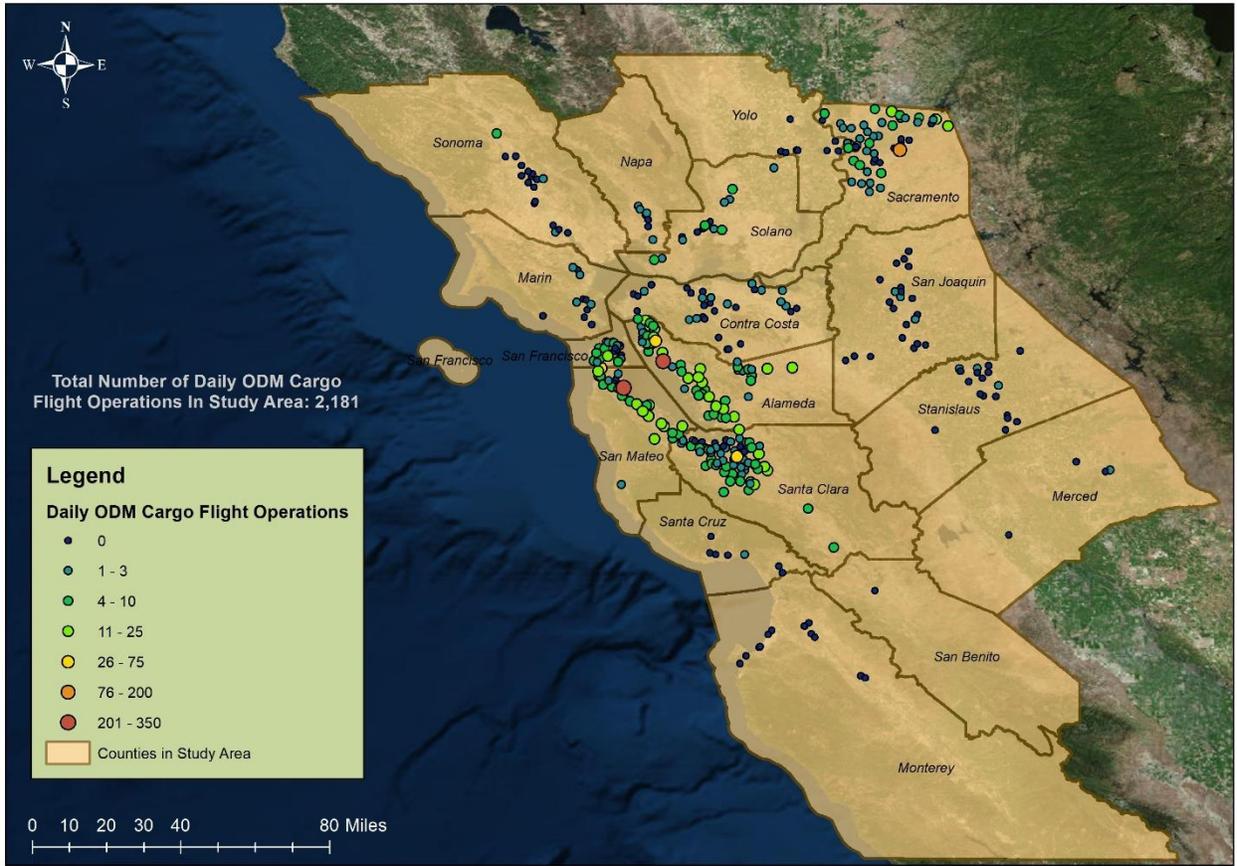


Figure 28: Daily Cargo ODM Flight Operations by Landing Site (Scenario II-2016).

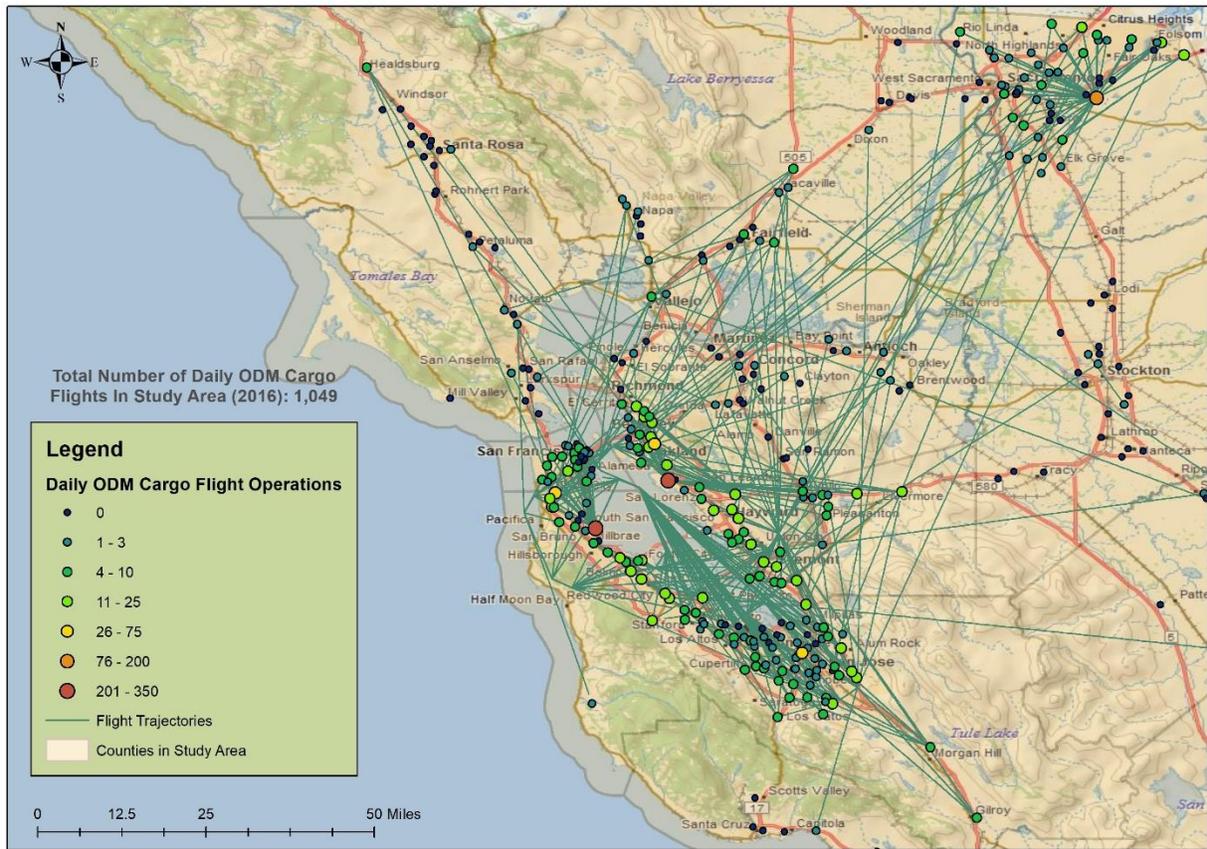


Figure 29: Cargo ODM Flight Trajectories for Scenario II (2016).

Model results for projection year (Scenario II)

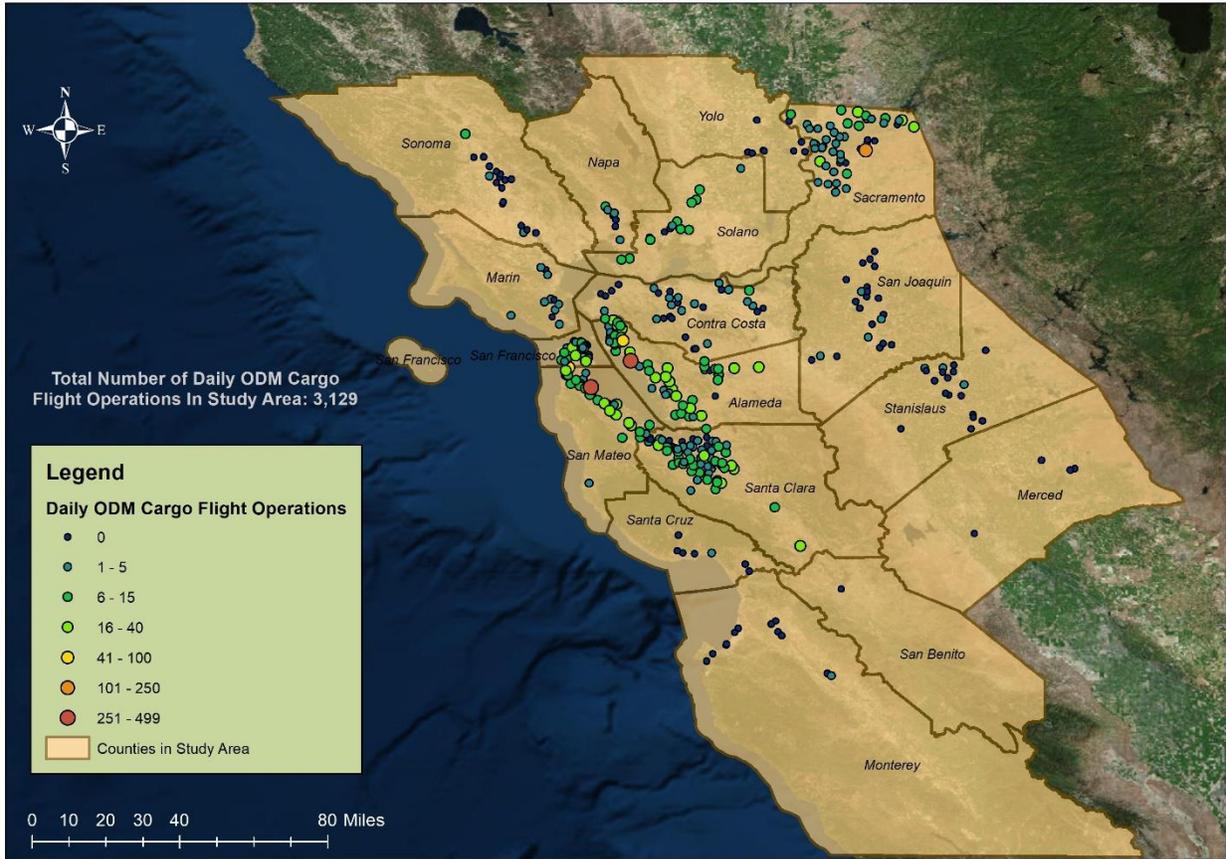


Figure 30: Daily Cargo ODM Flight Operations by Landing Site (Scenario II-2033).

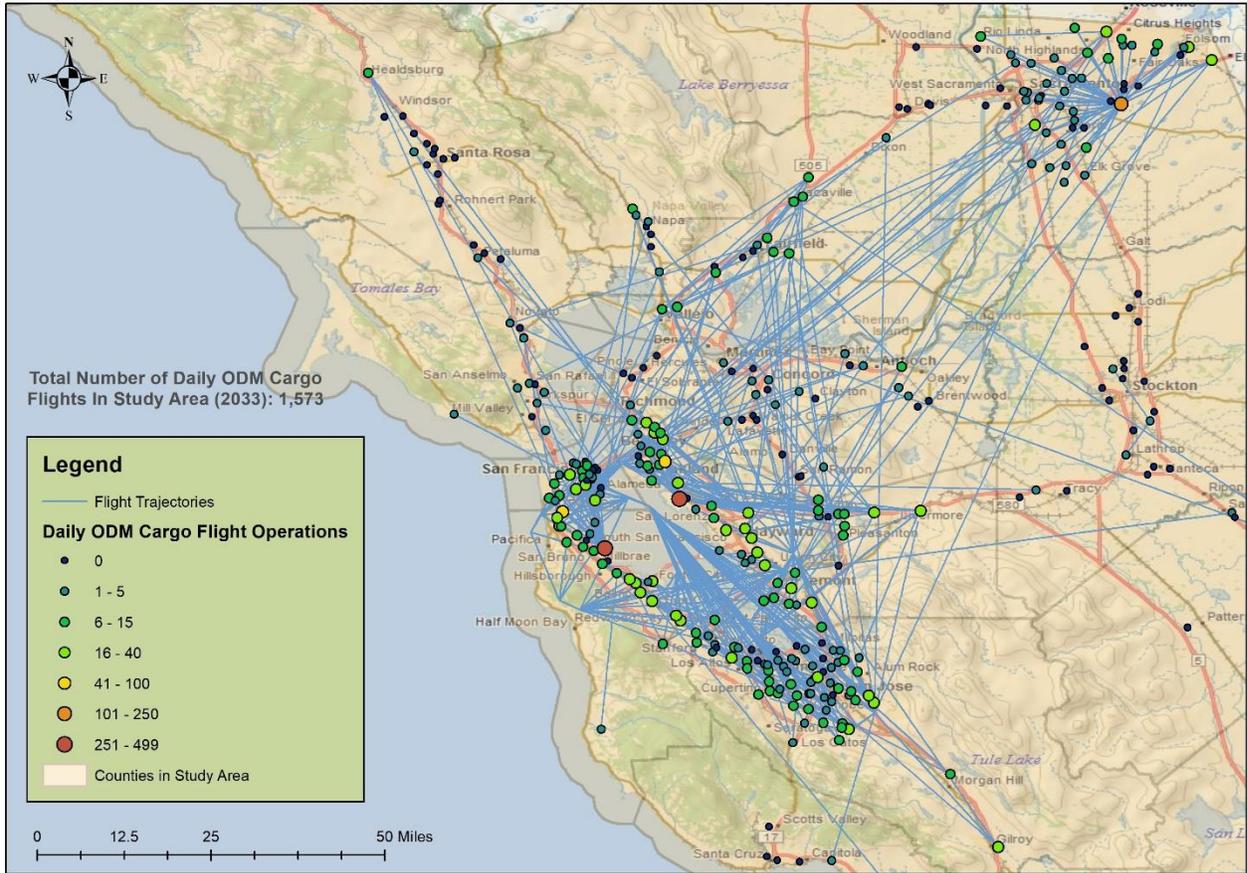


Figure 31: Cargo ODM Flight Trajectories for Scenario II (2033).

Scenario III

The market share assumptions for scenario III are included in Table 13. The scenario III results for the baseline year (2016) are included in Figure 32 and Figure 33. Similarly, the results for projection year (2033) are included in Figure 34 and Figure 35.

The total number of daily ODM cargo flights for baseline year (2016) is 747 and 1,049 for projection year (2033).

Table 13: Market Share Assumptions in Scenario III.

| Commodity | Truck (%) | Air (%) |
|-----------------------------------|-----------|---------|
| Fish and Marine products | - | 2.5 |
| Drugs | 1.25 | 1.25 |
| Pharmaceutical Equipment | 1.25 | 1.25 |
| Electric Measuring Instrument | 1.25 | 1.25 |
| Mail and Express Traffic | - | 8 |
| Small Freight Shipments | - | 8 |
| Solid State Semiconductors | 1.25 | - |
| Telephone and Telegraph Equipment | 1.25 | - |
| Jewelry and precious metals | 1.25 | - |

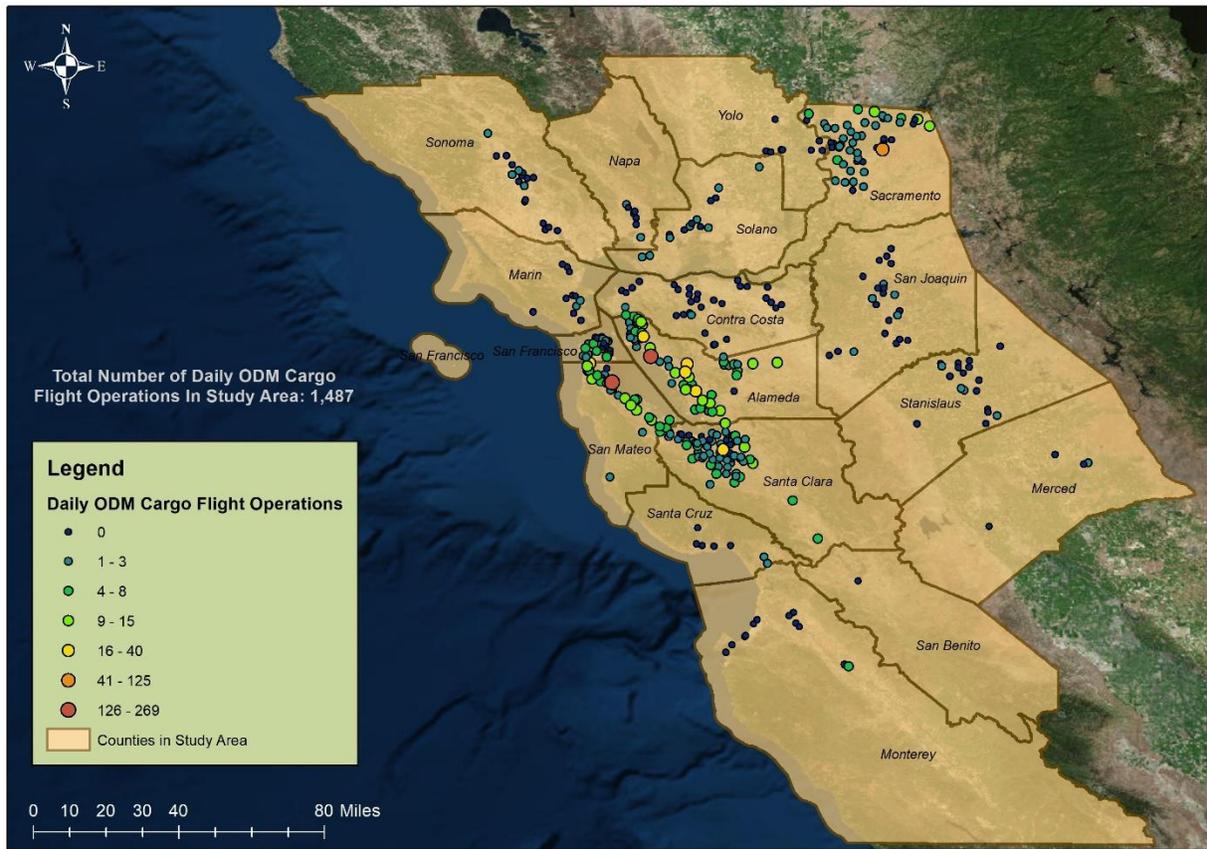


Figure 32: Daily Cargo ODM Flight Operations by Landing Site (Scenario III-2016).

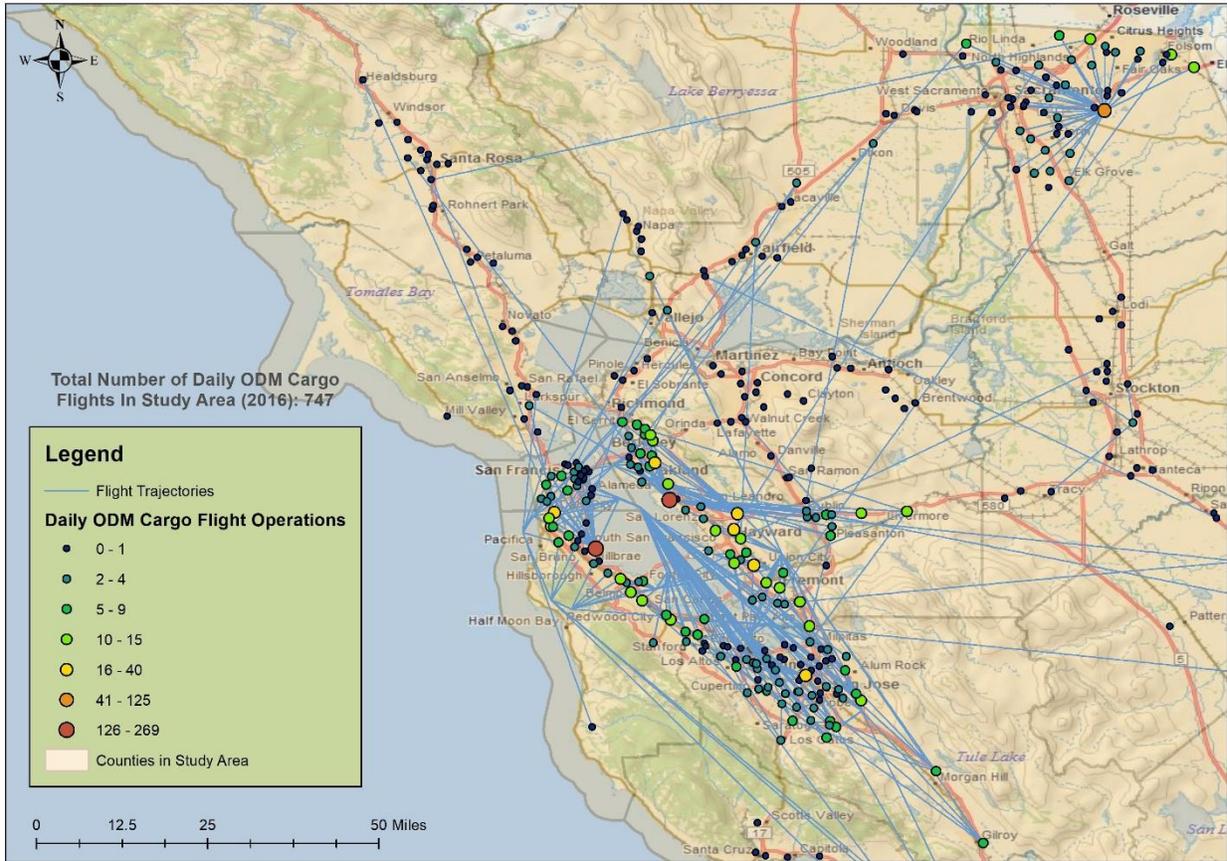


Figure 33: Cargo ODM Flight Trajectories for Scenario III (2016).

Model results for projection year (Scenario III)

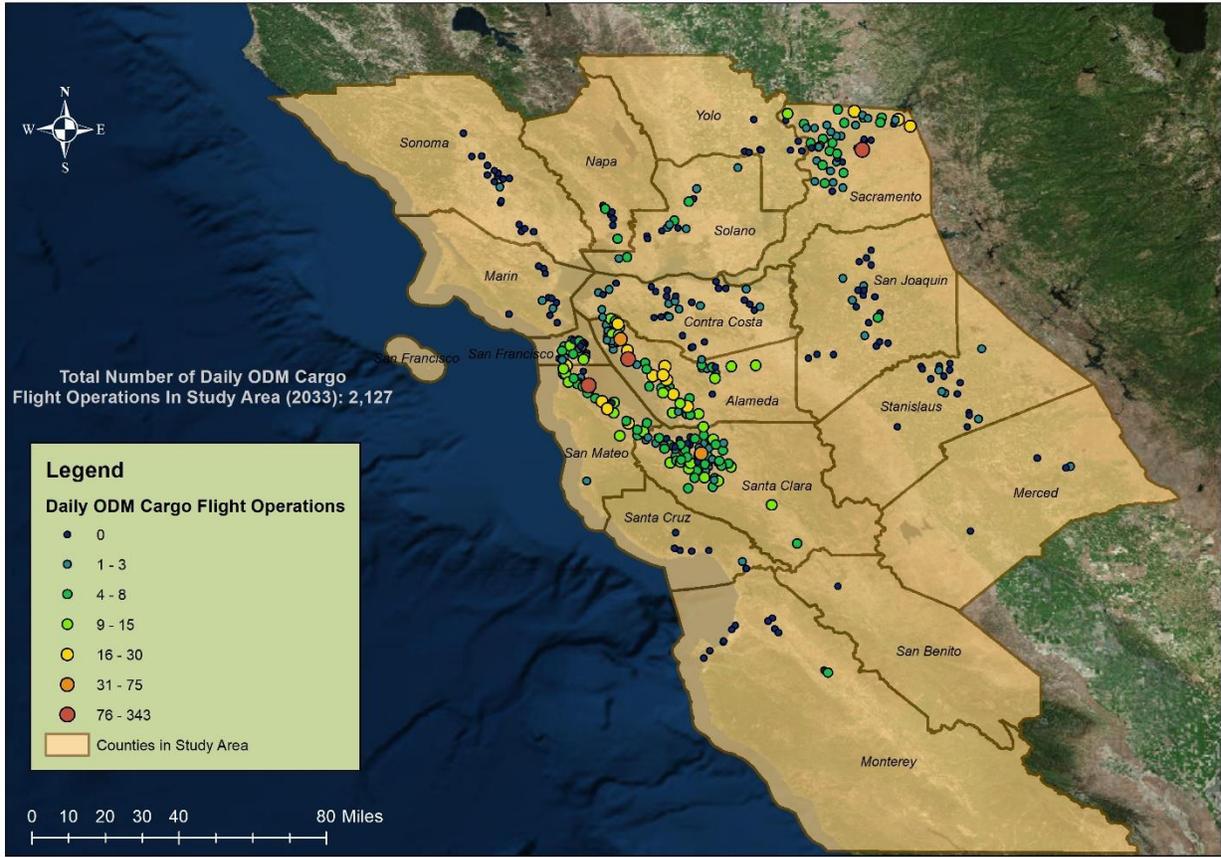


Figure 34: Daily Cargo ODM Flight Operations by Landing Site (Scenario III-2033).

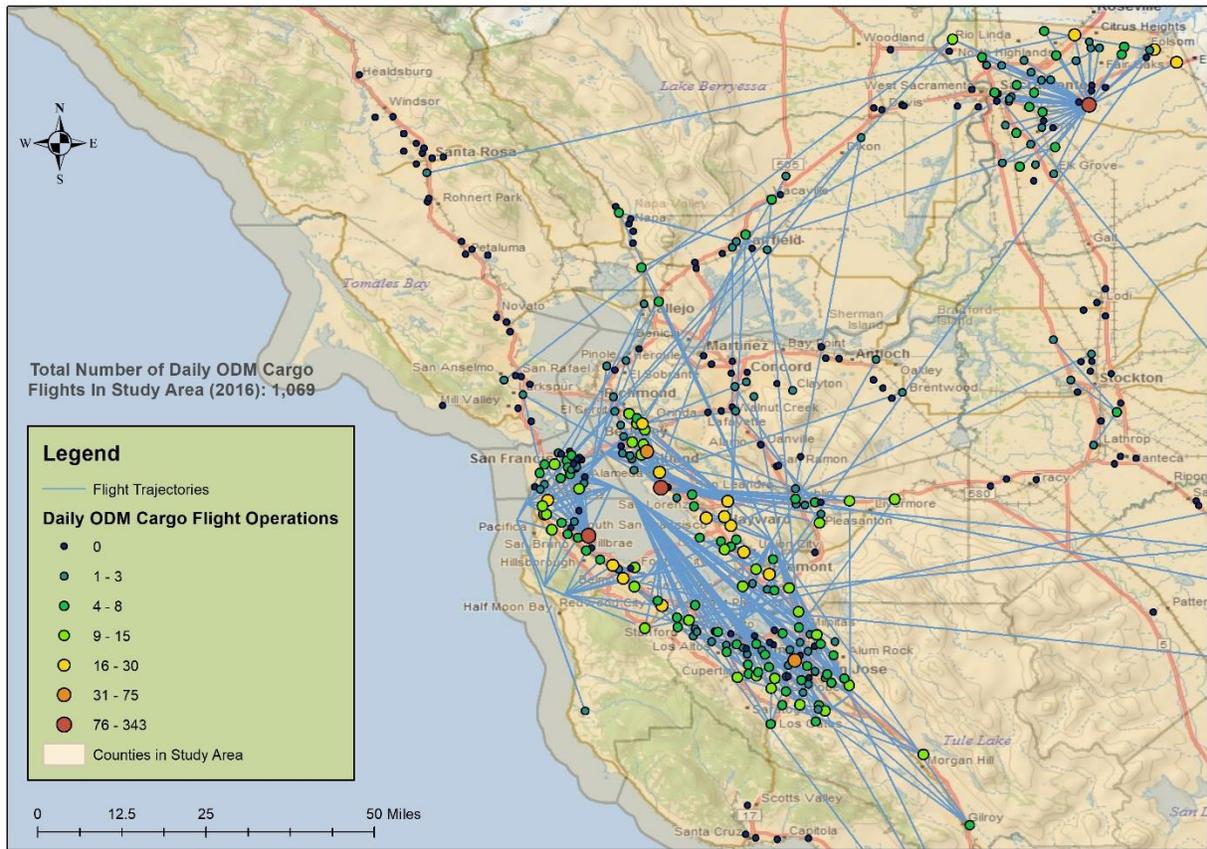


Figure 35: Cargo ODM Flight Trajectories for Scenario III (2033).

Scenario IV

The market share assumptions for scenario IV are included in Table 14. The scenario III results for the baseline year (2016) are included in Figure 36 and Figure 37. Similarly, the results for projection year (2033) are included in Figure 38 and Figure 39.

The total number of daily ODM cargo flights is 677 for baseline year (2016) and 801 for projection year (2033).

Table 14: Market Share Assumptions in Scenario IV.

| Commodity | Truck (%) | Air (%) |
|-----------------------------------|-----------|---------|
| Fish and Marine products | - | 2 |
| Drugs | 1 | 1 |
| Pharmaceutical Equipment | 1 | 1 |
| Electric Measuring Instrument | 1 | 1 |
| Mail and Express Traffic | - | 5 |
| Small Freight Shipments | - | 5 |
| Solid State Semiconductors | 1 | - |
| Telephone and Telegraph Equipment | 1 | - |
| Jewelry and precious metals | 1 | - |

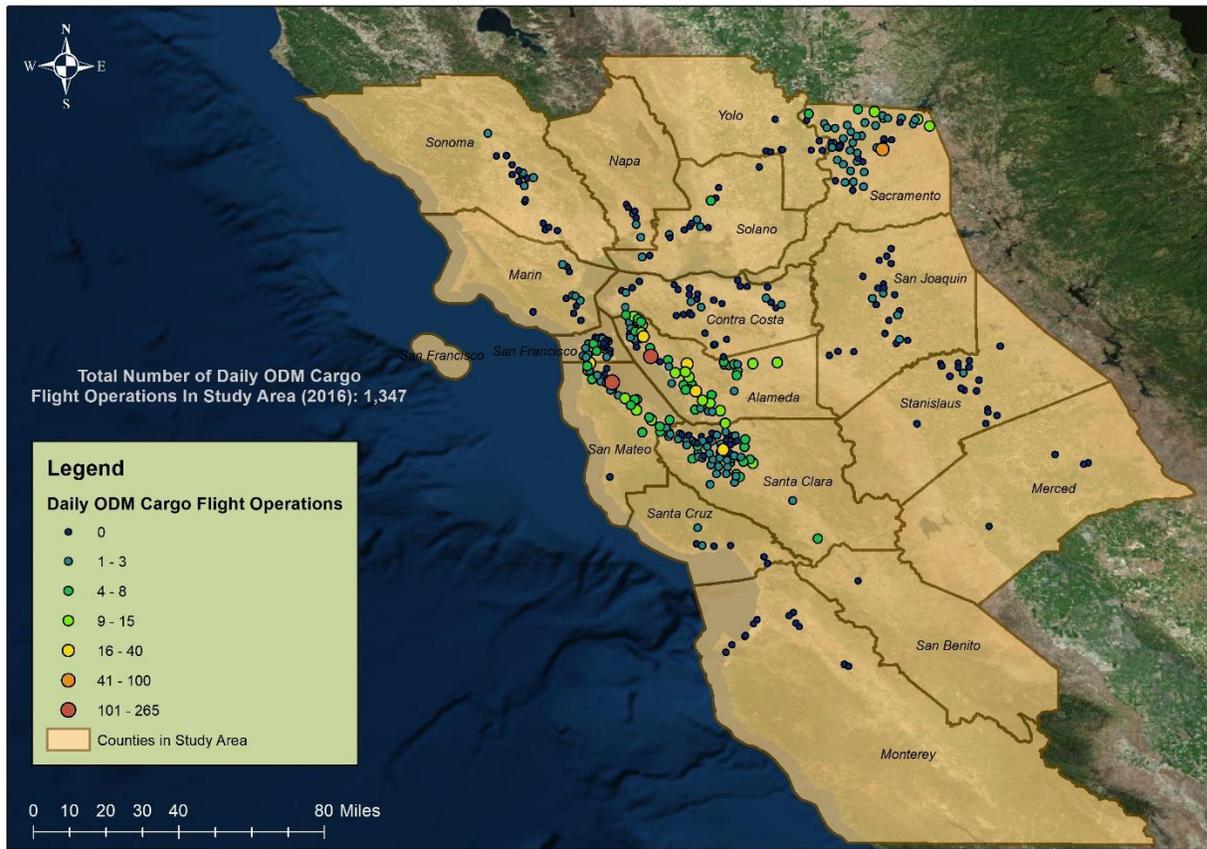


Figure 36: Daily Cargo ODM Flight Operations by Landing Site (Scenario IV-2016).

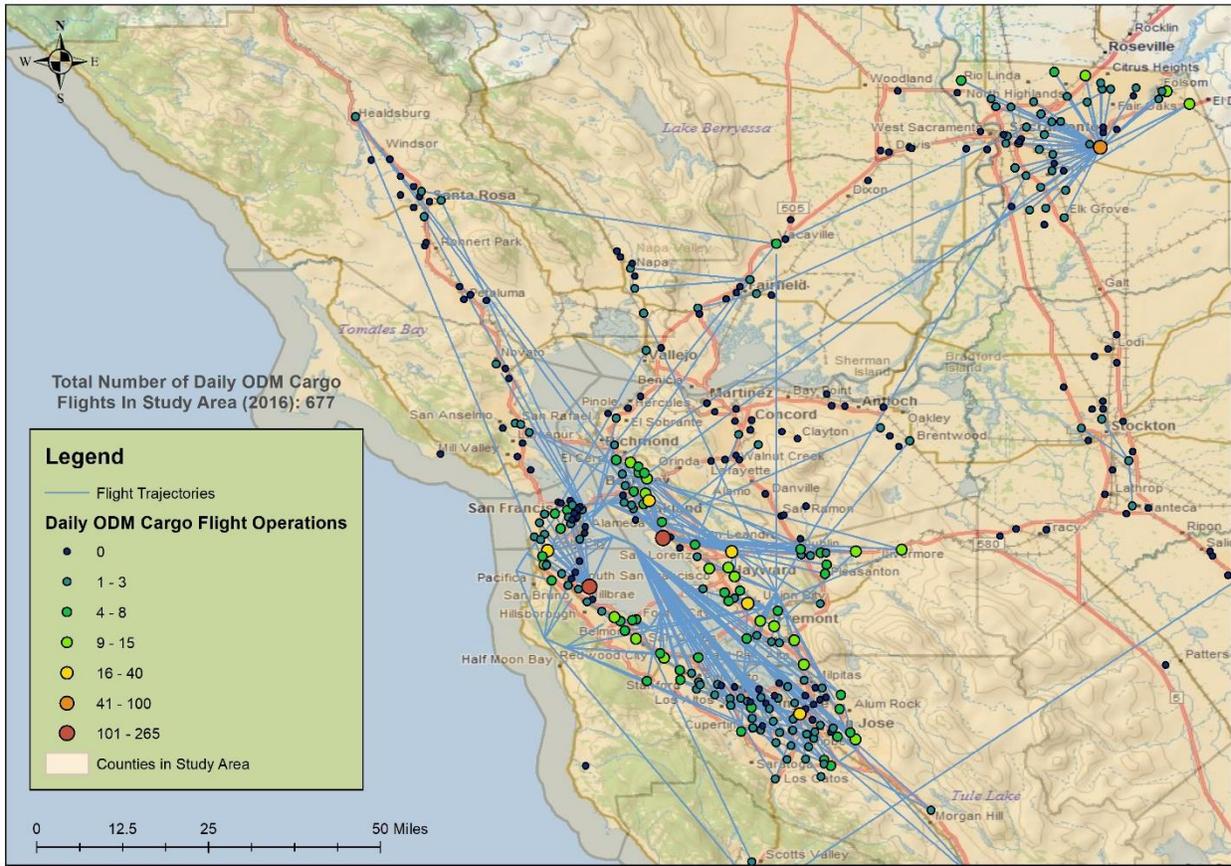


Figure 37: Cargo ODM Flight Trajectories for Scenario IV (2016).

Model results for projection year (Scenario IV)

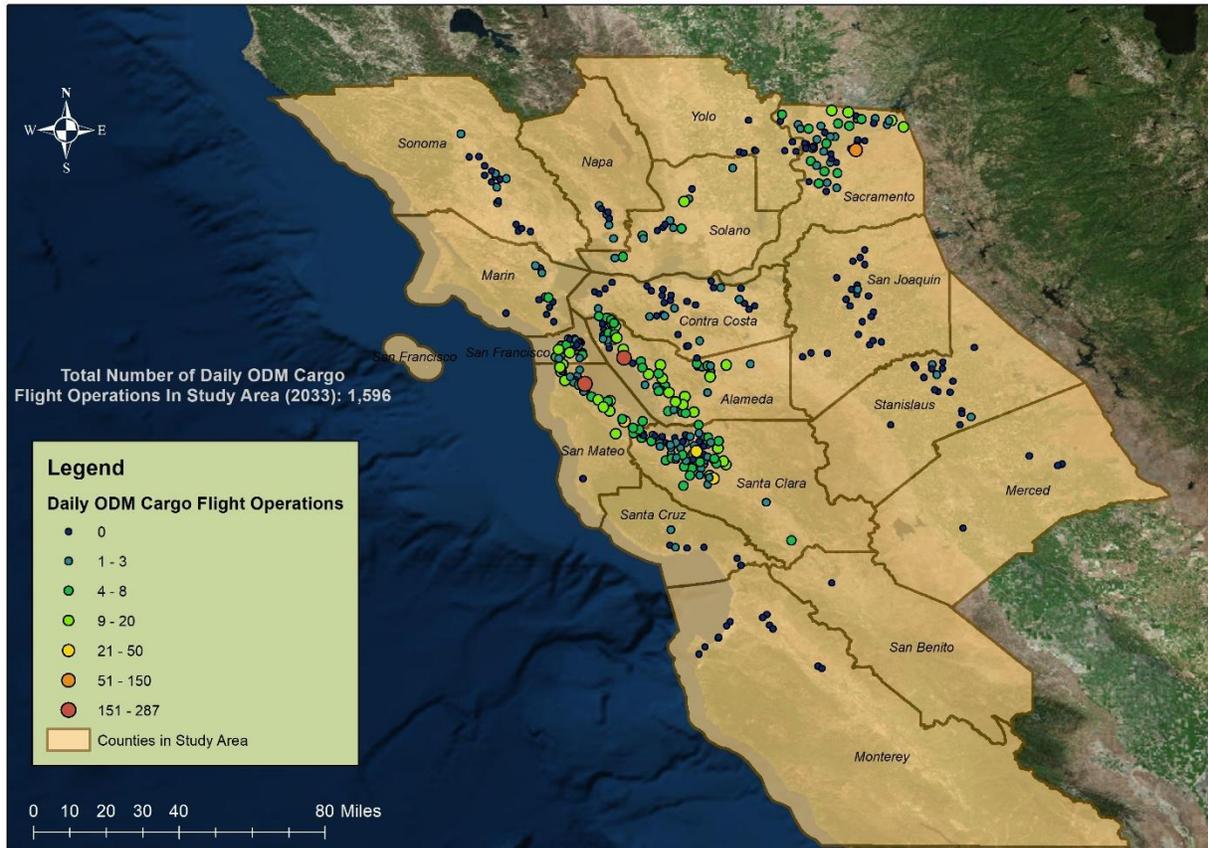


Figure 38: Daily Cargo ODM Flight Operations by Landing Site (Scenario IV-2033).

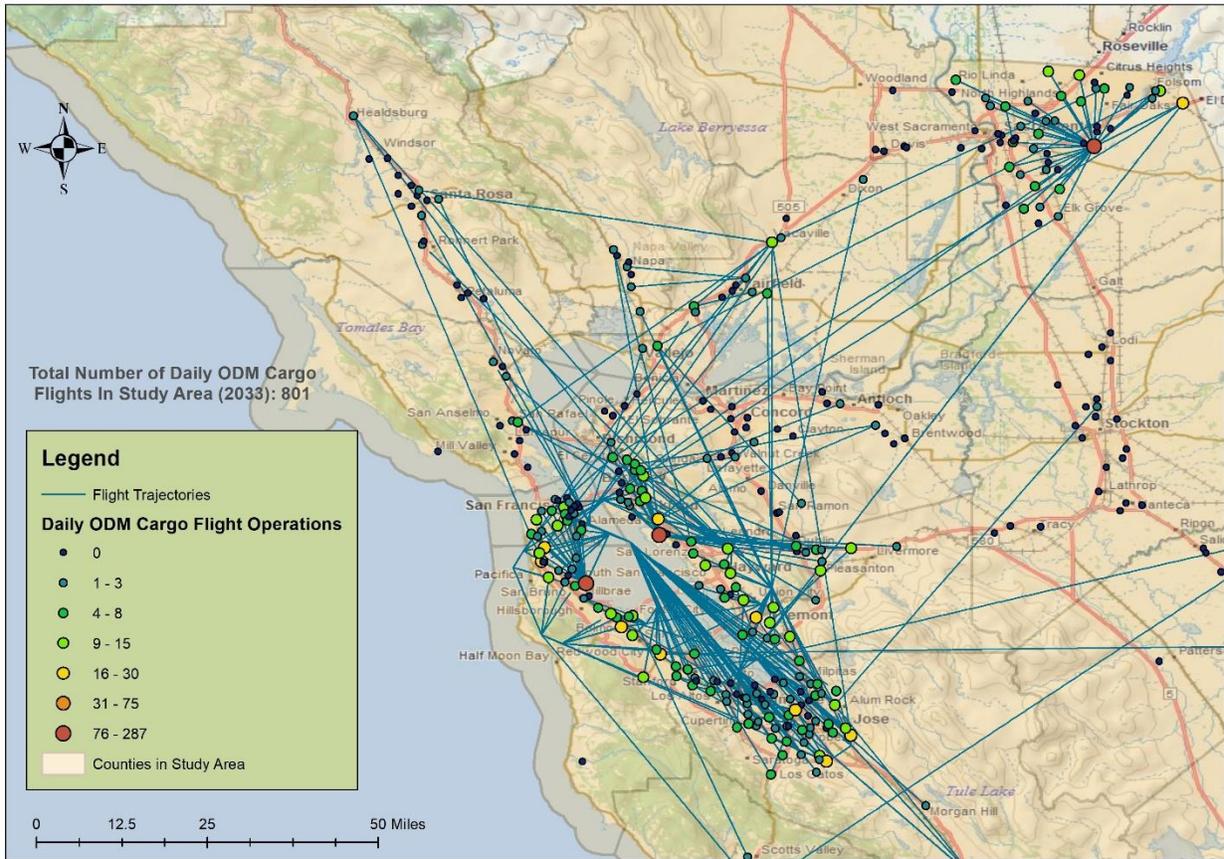


Figure 39: Cargo ODM Flight Trajectories for Scenario IV (2033).

Figure 40 shows a summary of daily cargo ODM flights in the Northern California region for all four scenarios.

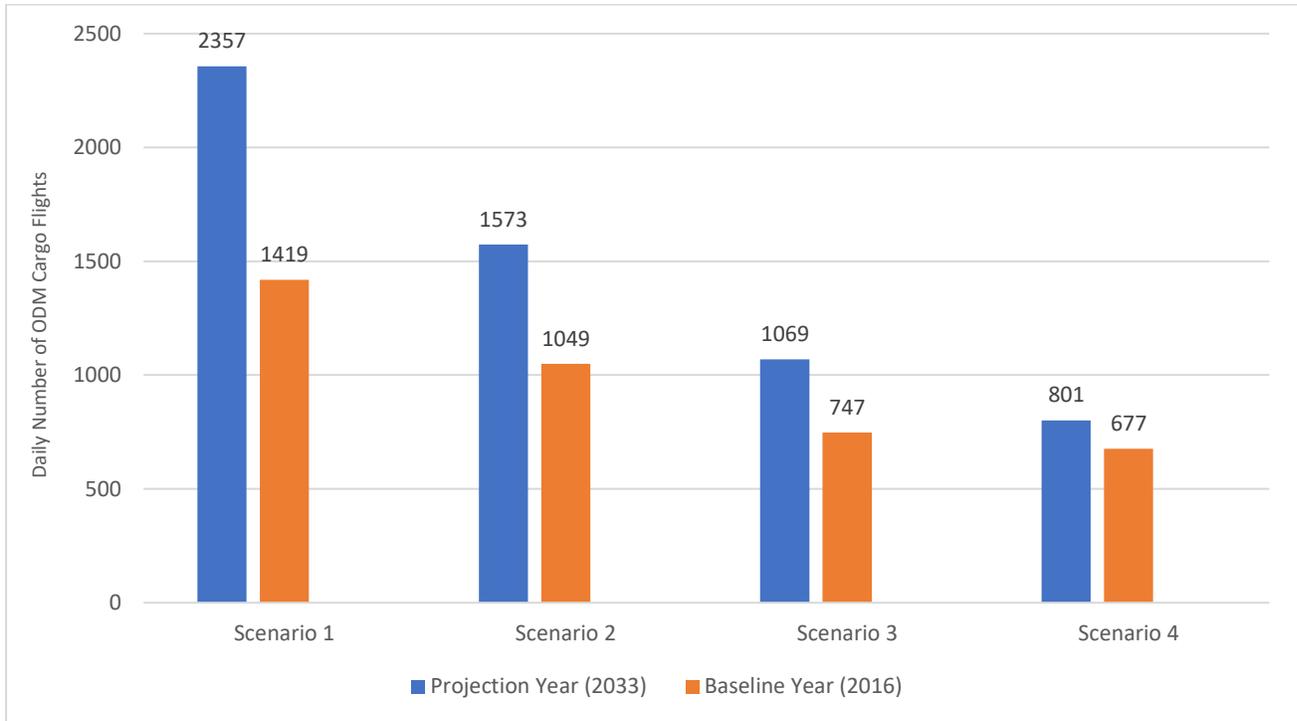


Figure 40: Summary of Potential Cargo ODM Flights in Northern California for Four Scenarios Studied.

The results from all the scenarios corroborate the high sensitivity of ODM cargo flights with respect to market share. Market share of each commodity has individual influencing power. As expected, the nature of commodity is an important parameter in ODM cargo analysis. The change in market share of commodities such as ‘Mail and Express Shipments’ and ‘Small Packaged Freight Shipments’ is more impactful than other commodities in the analysis. Therefore, this study recommends refined analysis on the potential market share of ODM cargo operations with considering the nature of commodity.

Effect of Cargo ODM Operations in Passenger Demand

The concept of ODM cargo operations is complementary to ODM passenger operations. The idea is to use the ODM vehicle in off-peak hours for cargo transport in order to utilize the vehicles more. With more utilization of ODM vehicles, the overall cost of ODM operations would decrease, and benefit will be carried out to ODM passenger services. The reduction in cost will have some effect on passenger demand. Therefore, in this section, we study the effect of cargo ODM flights on passenger ODM demand. Additional flights by eVTOL ODM aircraft, will increase the utilization of the ODM aircraft and hence reduce life cycle cost per mile for passengers using the same vehicles during peak-hour commuting periods. The life-cycle cost used in this analysis is briefly described in the next section.

Life Cycle Cost Model (developed during ODM passenger study)

A Life Cycle Cost (LCC) model was developed to estimate the cost per passenger mile for each ODM vehicle operating in the study area. The LCC model was developed in STELLA Architect - a Systems Dynamics tool developed by High-Performance Systems (HPS, 2018). The LCC model has an interface created to facilitate making sensitivity runs of various ODM aircraft operational factors. The Systems Dynamics LCC model tracks aircraft costs over the life cycle of operations to estimate an hourly operating cost. The model considers the following cost categories:

- Facilities cost (hangar, office space and landing site)
- Periodic costs (engine, paint, refurbishing, avionics, mid-life inspection, etc.)
- Variable costs (fuel, oil, parts, miscellaneous, maintenance, etc.)
- Fixed costs (hull insurance, liability, maintenance software, property tax)
- Personnel costs (we assumed a pilot-less vehicle in the study)

- Training costs (initial, maintenance, recurrent training, etc.)
- Capital and amortization costs (percent resale value, interest rate, purchase cost)
- Airline administrative cost

Figure 41 shows the interface of the LCC model for a four-seat ODM vehicle powered by electric engines. In the life-cycle cost analysis, we assumed a 20-year life-cycle. Using a purchase cost of \$750,000 per ODM aircraft, the LCC cost per hour is estimated to be \$207 per hour.

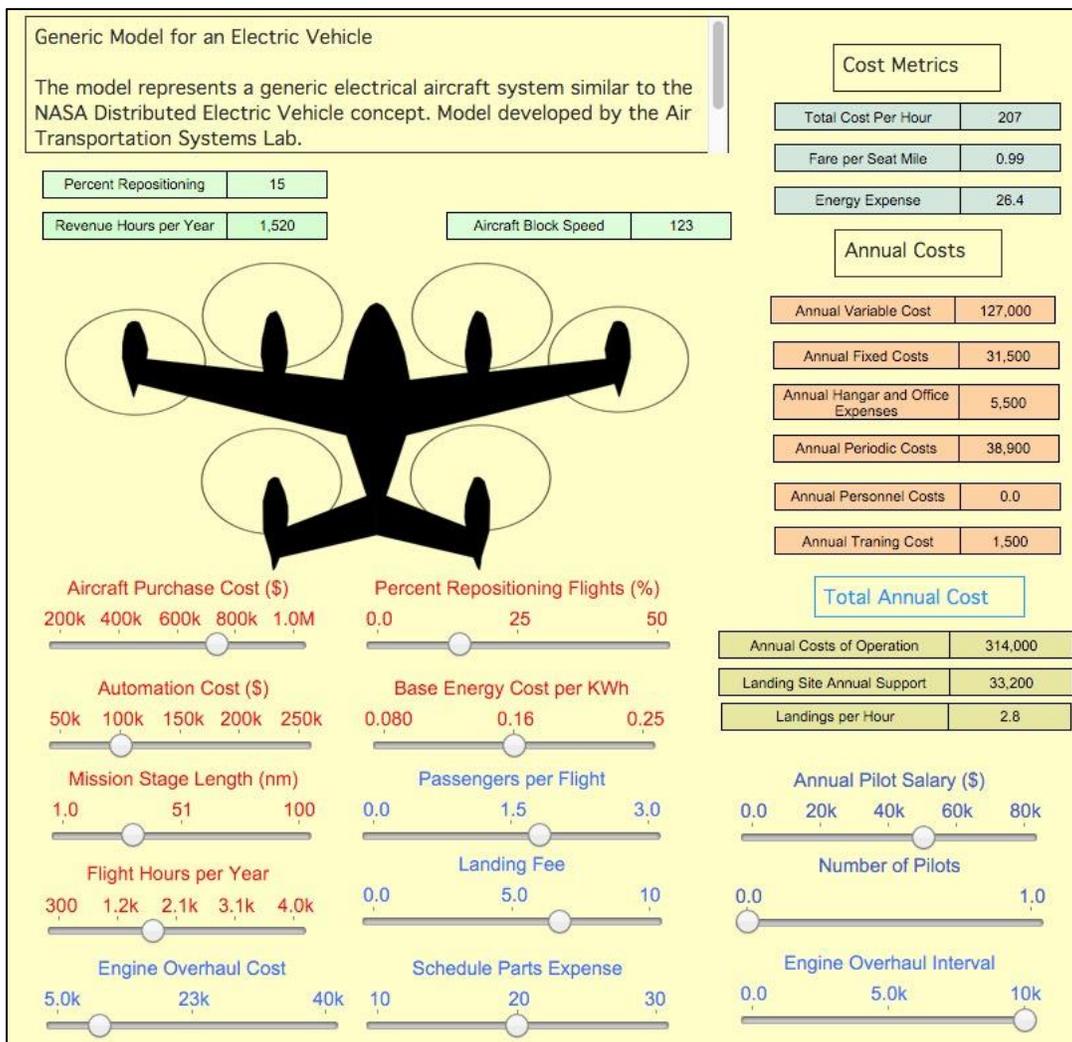


Figure 41: Life Cycle Cost Model User Interface for an ODM Vehicle Concept.

Table 15: Relevant Parameters for Passenger and Cargo ODM Vehicle Life Cycle Cost Model.

| Parameter | Value | Remarks |
|--|-------------------|---|
| Aircraft Baseline Cost (\$) | 800,000 | Estimated for eVTOL aircraft |
| Aircraft Seats | 4 | |
| Pilot Salary (\$) | 50,000 | 25% benefits (zero cost for autonomous UAS VTOL operations) |
| Engine Overhaul Cost (\$) | 10,000 per engine | Electric engine (6 engines) |
| Engine Overhaul Interval | 10,000 | Time between engine overhauls |
| /Flight Hours per Year (hr.) | 1,000 to 3,000 | Parametric analysis |
| Maintenance Man Hours per Flight Hour (hours) | 0.40 | Assumes a mature reliable vehicle |
| Load Factor per Flight (dim) | 0.60 | Fraction of number of seats occupied |
| Electric energy cost (\$/kWhr) | 0.16 | California rates in 2017 |
| Maintenance Labor Expense per Hour (\$/hr) | 50 | Typical for GA aircraft maintenance |
| Modernization Time Interval (hr.) | 3,000 | |
| Modernization and Upgrades Cost (hr.) | 12,000 | Cabin renovation is estimated separately |
| ODM Passenger/Cargo Service Provider Profit Margin (%) | 10 | Initial assumption |

Figure 42 shows the cost per seat-mile for the ODM VTOL aircraft as a function of the number of hours flown. The plot shows trends in cost per passenger mile when the number of hours of use of the aircraft increases from 1,000 to 3,000 hours per year. The results also show variations in passenger cost per mile as a function of the percent of repositioning flights. It is instructive to show that if cargo operations are conducted with the passenger ODM aircraft during off-peak hours, the cost per passenger mile is reduced for each passenger using the ODM vehicle during the commuting peak hours. The analysis is presented in Section 5 of the report. Figure 42 shows substantial changes in cost per passenger mile if the number of repositioning flights increases from 15% to 35%.

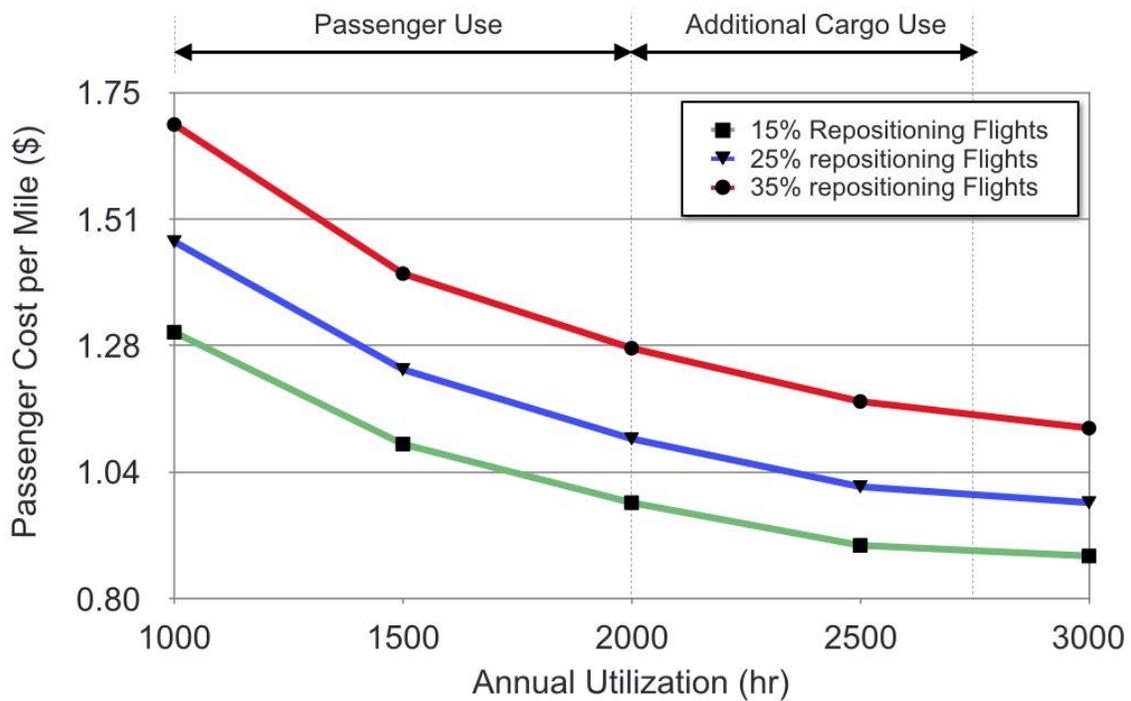


Figure 42: Estimated Life Cycle Cost Results for an all-Electric ODM Vehicle. Sensitivity concerning Annual Use of the ODM Vehicle.

Effect of Cargo ODM Operations on Passenger ODM System

Depending upon the assumptions made about the number of repositioning flights (see Figure 42) a 10% reduction in passenger ODM cost per mile may be achieved flying the vehicle an additional 500-750 hours per year. The effect of cargo ODM operations in passenger demand was studied on two scenarios from passenger study, one high demand, and one low demand scenario. The benefit of even 10% cost reduction in passenger trips came out to be enormous because the passenger ODM mode choice model is very sensitive to changes in cost as the average value of time for a rider in the Bay Area was found to be \$32 per hour.

Figure 43 shows the effect of reducing ODM passenger fares by 5% and 10% for a passenger Scenario with 369 Landing Sites (i.e., airport landing sites were not considered in the passenger ODM service), \$15 Base fare, \$1.23 per passenger mile, \$6.7 landing fee, \$0.30 per mile car cost, 5-mile cutoff distance. According to Figure 43, ODM passenger ridership could increase by 57% if the cost of the fare is reduced by 10%.

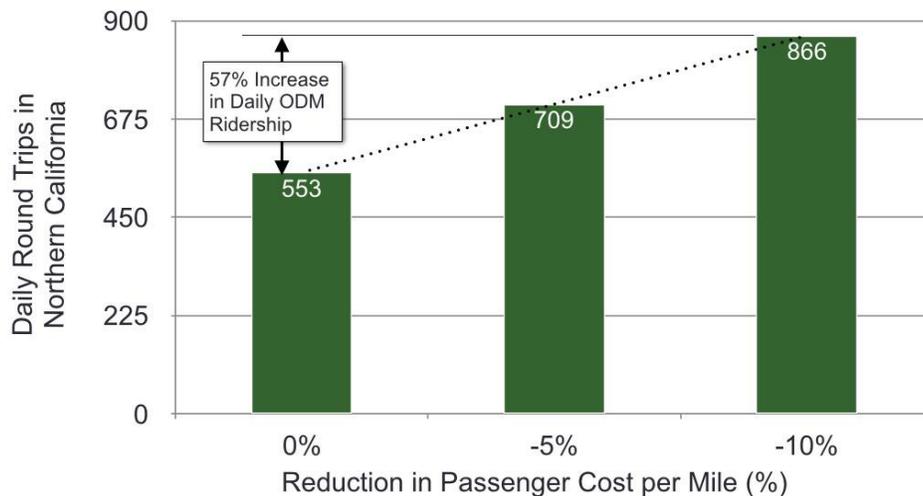


Figure 43: Parametric Effect of ODM Passenger Demand with Reduction in Cost per Passenger Mile. Assumptions: 369 Landing Sites, \$15 Base fare, \$1.23 per passenger mile, \$6.7 landing fee, \$0.30 per mile car cost, 5-mile Cutoff Distance.

Figure 44 shows the effect of reducing ODM passenger fares by 5% and 10% for a passenger Scenario with 369 Passenger Landing Sites, \$20 for a trip up to 20 miles, \$1.23 per mile beyond a 20-mile trip, \$6.7 landing fee, \$0.30 per mile car cost, 5-mile Cutoff Distance. Depending upon the assumptions made about the number of repositioning flights (see Figure 42) a 10% reduction in passenger ODM cost per mile may be achieved flying the vehicle an additional 500-750 hours per year. According to the Figure 44, ODM passenger ridership could be increased by 86% if the cost of the fare is reduced by 10%.

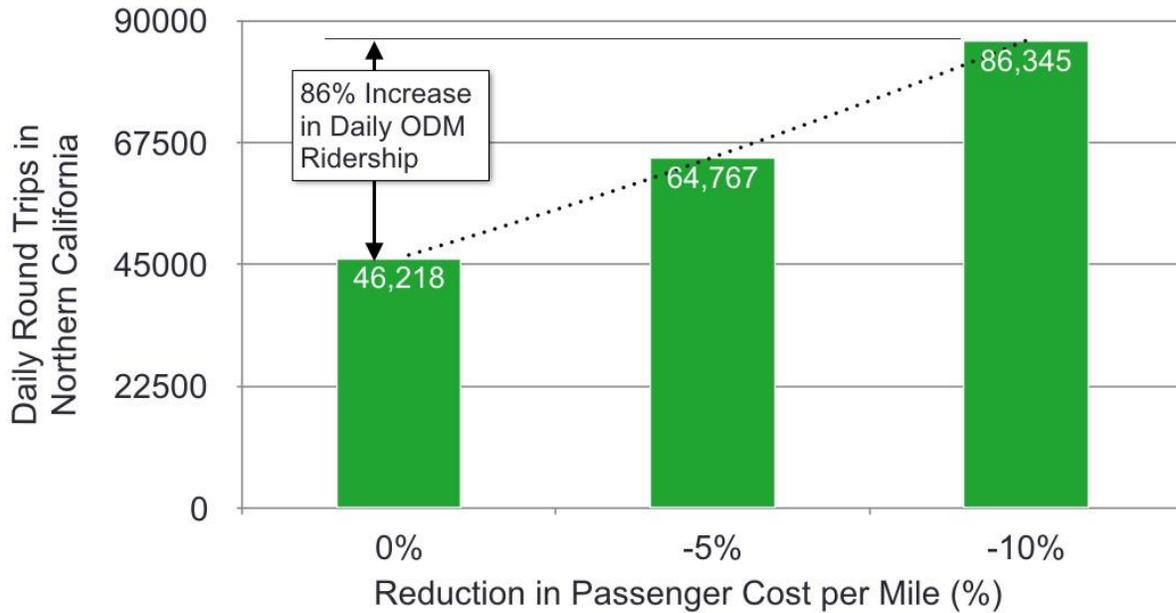


Figure 44: Parametric Effect of ODM Passenger Demand with Reduction in Cost per Passenger Mile. Assumptions: 369 Passenger Landing Sites, \$20 for a trip up to 20 miles, \$1.23 per mile beyond a 20-mile trip, \$6.7 landing fee, \$0.30 per mile car cost, 5-mile Cutoff Distance.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The demand for Cargo On-Demand Mobility is very sensitive to market share it can capture in the system. The parametric analysis concerning market share reveals the uncertainty in the prediction of cargo ODM demand. The cargo choice database is required to estimate the market share of on-demand mobility in freight. Predicting cargo demand using electric VTOL (ODM) vehicles is challenging due to the lack of cargo choice databases and the uncertainty of small package delivery information (i.e., commodity, value, etc.). This study used a combination of Transearch database and T-100 International data to do a first order estimation of cargo flows into the study area. However, neither Transearch nor T-100-I includes private warehouse-to-warehouse cargo flow information that could be relevant to estimate the cargo ODM demand.

It is believed that cargo ODM can compete for current ground modes in a shipment of high valued commodities and can also complement air cargo (both international and domestic) to some extent. On-demand mobility has great potential in urgent air shipments destined to urban areas because as of today only ground modes are available to transport air cargo from airports to the final destination in urban regions.

Market share analysis of cargo ODM operations in the Northern California region indicates that in the year 2033, between 801 to 2,357 daily cargo flights may be possible if the cost of ODM vehicle is modestly competitive with ground transportation modes. The study provided some initial estimates of the impact of reducing the cost per passenger mile for passenger ODM users if ODM vehicle is used in the cargo role at off-peak passenger hours. The passenger demand function is very sensitive to ODM price, and a 10% reduction in passenger ODM cost can have a significant effect on passenger demand in the region.

Market Share:

The results from this study involved a parametric analysis with respect to market share. Different scenarios were generated from low to high demand, and it could be inferred that total demand is highly sensitive to market share. It's difficult to predict market share for concept sub-mode credibly, and it becomes worse for freight or cargo transportation. The data for cargo choice from real sources (companies and consumers) is required for refined analysis for market share which would eventually lead to more credible demand results.

Distribution Methodology:

The distribution methodology used in this analysis considers only demographics (population) due to the lack of other publicly available databases. Such as the location of all warehouses. The hypothesis of the analysis is that people are the ultimate recipients of the cargo flowing into the area of interest. The population surrounding each landing site is used as a landing site “catchment” area. In the follow-up study, we recommend that catchment areas for warehouses and retail space be considered as part of the distribution method.

Landing Site Set:

The landing site selection used a first-order, cost model based on net present value, to eliminate and reduce the number of landing sites in the study area. We recommend a more detail study to understand better the costs associated with typical ODM landing sites and their impact on landing fees and passenger and cargo demand.

Effect on passenger ODM demand:

More insight into the repositioning flights is needed to understand their impact on passenger ODM cost per mile and both passenger and cargo demands. The cost per passenger-mile for the ODM vehicle is very sensitive to the fraction of flights used to re-position vehicles across landing sites. This needs to be investigated in more detail.

Load Factor:

In this study, the load factors were chosen based on the characteristics of the commodity being transferred and mode chosen. A detailed analysis of load factors could influence the potential demand calculation.

ODM Vehicle:

The vehicle used as a reference in this analysis is Joby S4 by Joby Aviation Ltd. The analysis was carried out using the specifications of Joby S4, i.e., capacity: 800 pounds, range: 150 miles. The results of the analysis could significantly change upon selection of other vehicles. Future analysis should consider multiple vehicle types for On-Demand mobility.

International Air Cargo:

The international air cargo moving through San Francisco International Airport doesn't have information about the commodity being transported. Therefore, some crude assumptions were made regarding the potential market share of these shipments. With better and detailed information about commodities being imported and exported, ODM cargo demand can reach more fidelity.

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APPENDIX A

Source Codes

A.1) Cargo distribution for 'Truck' mode flows (county level): Distributing internal cargo flows for truck modes

```
%Script to calculate number of flights from county level internal flows
%Step 1: Calculate county level flows
%Step 2: Calculate number of flights required on county-level to meet the
%demand
close all
clear all
clc

% Load Transearch Data
load('Transearch2016.mat')

%First phase analysis is performed on Baseline year
T_16=Transearch2016(table2array(Transearch2016(:,1))==2016,:);

%load commodity groups in Transearch database
[~,~,commodity_groups]=xlsread('Commodities.xlsx');

%Load Truck Sub-Mode group id's
truck=[4 5 6 7];

%Transearch records corresponding to truck mode only
T_16_T= T_16(ismember(table2array(T_16(:,8)),truck),:);

%Commodities selected for Truck mode analysis
%Jewelry and precious metals, Solid State Semiconductors, Electric Measuring
Instruments, Pharmaceutical equipments, Drugs, Telephone equip

%commodity group id's for above mentioned commodities
com_truck= [4 7 9 11 13 14];

%Market share defined for each commodity (Varies by Scenario)
com_truck_ms=[5 5 5 5 5 5];

%Parsing Truck mode flows for selected commodities in 2016
T_16_T=T_16_T(ismember(table2array(T_16_T(:,4)),com_truck),:);

%Load regions in Transearch database
Regions=readtable('Regions.xlsx');

%Parse Regions in California
Reg_cal=Regions(ismember(table2array(Regions(:,3)), 'CA'),:);
```

```

%Load 'Fips to Regions' table from Transearch database
FipstoRegion=readtable('FipstoRegion.xlsx');

%Phase One: Analyzing Internal flows

T_16_T_internal=
T_16_T(ismember(table2array(T_16_T(:,2)),table2array(Reg_cali(:,1))),:);
T_16_T_internal=
T_16_T_internal(ismember(table2array(T_16_T_internal(:,3)),table2array(Reg_cali(:,1))),:);

%Transearch flows travelling less than or equal to ODM vehicle range are
%only considered in the analysis at the moment.
%ODM vehicle range is 150 miles

range_of_ODM= 150;
T_16_T_odm_internal=T_16_T_internal(table2array(T_16_T_internal(:,12))<=range_of_ODM,:);

%Total number of records remaining in the analysis
no_entries= height(T_16_T_odm_internal);

%Nuber of commodities in the analysis
no_com=length(com_truck);

%Number of analysis in the analysis
no_reg= height(Reg_cali);

flows=struct();

%Generating fieldnames for the structure deleting punctuations and spaces
all_com_names=regexprep(commodity_groups(:,1), '[, \'.]', '');
all_com_names=regexprep(all_com_names, '\s+', '');

%Calculating county level flows (17*17 matrix)

for i=1:no_com

    %temp flows by each commodity
    temp_T_16_T_odm_internal=
T_16_T_odm_internal(ismember(table2array(T_16_T_odm_internal(:,4)),com_truck(i)),:);

    %Allocating space for temp flows
    flows.(all_com_names{com_truck(i),1})=zeros(no_reg,no_reg);

    %Calculating regional flows for each commodity group
    for j=1:no_reg

        temp_T_16_reg=
temp_T_16_T_odm_internal(ismember(table2array(temp_T_16_T_odm_internal(:,2)),table2array(Reg_cali(j,1))),:);

        if isempty(temp_T_16_reg)

```

```

        %if no flows originating from region (by commodity)
        flows.(all_com_names{com_truck(i),1})(j,:)=0;

    else

        %Number of unique destinations for temp origin county
        dest= unique(table2array(temp_T_16_reg(:,3)));

        %Number of unique destinations
        no_dest=length(dest);

        %flows to all unique destinations (aggregated)
        for k=1:no_dest

            %index of transearch records corresponding to destination
            region
            temp_ind= find(table2array(temp_T_16_reg(:,3))==dest(k));

            %Cumulative tonnage of all entries to destination county
            temp_tons= sum(table2array(temp_T_16_reg(temp_ind,9)));

            %index of destination region in the regions table of
            transearch
            ind_region=find(table2array(Reg_cali(:,1))==dest(k));

            %Allocating aggregated flows to flows' matrix
            flows.(all_com_names{com_truck(i),1})(j,ind_region)=temp_tons;

            %clearing temp variables
            clear temp_tons temp_ind ind_region
        end

        %clearing temp variables
        clear temp_T_16_reg dest

    end

end

%clearing temp variables
clear temp_T_16_T_odm_internal

end

%Parsing region level flows to only concerned flows (17 counties in the
%study area). Transearch involves 25 regions. Out of 25, 17 are the
%counties in the analysis

for i=1:no_com

flows_county.(all_com_names{com_truck(i),1})=flows.(all_com_names{com_truck(i)
),1})(9:25,9:25);
end

```

```

%-----
%Step 2: calculating the number of ODM cargo flights required for above
%calculated flows (share of flows)

%Load counties in the analysis
load('county_name.mat')

%number of counties in the analysis
counties_in_study=length(county_name);

%Defining ODM vehicle characteristics

% ODM vehicle capacity in metric tons
ODM_capacity= 0.4;

%Load factor for flights competing truck mode
load_factor=0.75;

%Number of working days in one annual year
no_days=250;

%allocating space
no_flights_combined=zeros(counties_in_study,counties_in_study);

%Calculating flights by commodity and combined too
%flights_internal_truck_L150 by commodity and no_flights_combined for all
%commodities combined

for i=1:no_com

    %flows by commodity
    temp_com_flow=flows_county.(all_com_names{com_truck(i),1});

    %market share for that commodity
    temp_ms=com_truck_ms(i);

    %calculating daily number of flights

no_flights=((temp_com_flow*temp_ms)./(100*no_days*load_factor*ODM_capacity));

    %commodity wise number of flights
    flights_internal_truck_L150.(all_com_names{com_truck(i),1})=no_flights;

    %combined number of flights

no_flights_combined=no_flights_combined+(temp_com_flow*temp_ms)./(100*no_days
*load_factor*ODM_capacity);

end

%the output is further used in m*n distribution of county level flows

```

A.2) Distribution factor: calculating distribution factor for each landing site in the study area

```
%Script to calculate distribution factor for distributing county level flows  
%to landing sites in the study area (methodology explained in cargo  
%distribution model)
```

```
%The input for this calculation requires 2010 census block group  
%information for the study area and the final set of landing sites selected  
%for the analysis
```

```
%clearing space  
close all  
clear all  
clc
```

```
%Load census block group information for study area  
readtable('censusBG.xlsx')
```

```
%census block group coordinates (study area {17 counties} block groups)  
census_BG_coor=[table2array(censusBG(:,4)),table2array(censusBG(:,5))];
```

```
%Load landing site set information  
readtable('LS.xlsx')
```

```
%Landing site coordinates (latitude/longitude)  
LS_coor=[table2array(LS(:,3)),table2array(LS(:,2))];
```

```
%Number of census block groups  
no_censusBG=length(census_BG_coor);
```

```
%Connecting each census block group to nearest landing site  
%finding nearest landing site using dsearchn function
```

```
%connected ls set  
%format: connected_LS LS_lat LS_long (LS:landing site)  
connected_ls_set=zeros((no_censusBG),3);
```

```
for i=1:no_censusBG
```

```
    %finding nearest landing site  
    k=dsearchn(LS_coor,census_BG_coor(i,:));
```

```
    %id of the connected (nearest) landing site  
    connected_ls_set(i,1)= table2array(LS(k,1));
```

```
    %Latitude of the connected (nearest) landing site  
    connected_ls_set(i,2)= LS_coor(k,1); %LS lat
```

```
    %longitude of the connected (nearest) landing site  
    connected_ls_set(i,3)= LS_coor(k,2); %LS long
```

```
end
```

```

%all connected landing sites
con_ls=connected_ls_set(:,1);

%number of landing sites connected to atleast one census block groups
no_of_con=tabulate(con_ls);

%removing landing site not connected to any block group
no_of_con((no_of_con(:,2)==0),:)=[];

%Calculating cummulative population of catchment are for each landing site
%catchment area is number of census block groups connected to each landing
%site

for i=1:length(no_of_con)

    %finding index (or coordinates) of landing site in ls set
    temp_ind=find(connected_ls_set(:,1)==no_of_con(i));

    %cummulative population of connected census block groups
    temp_pop=sum(table2array(censusBG(temp_ind,7)));

    %assinging population to connected landing site set
    no_of_con(i,4)=temp_pop;

    %clearing temp index
    clear temp_ind

end

%finding distribution factor: extracting LS id and population of catchment
%area
LS_set=no_of_con(:,[1 4]);

%creating ls set with cummulative population and coordinates
for i=1:length(LS_set)
    temp_ind=find((LS_set(i,1)==table2array(LS(:,1))));
    LS_set(i,3)=LS_coor(temp_ind,1);
    LS_set(i,4)=LS_coor(temp_ind,2);
end

%Segregation of landing site on the basis on spatial loaction is important
%to distribute county level flows to landing sites

%Reading study area shapefile from ArcGis

%extracting useful information from the shapefile
cali_counties=shaperead('Export_Output.shp');
[~,index] = sortrows({cali_counties.NAME}.');
cali_counties = cali_counties(index);
clear index

%selecting counties from the california state (17 counties of study area)
study_area_index=[1, 7, 21, 24, 27:28, 34:35, 38:39, 41, 43:44, 48:50, 57];

%extracting information only for study area counties
Study_counties=cali_counties(study_area_index);

```

```

%Segregating landing sites by location in the counties

for i=1:length(Study_counties)

    %temp county
    temp_county=Study_counties(i).';

    %Finding landing sites in temp county
    in=inpolygon(LS_set(:,3),LS_set(:,4),(temp_county.Y)',(temp_county.X)');

    %landing site id found inside temp county
    id=(LS_set((in==1),1));

    %name of temp county
    temp_name=regexprep(temp_county.NAME, '\s+', '');
    county_name{i}=(temp_name);

    %assing landing site ids to county
    LS_in_counties.(temp_name).landing_site_id=id;
    LS_in_counties.(temp_name).landing_site_ind=find(in==1);

    %clearing temp variables
    clear temp
end

%Number of counties
no_counties=length(fieldnames(LS_in_counties));

%creating landing site structure (all landing sites) with distribution factor

for i=1:17
    %temp_county
    temp_struct=LS_in_counties.(county_name{i}).';

    %total population of county
    temp_tot_pop=sum(LS_set(temp_struct.landing_site_ind,2));

    for j=1:length(temp_struct.landing_site_id)
        %distribution factor calculation

temp_struct.landing_site_id(j,2)=LS_set(temp_struct.landing_site_ind(j),2)/te
mp_tot_pop;
    end
    %assinging df

LS_in_counties.(county_name{i}).comb=[temp_struct.landing_site_id,temp_struct
.landing_site_ind];
end

```

A.3) M by N distribution for internal cargo flows from Truck mode

```
%Script to generate m*n distribution for county level flows
%input is county level number of ODM cargo flights from truck mode

%load county level ODM flights
load('no_flights_combined.mat')

%load distribution factor for landing site set (LS_in_counties)
load('LS_in_counties.mat')

%flights by counties (17*17 counties)
all_flights=no_flights_combined;

%counties in study
county_name=counties_in_study;

%number of counties
no_counties=length(all_flights);

%distributing each county level flow into landing site between two counties

for i=1:no_counties

    %all flights from origin county
    temp_county_flights=all_flights(i,:);

    %landing site in origin county
    temp_origin_LS=LS_in_counties.(county_name{i}).comb;

    for j=1:no_counties

        %if origin is destination county (intracounty flows)
        if j==i
            temp_county2county_flights=temp_county_flights(j);

            %destination ls set
            temp_dest_LS=LS_in_counties.(county_name{j}).comb;

            %number of landing sites in origin county
            no_ls_origin=length(temp_origin_LS(:,1));

            %number of landing sites in destination county
            no_ls_dest=length(temp_dest_LS(:,1));

            temp_flows=zeros(no_ls_origin,no_ls_dest);

            %distributing flows from each landing site in origin county to
            %desitnation county using the distribution factor of ls in
            %destination county

temp_distributed_flights=temp_county2county_flights.*(temp_dest_LS(:,2));

            for k=1:no_ls_dest
                temp_origin_LS_set=temp_origin_LS(:,2);
```

```

        temp_origin_LS_set(k)=0;

        %further distributing

temp_flows(:,k)=temp_distributed_flights(k).*(temp_origin_LS_set);

        %clearing temp variable
        clear temp_origin_LS_set
    end

        %final structure of distributed flights

internal_flights.(county_name{i}).([county_name{i}, 'to', county_name{j}])=temp
_flows;

    else
        %intercounty flows (origin county and destination county are d
        %ifferent)
        temp_county2county_flights=temp_county_flights(j);

        %destination ls set
        temp_dest_LS=LS_in_counties.(county_name{j}).comb;

        %number of landing sites in origin county
        no_ls_origin=length(temp_origin_LS(:,1));

        %number of landing sites in destination county
        no_ls_dest=length(temp_dest_LS(:,1));

        temp_flows=zeros(no_ls_origin,no_ls_dest);

temp_distributed_flights=temp_county2county_flights.*(temp_dest_LS(:,2));

        for k=1:no_ls_dest

            %further distributing

temp_flows(:,k)=temp_distributed_flights(k).*(temp_origin_LS(:,2));
        end

            %final structure of distributed flights

internal_flights.(county_name{i}).([county_name{i}, 'to', county_name{j}])=temp
_flows;

        end
    end
end

%the output is further used in generating OD pair for daily ODM cargo
%flights

```

A.4) Cargo flows distribution for 'Air' Mode flows

```
%This script is used to distribute cargo received by counties from "AIR"  
%mode to landing sites  
%the 'air' mode cargo moves through nearest airport  
%ODM sub-mode has potential in delivering cargo from airports to landing  
%sites  
%-----  
  
%Load transearch data (2016) for air mode only  
load('.\Transearch2016_air_w_dist.mat')  
  
%Commodities selected for Air mode (methodology in text)  
%Fish and marine products, drugs, mail and express traffic, small packaged  
%freight shipments, Pharmaceutical equipment and EMI  
  
%commodity groups in transearch  
[~,~,commodity_groups]=xlsread('Commodities.xlsx');  
  
%commodity groups id for air mode  
com_air= [1 4 7 13 21 27];  
  
%market share for selected commodities respectively. SCENARIO DEPENDENT.  
com_air_ms=[10 5 5 5 20 20];  
  
%Transearch air mode data only for selected commodities  
T_16_A=T_16(ismember(table2array(T_16(:,4)),com_air),:);  
  
%Regions in Transearch database  
Regions=readtable('Regions.xlsx');  
  
%Regions in Cali  
Reg_cali=Regions(ismember(table2array(Regions(:,3)), 'CA'),:);  
  
%Fips to Regions table in Transearch database  
FipstoRegion=readtable('FipstoRegion.xlsx');  
  
%The internal flows are divided in two parts: within ODM vehicle range and  
%otherwise  
%Limited records and non feasibility of air mode in short distance  
  
%Internal flows  
T_16_A_internal=  
T_16_A(ismember(table2array(T_16_A(:,2)),table2array(Reg_cali(:,1))),:);  
T_16_A_internal=  
T_16_A_internal(ismember(table2array(T_16_A_internal(:,3)),table2array(Reg_ca  
li(:,1))),:);  
  
%range of ODM vehicle  
range_of_ODM= 150;  
  
%Within ODM Range  
T_16_A_odmrange_internal=T_16_A_internal(table2array(T_16_A_internal(:,12))<=  
range_of_ODM,:);  
  
%Outside ODM range (Pseudo external flows: Behave similar to external flows)
```

```

T_16_A_nonodmrange_internal=T_16_A_internal(table2array(T_16_A_internal(:,12)
)>range_of_ODM,:);

%number of commodities
no_com=length(com_air);

%number of regions
no_reg= height(Reg_cali);
flows=struct();

%generating fieldnames
%deleting punctuations
all_com_names=regexprep(commodity_groups(:,1), '[, \'.]', '');
%deleting spaces
all_com_names=regexprep(all_com_names, '\s+', '');

%-----
%-----
%extracting external flows which are critical for analysis of 'air' mode
shipments
%External flows

%freight flowing out of study area is production and freight incoming is
%attraction

T_16_A_external=
T_16_A(ismember(table2array(T_16_A(:,2)),table2array(Reg_cali(:,1))),:);

%production
T_16_A_external_prod=
T_16_A_external(~ismember(table2array(T_16_A_external(:,3)),table2array(Reg_c
ali(:,1))),:);

T_16_A_external2=T_16_A(ismember(table2array(T_16_A(:,3)),table2array(Reg_cal
i(:,1))),:);

%attraction
T_16_A_external_att=
T_16_A_external2(~ismember(table2array(T_16_A_external2(:,2)),table2array(Reg
_cali(:,1))),:);

%-----
%-----
%External flows for attraction with psuedo external flows (from internal
flows)
external_all_com_odm_att_w_internal_nonodmrange=0;

%External flows for production with psuedo external flows (from internal
flows)
external_all_com_odm_prod_w_internal_nonodmrange=0;

for i=1:no_com

```

```

    %flows by commodity
    %attraction
    temp_T_16_A_external_att=
T_16_A_external_att(ismember(table2array(T_16_A_external_att(:,4)),com_air(i)
),:);

    %production
    temp_T_16_A_external_prod=
T_16_A_external_prod(ismember(table2array(T_16_A_external_prod(:,4)),com_air(
i)),:);

temp_T_16_A_nonodmrange_internal=T_16_A_nonodmrange_internal(ismember(table2a
rray(T_16_A_nonodmrange_internal(:,4)),com_air(i)),:);

    %market share of commodity in loop
    temp_com_air_ms=com_air_ms(i);

    for j=1:no_reg

        %regional flows attraction and prodcutio
        %index in region table

temp_reg_ind=temp_T_16_A_external_att(ismember(table2array(temp_T_16_A_extern
al_att(:,3)),table2array(Reg_cali(j,1))),:);

temp_reg_ind2=temp_T_16_A_external_prod(ismember(table2array(temp_T_16_A_exte
rnal_prod(:,2)),table2array(Reg_cali(j,1))),:);

        %index in region table for psuedo external flows

temp_reg_ind3=temp_T_16_A_nonodmrange_internal(ismember(table2array(temp_T_16
_A_nonodmrange_internal(:,3)),table2array(Reg_cali(j,1))),:);

temp_reg_ind4=temp_T_16_A_nonodmrange_internal(ismember(table2array(temp_T_16
_A_nonodmrange_internal(:,2)),table2array(Reg_cali(j,1))),:);

        %Share of cargo transported by ODM vehicle (based on market share
        %assumed)
        %attraction
        if ~isempty(temp_reg_ind)
            %destination region exist

external_att.(all_com_names{com_air(i),1})(j)=sum(table2array(temp_reg_ind(:,
9)));

external_att_odm.(all_com_names{com_air(i),1})(j)=temp_com_air_ms*sum(table2a
rray(temp_reg_ind(:,9)))/100;
        else
            external_att.(all_com_names{com_air(i),1})(j)=0;
            external_att_odm.(all_com_names{com_air(i),1})(j)=0;
        end

        %production
        if ~isempty(temp_reg_ind2)

```

```

external_prod.(all_com_names{com_air(i),1})(j)=sum(table2array(temp_reg_ind2(
: ,9)));

external_prod_odm.(all_com_names{com_air(i),1})(j)=temp_com_air_ms*sum(table2
array(temp_reg_ind2(:,9)))/100;
else
external_prod.(all_com_names{com_air(i),1})(j)=0;
external_prod_odm.(all_com_names{com_air(i),1})(j)=0;
end

%siilarly for psuedo external flows
if ~isempty(temp_reg_ind3)

internal_nonodmrange_att.(all_com_names{com_air(i),1})(j)=sum(table2array(tem
p_reg_ind3(:,9)));

internal_nonodmrange_att_odm.(all_com_names{com_air(i),1})(j)=temp_com_air_ms
*sum(table2array(temp_reg_ind3(:,9)))/100;
else
internal_nonodmrange_att.(all_com_names{com_air(i),1})(j)=0;
internal_nonodmrange_att_odm.(all_com_names{com_air(i),1})(j)=0;
end

if ~isempty(temp_reg_ind4)

internal_nonodmrange_prod.(all_com_names{com_air(i),1})(j)=sum(table2array(te
mp_reg_ind4(:,9)));

internal_nonodmrange_prod_odm.(all_com_names{com_air(i),1})(j)=temp_com_air_m
s*sum(table2array(temp_reg_ind4(:,9)))/100;
else
internal_nonodmrange_prod.(all_com_names{com_air(i),1})(j)=0;
internal_nonodmrange_prod_odm.(all_com_names{com_air(i),1})(j)=0;
end

end

end

%Combined external flows includes both external and psuedo external flows
%Commodity wise cargo flows for ODM sub mode

for i=1:no_com

%combined flow for attraction

external_att_odm_comb.(all_com_names{com_air(i),1})=external_att_odm.(all_com
_names{com_air(i),1})(9:25)...
+internal_nonodmrange_att_odm.(all_com_names{com_air(i),1})(9:25);

%combined flow for production

external_prod_odm_comb.(all_com_names{com_air(i),1})=external_prod_odm.(all_c
om_names{com_air(i),1})(9:25)...
+internal_nonodmrange_prod_odm.(all_com_names{com_air(i),1})(9:25);

```

```

end

%all commodity combined flows (both external and psudeo external flows) for
%study area region (17 counties)
for i=9:25
    temp_com_att=0;
    temp_com_prod=0;

    for j=1:no_com

temp_com_att=temp_com_att+external_att_odm.(all_com_names{com_air(j),1})(i)+i
nternal_nonodmrange_att_odm.(all_com_names{com_air(j),1})(i);

temp_com_prod=temp_com_prod+external_prod_odm.(all_com_names{com_air(j),1})(i
)+internal_nonodmrange_prod_odm.(all_com_names{com_air(j),1})(i);
        end
        %attraction
        external_all_com_odm_att_w_internal_nonodmrange(i-8)=temp_com_att;
        %production
        external_all_com_odm_prod_w_internal_nonodmrange(i-8)=temp_com_prod;
    end

end

%-----
%Airport assignment (methedology in text)
%each county is assigned to an airport

%airports selected
Dist_airports=readtable('distribution_airports.xlsx');

%number of region
no_reg=17;

%capacity of odm vehicle
odm_capacity=0.4; %metric tons

%number of working days in a year
no_days=250;

%load factor for selected commoditeis respectively (reason in text)
load_factor=[0.6 0.6 0.65 0.65 0.5 0.5];

%Load distribution factor for each county
load('distribution_factor_new.mat')

counties_in_study=fieldnames(LS_in_counties);

%calculation of number of ODM cargo flights from flows calculated

for i=1:no_reg

    temp_reg_ind=i;

    %no of flights for attraction on county level
    temp_no_flights_all_com_att=0;

```

```

%no of flights for production on county level
temp_no_flights_all_com_prod=0;

%no of flights for attraction at each landing site
temp_no_flights_all_com_att_distributed=0;

%no of flights for production at each landing site
temp_no_flights_all_com_prod_distributed=0;

%landing site set in the region (loop)
temp_landing_sites=LS_in_counties.(counties_in_study{i}).comb;

%commodity wise
for j=1:no_com

    %temp attraction and production
    temp_att=external_att_odm_comb.(all_com_names{com_air(j),1})(i);
    temp_prod=external_prod_odm_comb.(all_com_names{com_air(j),1})(i);

    %number of flights commodity wise for whole county (attraction and
    %production)
    no_flights_air_external_att.(all_com_names{com_air(j),1})(i)=
temp_att/(no_days*odm_capacity*load_factor(j));

    no_flights_air_external_prod.(all_com_names{com_air(j),1})(i)=
temp_prod/(no_days*odm_capacity*load_factor(j));

    %number of flights for all commodities (whole county), production
    %and attraction

temp_no_flights_all_com_att=temp_no_flights_all_com_att+no_flights_air_extern
al_att.(all_com_names{com_air(j),1})(i);

temp_no_flights_all_com_prod=temp_no_flights_all_com_prod+no_flights_air_exte
rnal_prod.(all_com_names{com_air(j),1})(i);

    %amount of distributed cargo (commodity wise) production and
    %attraction

distributed_cargo_att.(counties_in_study{i}).(all_com_names{com_air(j),1})=te
mp_att.*(temp_landing_sites(:,2));

distributed_cargo_prod.(counties_in_study{i}).(all_com_names{com_air(j),1})=t
emp_prod.*(temp_landing_sites(:,2));

    %calculating number of flights required to meet the figure of
    %distribtued cargo
    %attraction of flights

temp_att_dist=distributed_cargo_att.(counties_in_study{i}).(all_com_names{com
_air(j),1});

    %production no of flights

temp_prod_dist=distributed_cargo_prod.(counties_in_study{i}).(all_com_names{c
om_air(j),1});

```

```

distributed_no_of_flights_att.(counties_in_study{i}).(all_com_names{com_air(j),1})=temp_att_dist/(no_days*odm_capacity*load_factor(j));

distributed_no_of_flights_prod.(counties_in_study{i}).(all_com_names{com_air(j),1})=temp_prod_dist/(no_days*odm_capacity*load_factor(j));

end

%Number of flights for each commodity combined in the county attraction
%and production
no_flights_all_com_att(i)=(temp_no_flights_all_com_att);

no_flights_all_com_prod(i)=(temp_no_flights_all_com_prod);

end

%all flights combined
no_flights_comb_air=(no_flights_all_com_att+no_flights_all_com_prod);

%finding amount of cargo moving through odm sub mode at each landing site
%by commodity for both attraction and production

for i=1:length(counties_in_study)

    %amount of cargo commodity wise (prod and att)
    temp_county_att=distributed_cargo_att.(counties_in_study{i});
    temp_county_prod=distributed_cargo_prod.(counties_in_study{i});

    %landing site set in the county
    temp_landing_sites=LS_in_counties.(counties_in_study{i}).comb;

    for j=1:length(temp_landing_sites(:,1))
        for k=1:no_com
            %cargo flowing through ls by commodity
            if (temp_county_att.(all_com_names{com_air(k),1})(j)~=0)

Distribution_att.(counties_in_study{i}).(['LS',num2str(temp_landing_sites(j,1))]).(all_com_names{com_air(k),1})=temp_county_att.(all_com_names{com_air(k),1})(j);

                end
                if (temp_county_prod.(all_com_names{com_air(k),1})(j)~=0)

Distribution_prod.(counties_in_study{i}).(['LS',num2str(temp_landing_sites(j,1))]).(all_com_names{com_air(k),1})=temp_county_prod.(all_com_names{com_air(k),1})(j);

                end
            end
        end
    end

end

end

```

```

%calculating number of flights required at each landing site with all
%commodity combined
for i=1:length(counties_in_study)
    %attracted number of flights

temp_county_no_flights_att=distributed_no_of_flights_att.(counties_in_study{i
});

    %produced number of flights

temp_county_no_flights_prod=distributed_no_of_flights_prod.(counties_in_study
{i});

    %landing site set in the county
temp_landing_sites=LS_in_counties.(counties_in_study{i}).comb;

    for j=1:length(temp_landing_sites(:,1))
        temp_no_flights_counter_att=0;
        temp_no_flights_counter_prod=0;

        for k=1:6

temp_no_flights_counter_att=temp_no_flights_counter_att+(temp_county_no_fli
hts_att.(all_com_names{com_air(k),1})(j));

temp_no_flights_counter_prod=temp_no_flights_counter_prod+(temp_county_no_fli
ghts_prod.(all_com_names{com_air(k),1})(j));
            end
            %total number of flights for landing sites all commodities combined
            %production and attraction

no_flights_att.(counties_in_study{i}).(['LS',num2str(temp_landing_sites(j,1)
)])=temp_no_flights_counter_att;

no_flights_prod.(counties_in_study{i}).(['LS',num2str(temp_landing_sites(j,1)
)])=temp_no_flights_counter_prod;
        end
    end

%the output will be used in generating origin destination pairs for air
%mode cargo shipments

```

A.5) Origin Destination pair generator for truck mode flows

%This script generates the OD pairs from daily demand of ODM cargo flights
%at each landing site for Truck mode through random number generator

```
close all
clear all
clc

%load the m*n distribution result (internal_flights)
load('MN_distribution_result.mat');

%load commodities names
load('fieldnames.mat')

all_com_names=fieldnames;

clear fieldnames

%Load the new landing site set
LS_set=readtable('new_coordinates_wo_dp.xls','ReadVariableNames',true);

%load the distribution factor for each landing site
load('distribution_factor_new.mat')

%all counties in the analysis
counties=fieldnames(LS_in_counties);

%number of counties
no_counties=length(counties);

%random number benchmark
rng(0);
internal_all_counties=[];
for i=1:no_counties

    %internal flows between counties (m*n distribution)
    temp_county_flights=internal_flights.(counties{i});

    temp_fieldnames=fieldnames(temp_county_flights);

    no_counties_pairs=length(temp_fieldnames);

    %origin landing site id
    LS_origin_id=LS_in_counties.(counties{i}).landing_site_id;

    temp_int_flight_full_county=[];
    for j=1:no_counties_pairs

        %county to county flows
        temp_county2county=temp_county_flights.(temp_fieldnames{j});

        %destination landing site id
        LS_dest_id=LS_in_counties.(counties{j}).landing_site_id;

        %size of county 2 county flow is total number of flights
```

```

[no_origin_ls,no_dest_ls]=size(temp_county2county);
temp_int_flight_county=[];

%flights from each landing site in origin county to each landing
%site in the destination county

for k=1:no_origin_ls

    %origin ls id
    temp_flight_origin_ls=(temp_county2county(k,:))';
    temp_int_flight=[];

    %to each landing site in destination county
    for l=1:no_dest_ls

        %number of daily flight between OD pair (0.37 or 5.43 etc.)
        temp_flight_pair=temp_flight_origin_ls(l);

        %absolute number of flights between this set of landing
        %site ids
        no_abs=floor(temp_flight_pair);
        no_prob=temp_flight_pair-no_abs;

        %random number to decide the fractional part of demand
        random_no(l)=rand();
        if random_no(l)<=no_prob

            %fractional part converts to a flight
            flag=1;
        else
            %fractional part doesn't convert to a flight
            flag=0;
        end

        no_flights_pair=no_abs+flag;

        %assigning od pair according to number of flight
        if no_flights_pair==1

            %single od pair
            temp_od=[LS_origin_id(k) LS_dest_id(l)];

        elseif no_flights_pair>1

            %multiple OD pairs
            temp_od=[0 0];
            ind=1;

            while ind<=no_flights_pair

                temp_od(ind,:)= [LS_origin_id(k) LS_dest_id(l)];

                ind=ind+1;
            end
        else
            temp_od=[0 0];
        end
    end
end

```

```

        temp_int_flight=vertcat(temp_int_flight,temp_od);
    end

temp_int_flight_county=vertcat(temp_int_flight_county,temp_int_flight);
    end
    %full county OD pair aggregated

temp_int_flight_full_county=vertcat(temp_int_flight_full_county,temp_int_flight_county);
    end
    %all counties OD pair aggregated for TRUCK mode

internal_all_counties=vertcat(internal_all_counties,temp_int_flight_full_county);
end

internal_flights_all_counties_OD=internal_all_counties(internal_all_counties(:,1)~=0,:);

%final all flights after removing null entries
final_all_flights_truck=internal_flights_all_counties_OD;

% the output from this script will be used as input in flight path
% generator model

```

A.6) Origin Destination pair generator for ‘Air’ mode flows

```
%%This script generates the OD pairs from daily demand of ODM cargo flights
%at each landing site (from connected airport) for AIR mode through random
number generator
%origindesintaionfile_air

%load attraction data (no_flight_combined)
load('Distribution_att_air_combined.mat'); %no_flight

%load production data (no_flight_combined)
load('Distribution_prod_air_combined.mat');

%load commodities names
load('fieldnames.mat')

all_com_names=fieldnames;

clear fieldnames

%Load the new landing site set
LS_set=readtable('new_coordinates_wo_dp.xls','ReadVariableNames',true);

%load the distribution factor for each landing site
load('distribution_factor_new.mat')

%all counties in the analysis
counties=fieldnames(LS_in_counties);

%number of counties
no_counties=length(counties);

%distribution airports in the analysis
airports=readtable('distribution_airports.xlsx');

flights_all_counties_att=[];
flights_all_counties_prod=[];

%random number benchmark
rng(1);

for i=1:no_counties

    %attraction flights
    temp_county_flights=no_flights_att.(counties{i});

    temp_landing_sites=fieldnames(temp_county_flights);

    %landing site id
    temp_landing_sites_id=cellfun(@(x) x(3:end),temp_landing_sites,'un',0);

    temp_flights_county=[];

    %number of landing sites in the county
    temp_no_ls=length(temp_landing_sites);
```

```

%in attraction the landing site is the destination and the connected
%airport is the origin
%LS
LS_dest_id=LS_in_counties.(counties{i}).landing_site_id;

%airport
LS_origin_id=table2array(airports(i,6));

for j=1:temp_no_ls
    %number of daily cargo odm flights
    temp_flight_no=temp_county_flights.(temp_landing_sites{j});

    %abs value
    no_abs=floor(temp_flight_no);
    no_prob=temp_flight_no-no_abs;

    %random number to decide the fractional part of demand
    random_no(j)=rand();

    if random_no(j)<=no_prob

        %fractional part converts to a flight
        flag=1;
    else

        %fractional part doesn't convert to a flight
        flag=0;
    end
    no_flights_pair=no_abs+flag;

    if no_flights_pair==1

        %single flight per day
        temp_od=[LS_dest_id(j) LS_origin_id];

    elseif no_flights_pair>1

        %multiple OD pairs
        temp_od=[0 0];
        ind=1;

        while ind<=no_flights_pair

            temp_od(ind,:)= [LS_dest_id(j) LS_origin_id];

            ind=ind+1;
        end
    else
        temp_od=[0 0];
    end
    temp_flights_county=vertcat(temp_flights_county,temp_od);
end
%all counties OD pair aggregated for AIR mode attraction

```

```

flights_all_counties_att=vertcat(flights_all_counties_att,temp_flights_county
);
end

%final all flights (attraction) after removing null entries
flights_all_counties_att=flights_all_counties_att(flights_all_counties_att(:,
1)~=0,:);

for i=1:no_counties

    %production flights
    temp_county_flights=no_flights_prod.(counties{i});

    %landing sites in county
    temp_landing_sites=fieldnames(temp_county_flights);

    %landing site id
    temp_landing_sites_id=cellfun(@(x) x(3:end),temp_landing_sites,'un',0);

    temp_flights_county=[];

    %number of landing sites in the county
    temp_no_ls=length(temp_landing_sites);

    %in production the connected airport is the destination and
    %origin is the landing site

    %destination (LS)
    LS_dest_id=LS_in_counties.(counties{i}).landing_site_id;

    %origin airport
    LS_origin_id=table2array(airports(i,6));

    for j=1:temp_no_ls

        %number of daily cargo odm flights
        temp_flight_no=temp_county_flights.(temp_landing_sites{j});

        %abs value
        no_abs=floor(temp_flight_no);
        no_prob=temp_flight_no-no_abs;

        %random number to decide the fractional part of demand
        random_no(j)=rand();

        if random_no(j)<=no_prob
            %fractional part converts to a flight
            flag=1;
        else
            %fractional part doesn't convert to a flight
            flag=0;
        end

        no_flights_pair=no_abs+flag;
    end
end

```

```

if no_flights_pair==1

    %single od pair
    temp_od=[LS_origin_id LS_dest_id(j)];
elseif no_flights_pair>1

    %multiple flights between same od pair
    temp_od=[0 0];
    ind=1;

    while ind<=no_flights_pair

        temp_od(ind,:)= [LS_origin_id LS_dest_id(j)];

        ind=ind+1;
    end
else
    temp_od=[0 0];
end
temp_flights_county=vertcat(temp_flights_county,temp_od);
end
%all counties OD pair aggregated for AIR mode production

flights_all_counties_prod=vertcat(flights_all_counties_prod,temp_flights_county);
end

%final all flights (production) after removing null entries
flights_all_counties_prod=flights_all_counties_prod(flights_all_counties_prod(:,1)~=0,:);

%Combined all flights from air mode (prod+att)
final_all_flights_air=[flights_all_counties_att;flights_all_counties_prod];

%The output from this script will be used as input in flight plan generator

```

A.7) Cargo flight plan generator

```
%Cargo Flight Plan Generator
%Output: Flight plan in ACES format
%input: OD pairs and flights
%Detour factors
%-----
clear all
clc

%load OD pairs for daily cargo odm flights
%truck
load ('final_all_flights_truck.mat');
%Air
load('final_all_flights_air.mat');

%All flights combined air and truck
final_all_flights=[final_all_flights_air;final_all_flights_truck];

%Distance calculator (btw od pairs)
[~,~,Coordinates_landing_sites]=xlsread('..\new_coordinates_all.xls');

%number of flights
no_flights=length(final_all_flights);
Coordinates_landing_sites(1,:)=[];

for i=1:no_flights

    %origin ls id
    temp_origin_id= final_all_flights(i,1);

    %destination ls id
    temp_dest_id= final_all_flights(i,2);

    %origin index
    Index_Origin_in_Coordinates=find(cell2mat(Coordinates_landing_sites(:,1))==temp_origin_id);

    %destination index
    Index_Destination_in_Coordinates=find(cell2mat(Coordinates_landing_sites(:,1))==(temp_dest_id));

    %coordinates of origin landing site
    latitude_Origin=cell2mat(Coordinates_landing_sites(Index_Origin_in_Coordinates,3));
    longitude_Origin=cell2mat(Coordinates_landing_sites(Index_Origin_in_Coordinates,2));

    %latitude and longitude of destination landing landing site
```

```

latitude_Destination=cell2mat(Coordinates_landing_sites(Index_Destination_in_
Coordinates,3));

longitude_Destination=cell2mat(Coordinates_landing_sites(Index_Destination_in
_Coordinates,2));

temp_lat=[latitude_Origin;latitude_Destination];
temp_long=[longitude_Origin;longitude_Destination];

%calculating great circle distance between od pairs
[~,temp_dist]=legs(temp_lat,temp_long,'gc'); %nautical miles

%5percent detour
final_all_flights(i,3)=temp_dist*1.05;
end

%removing null entries
final_all_flights=final_all_flights(~(final_all_flights(:,3)==0),:);

%distance filter (cut-off distance)
% the minimum distance for ODM cargo flight is 5 miles
%parsing flights greater than 5 miles
distance_cutoff=5;

final_all_flights=final_all_flights((final_all_flights(:,3)>=distance_cutoff)
,:);

%-----
%Flight plan genertor

>Loading the flight route of all OD pairs with detour points
load('.\path_375.mat'); %all_paths

%Preparing all_paths for analysis and removing invalid entries
maxLength = max( cellfun(@ (x) (numel(x)), all_paths));
all_paths_equal_size = cell2mat( cellfun(@ (x) cat(2,x,0*ones(1,maxLength -
length(x))), all_paths, 'UniformOutput', false));

%Equal sized all_paths matrix with valid entries (ODpairs)
valid_all_paths_equal_size=all_paths_equal_size((all_paths_equal_size(:,2)~=0)
,:);
%-----

no_flights=length(final_all_flights);
waypoints=cell(no_flights,1);

%time tags for flights
time_tag=load('.\Scenario_9_Morning_Tags.mat');
time_tag_DTformat=datetime(time_tag.time_tag, 'Format', 'HH:mm:ss');
time_tag_DTformat=time_tag_DTformat+hours(3);

time_tag_DTformat=time_tag_DTformat(1:no_flights,1);

%time span between each waypoint generated
time_span_generate_waypoints_seconds=30;

```

```

for i=1:no_flights

    %Landing site id for origin
    Landing_Site_Origin=final_all_flights(i,1);

    %Landing site id for destination
    Landing_Site_Destination=final_all_flights(i,2);

    %Distance of flight
    flight_dist_miles= final_all_flights(i,3);

    %Finding index of Origin and destination in coordinates matrix to
    %extract coordinates

Index_Origin_in_Coordinates=find(cell2mat(Coordinates_landing_sites(:,1))==(L
anding_Site_Origin));

Index_Destination_in_Coordinates=find(cell2mat(Coordinates_landing_sites(:,1)
)==(Landing_Site_Destination));

    %latitude and longitude of origin landing site
    latitude_Origin=Coordinates_landing_sites(Index_Origin_in_Coordinates,3);

longitude_Origin=Coordinates_landing_sites(Index_Origin_in_Coordinates,2);

    %latitude and longitude of destination landing landing site

latitude_Destination=Coordinates_landing_sites(Index_Destination_in_Coordinat
es,3);

longitude_Destination=Coordinates_landing_sites(Index_Destination_in_Coordina
tes,2);

    %finding pair in all paths

Index_Origin_in_allpaths=find(valid_all_paths_equal_size(:,1)==(Landing_Site_
Origin));

Index_Destination_in_allpaths=find(valid_all_paths_equal_size(:,1)==(Landing_
Site_Destination));

    OD_pair_index=zeros(1,1);
    if ~isempty(Index_Origin_in_allpaths)
        %Examining all OD pairs originating from concerned Origin
        for j=Index_Origin_in_allpaths(1):Index_Origin_in_allpaths(end)

            temp_OD_pair=valid_all_paths_equal_size(j,:);

            %Finding destination [1 1014 1022 1033 43]; 43 is destination
            %or [1 64]; 64 is destination; last is destination
            temp_Destination=temp_OD_pair(find(temp_OD_pair,1,'last'));

            %OD pair index for concerned OD pair
            if temp_Destination==(Landing_Site_Destination)
                OD_pair_index=j;
            end
        end
    end
end

```

```

        end

    end

    %If OD pair is found
    if OD_pair_index~=0
        Flight_route_with_OD=valid_all_paths_equal_size(OD_pair_index,:);
    else
        %If OD pair is in reverse
        for
j1=Index_Destination_in_allpaths(1):Index_Destination_in_allpaths(end)

            temp_OD_pair_reverse=valid_all_paths_equal_size(j1,:);

temp_Destination_reverse=temp_OD_pair_reverse(find(temp_OD_pair_reverse,1,'last'));

            if temp_Destination_reverse==(Landing_Site_Origin)
                OD_pair_index=j1;
            end

        end

        %Flight route for OD pair in reverse
        Flight_route_with_OD=valid_all_paths_equal_size(OD_pair_index,:);

        %Number of elements in flight route
        nonzero_points=nnz(Flight_route_with_OD);

        %Flipping the reverse OD pair
Flight_route_with_OD=fliplr(Flight_route_with_OD(1:nonzero_points));
    end
else
        %If OD pair is in reverse format in all_paths [1 40] is [40 1]
        for
j1=Index_Destination_in_allpaths(1):Index_Destination_in_allpaths(end)

            temp_OD_pair_reverse=valid_all_paths_equal_size(j1,:);

temp_Destination_reverse=temp_OD_pair_reverse(find(temp_OD_pair_reverse,1,'last'));

            if temp_Destination_reverse==(Landing_Site_Origin)
                OD_pair_index=j1;
            end

        end

        %Flight route for OD pair in reverse
        Flight_route_with_OD=valid_all_paths_equal_size(OD_pair_index,:);

        %Number of elements in flight route
        nonzero_points=nnz(Flight_route_with_OD);

        %Flipping the reverse OD pair

```

```

        Flight_route_with_OD=fliplr(Flight_route_with_OD(1:nonzero_points));
end
clear OD_pair_index j j1 nonzero_points

%Index of destination in flight route array, ex: [2 1024 1010 1032 5 0]
%destination index= 5;
Index_last_site_route=find(Flight_route_with_OD,1,'last');

%Length of flight route will be 2 if no detour. ex: [1 78]
flight_route_length_no_detour=2;

%If length of flight route is greater than 2, detour exist on that OD
%pair route

if nnz(Flight_route_with_OD)>flight_route_length_no_detour

    %intializing timetags vector
    DTVec_generate_timetags=datetime();

    %Intializing detour coordinates matrix
    detour_coordinates=cell(Index_last_site_route,1);

    %temporarily treating origin as first detour point
    detour_coordinates{1}=[latitude_Origin,longitude_Origin];

    %Intializing full detour matrix
    all_detour_coordinates=zeros(1,2);

    count=2;

    %extracting coordinates for each detour point in the route
    while count<=Index_last_site_route

        %Detour point ID
        detour_point=Flight_route_with_OD(count);

        %detour point index

        detour_index=find(cell2mat(Coordinates_landing_sites(:,1))==detour_point);

        %detour point latitude and longitude
        latitude_detour_point=Coordinates_landing_sites(detour_index,3);
        longitude_detour_point=Coordinates_landing_sites(detour_index,2);

        detour_coordinates{count}=[latitude_detour_point,longitude_detour_point];

        %adding coordinates to detour coordinates matrix in a loop

    all_detour_coordinates=[all_detour_coordinates;cell2mat(detour_coordinates{count})];

        count=count+1;
    end

    %Speed of travel (between 150 and 200)

```

```

speed1_mph=round(150+rand()*50);

%removing origin and destination coordinates from detour matrix
all_detour_coordinates(1,:)=[];
all_detour_coordinates(end,:)=[];

%calculate waypoints between each detour points
%time between each waypoint
time_span_generate_waypoints_seconds=30;

count2=2;
part_between_detour_points={};
temp_results=[];

length_detour_coordinates=length(detour_coordinates);
%Generating waypoints between detour points
while count2<=length_detour_coordinates

    %Latitude and longitude of point a
    latitude_a=cell2mat(detour_coordinates{count2-1}(1,1));
    longitude_a=cell2mat(detour_coordinates{count2-1}(1,2));

    %latitude and longitude of point b
    latitude_b=cell2mat(detour_coordinates{count2}(1,1));
    longitude_b=cell2mat(detour_coordinates{count2}(1,2));

    %Latitude vector for 'legs' function input
    lat=[latitude_a;latitude_b];
    long=[longitude_a;longitude_b];

    %calculating great circle distance between two points
    [~,distance_btw_detour_points]=legs(lat,long,'gc');

    %Distance output from legs is in nautical miles and speed is in
mph
    travel_time_sec=distance_btw_detour_points*3600*1.15/(speed1_mph);

    %finding number of waypoints required

no_of_waypoints=floor(travel_time_sec/time_span_generate_waypoints_seconds);

    inter_waypoints=[];

    %Waypoints will be generated only when time_span is greater
    %than time taken to travel between points

    if no_of_waypoints>0

        %calculating distance between origin and last waypoints for
        %function gcwaypoints

Distance_btw_origin_last_waypoint=speed1_mph*no_of_waypoints*time_span_genera
te_waypoints_seconds/3600;

        %calculating the fraction of distance from origin to last
        waypoint is to total distance

```

```

fraction_of_total_dist_bt看_detour=Distance_bt看_origin_last_waypoint/(1.15*(di
stance_bt看_detour_points));

    %Using Interarc function to interpolate between origin and
    %destination coordinates to generate coordinates for last
    %waypoint

coordinates_last_waypoint=interparc(fraction_of_total_dist_bt看_detour, (lat), (
long));

    %Generating equidistant points between origin and last way
    %point using gcwaypts

[inter_waypoints(:,1),inter_waypoints(:,2)]=gcwaypts((latitude_a), (longitude_
a), coordinates_last_waypoint(1), coordinates_last_waypoint(2), no_of_waypoints)
;

    %appending point b coordinates
    inter_waypoints(end+1, :)=[(latitude_b), (longitude_b)];

    part_between_detour_points{count2-1}=inter_waypoints;
else
    %if no waypoints needed
    part_between_detour_points{count2-
1}=[latitude_a, longitude_a; latitude_b, longitude_b];
end

    %removing last coordinate
    part_between_detour_points{count2-1}(end, :)=[];

    %creating the route waypoints by adding all waypoints with detour
    temp_results=[temp_results; (part_between_detour_points{count2-
1})];

    count2=count2+1;

end
temp_results(1, :)=[];

    %adding destination coordinates to complete the route

temp_results(end+1, :)=[cell2mat(latitude_Destination), cell2mat(longitude_Dest
ination)];

    %Generating timestamps for each waypoint along the route
    DTVec_generate_timetags(1)=time_tag_DTformat(i);

    for e=2:length(temp_results)

        %if not a detour point, waypoint timestamp is last timestamp
        %plus span duration
        if ~ismember(temp_results(e, :), all_detour_coordinates, 'rows')
            %waypoint
            DTVec_generate_timetags(e)=DTVec_generate_timetags((e-
1))+seconds(time_span_generate_waypoints_seconds);
        else

```

```

    %if detour point, timestamp is last timestamp plus time
    %taken to travel from last waypoint to detour point

    %coordinates of detour point and last waypoint
    latitude_a1=temp_results((e-1),1);
    latitude_b1=temp_results((e),1);

    longitude_a1=temp_results((e-1),2);
    longitude_b1=temp_results((e),2);

    %calculating distance between last waypoint and detour
    %point
    temp_lat1=[latitude_a1;latitude_b1];
    temp_long1=[longitude_a1;longitude_b1];

    [~,dist]=legs(temp_lat1,temp_long1,'gc');

    %calculating time taken to travel from last waypoint to
    %detour point in seconds
    time_to_detour_point_seconds=dist*1.15*3600/(speed1_mph);

    %timestamp of detour point
    DTVec_generate_timetags(e)=DTVec_generate_timetags(e-
1)+seconds(time_to_detour_point_seconds);
    end
end

%the date time format of time tags
DTVec_generate_timetags.Format='hh:mm:ss';
all_time_tags_string=(cellstr(DTVec_generate_timetags))';

%Adding cruise altitude to each flight
%cruise altitude is dependent on the distance of flight

%Altitude and distance matrix
dist_sm = [ 2 5 10 20 30 50 100 5000];
altitude_ft = [ 600 800 1500 2000 2000 2500 3000 3000];

%Interpolating to find altitude for specific distance
alt_ft= round(interp1(dist_sm,altitude_ft,flight_dist_miles));

%Latitude of waypoints
waypoints(i,1)={temp_results(:,1)};

%Longitude of waypoints
waypoints(i,2)={temp_results(:,2)};
clear temp_results

%timetag of waypoint
waypoints(i,3)={all_time_tags_string};

%cruise speed of flight
waypoints(i,4)={speed1_mph};

%cruise altitude of flight
waypoints(i,5)={alt_ft};

```

```

clear all_time_tags_string all_detour_coordinates detour_coordinates
DTVec_generate_timetags part_between_detour_points speedcheck_alert

else %If no detour points along the route

    speed2_mph=round(150+rand()*50);

    %Initializing
    internal_waypoints=[];

    all_time_tags_string_no_detour={};

    DateTime_vec_time_tages=datetime();

    %calculating travel time between origin and destination
    travel_time_sec=flight_dist_miles*3600/(speed2_mph);

    %latitude of origin and destination for interparc
    latitude_no_detour=[latitude_Origin{1},latitude_Destination{1}];

    %longitude of origin and destination for interparc
    longitude_no_detour=[longitude_Origin{1},longitude_Destination{1}];

    %calculating number of waypoints according to time span required
no_of_waypoints=floor(travel_time_sec/time_span_generate_waypoints_seconds);

    %distance from origin to last waypoint

distance_to_last_waypoint=speed2_mph*no_of_waypoints*time_span_generate_waypo
ints_seconds/3600;

    %the fraction value (required for Interparc funtion) of last waypoint
distance to whole distance

fraction_of_tot_distance=distance_to_last_waypoint/(flight_dist_miles);

    %coordinates of last waypoint

coordinates_last_waypoints=interparc(fraction_of_tot_distance,latitude_no_det
our,longitude_no_detour);

    %generating waypoints between origin and last waypoint at
%equidistant using gcwaypts

[internal_waypoints(:,1),internal_waypoints(:,2)]=gcwaypts(cell2mat(latitude_
Origin),cell2mat(longitude_Origin),coordinates_last_waypoints(1),coordinates_
last_waypoints(2),no_of_waypoints);

    %Appending destination coordinates

internal_waypoints(end+1,:)=cell2mat(latitude_Destination),cell2mat(longitud
e_Destination)];

```

```

%Extracting time stamp from time tags
DateTime_vec_time_tages(1)=time_tag_DTformat(i);

%estabilishing the format for time tags
DateTime_vec_time_tages.Format='hh:mm:ss';

count3=2;

%Adding timestamps to every waypoint along the route
while count3<length(internal_waypoints(:,1))
    DateTime_vec_time_tages(count3)=DateTime_vec_time_tages(count3-
1)+seconds(time_span_generate_waypoints_seconds);
    count3=count3+1;
end

%Generating time stamp of destination
latitude_a2=internal_waypoints(end-1,1);
latitude_b2=internal_waypoints(end,1);

longitude_a2=internal_waypoints(end-1,2);
longitude_b2=internal_waypoints(end,2);

%coordinates of origin and destination
lat2=[latitude_a2;latitude_b2];
long2=[longitude_a2;longitude_b2];

[~,dist1]=legs(lat2,long2,'gc'); %distance calculated is in nautical
miles

%time taken to travel between two points in seconds
time2_seconds=dist1*1.15*3600/(speed2_mph);

%generating destination time stamps

DateTime_vec_time_tages(end+1)=DateTime_vec_time_tages(1)+seconds(time2_secon
ds);

%Altitude and distance matrix
dist_sm = [2 5 10 20 30 50 100 5000];
altitude_ft = [600 800 1500 2000 2000 2500 3000 3000];

%Interpolating to find the cruise altitude of flight
alt1_ft= round(interp1(dist_sm,altitude_ft,flight_dist_miles));

%Latitude of waypoints
waypoints(i,1)={internal_waypoints(:,1)};

%Longitude of waypoints
waypoints(i,2)={internal_waypoints(:,2)};

clear internal_waypoints

%Generating time stamps
DateTime_vec_time_tages.Format='hh:mm:ss';
all_time_tags_string_no_detour=cellstr(DateTime_vec_time_tages);

%Time stamps of waypoints

```

```

        waypoints(i,3)={all_time_tags_string_no_detour};

        %cruise speed of flight
        waypoints(i,4)={speed2_mph};

        %cruise altitude of flight
        waypoints(i,5)={alt1_ft};
        clear all_time_tags_string_no_detour DateTime_vec_time_tages

    end
end

Cargo_flights_air=struct();

%fieldnames of structure
fieldnames_aces={'ETM_Flight_Id', 'Airplane_Flight_number', 'Aircraft_type', 'Equipage', 'TCAS', 'departure_airport', 'arrival_airport'...
    , 'start_time', 'cruise_speed', 'cruise_altitude', 'flightplan'};

no_of_flights=length(final_all_flights);

for i=1:no_of_flights

    %Array of departure airport
    departure=(final_all_flights(i,1));

    %Array of arrival airport
    arrival=(final_all_flights(i,2));

    flight_plan=[];

    %length of ith flight plan
    length_route=length(waypoints{i,1});

    for j=1:length_route

        %Joining Latitude Longitude and respective timestamp
        temp_flight_plan_part=[num2str(waypoints{i,1}(j)), '/', ...
            num2str(waypoints{i,2}(j)), '/', cellstr(waypoints{i,3}(j))];

temp_flight_plan=[temp_flight_plan_part{1,1}, '/', temp_flight_plan_part{1,3}, '
/', temp_flight_plan_part{1,5}, ' '];

        %adding waypoints till destination landing site
        flight_plan=[flight_plan, temp_flight_plan];

    end

    %ETM flight ID
    Cargo_flights_air(i).(fieldnames_aces{1})=num2str(i);

    %Airline Flight number
    Cargo_flights_air(i).(fieldnames_aces{2})=['VT_', num2str(i)];

```

```

%Aircraft type
Cargo_flights_air(i).(fieldnames_aces{3})='ODM';

%Equipage
Cargo_flights_air(i).(fieldnames_aces{4})='RNAV';

%TCAS
Cargo_flights_air(i).(fieldnames_aces{5})='TCAS';

%Departure Airport
Cargo_flights_air(i).(fieldnames_aces{6})=['K',num2str(departure)];

%Arrival Airport
Cargo_flights_air(i).(fieldnames_aces{7})=['K',num2str(arrival)];

%Scheduled Gate Departure Time
Cargo_flights_air(i).(fieldnames_aces{8})=waypoints{i,3}(1,1);

%Cruise altitude
Cargo_flights_air(i).(fieldnames_aces{10})=waypoints{i,5};

%Cruise Speed
Cargo_flights_air(i).(fieldnames_aces{9})=waypoints{i,4};

%Flight Plan
Cargo_flights_air(i).(fieldnames_aces{11})=flight_plan;

end

%Cargo
writetable(struct2table(Cargo_flights_air),
'..\Output\Input_ACES_cargo_flights_air_baseline.xlsx');

%validation using mapshow
%Enter 1 if map display is required
mapshow_indicator_cargo=input('display all flights in morning (Y=1, N=0):');

if mapshow_indicator_cargo==1

    AS=kml2struct('Approach_surface_boundaries.kml');

    states = geoshape(shaperead('usastatehi', 'UseGeoCoords', true));
    stateName = 'California';
    ca = states(strcmp(states.Name, stateName));
    geoshow(ca, 'LineWidth', 1.5, 'FaceColor', [0.9290, 0.6940, 0.1250]);
    hold on
    for i=1:no_flights
        latitude_sets=waypoints{i,1};
        longitude_sets=waypoints{i,2};
        geoshow(latitude_sets,longitude_sets,'LineWidth',1);
        hold on
    end

    %approach surface boundaries for commercial airspace
    for i=1:3

```

```
temp_x=AS(i).X;  
temp_y=AS(i).Y;  
geoshow(temp_y,temp_x,'Color','black','LineWidth',2);  
hold on  
end  
hold off  
end
```