Analysis of Urban Air Transportation Operational Constraints and Customer Value Attributes

By

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Submitted to the MIT Sloan School of Management and the Department of Aeronautics and Astronautics in partial fulfillment of the requirements for the degrees of

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ABSTRACT

Urban Air Mobility (UAM) is a concept that proposes to provide short-range transportation solutions that enable customers to travel point-to-point more quickly than they can today using cars or public transportation. The concept of Urban Air Mobility is not new, but there has been rapidly increasing interest in providing air transportation services within major metropolitan areas. The combination of increasing congestion and advancements in electric aircraft and automation makes the Urban Air Mobility market more attractive for vehicle manufactures and transportation companies.

There are many potential applications for new aircraft. However, these applications cannot be based solely on what is technological feasible, but must consider the market, demand, and customer needs. This thesis investigates these factors in order to identify operational challenges that may develop during the implementation and operation of an Urban Air Mobility system. The study focuses on Dallas-Fort Worth to set the scope to one potential early adoption market.

The objective is to understand the Dallas-Fort Worth environment better in two dimensions. The first is resident's current perceptions and values. The second is the operational challenges and constraints associated with operating a UAM system. In order to meet this objective, a survey of community members and potential early adopters is conducted to determine customer's perceptions of a UAM system and identify operational challenges that may develop based on customer needs. Next, a case study is completed using 10 reference missions in the Dallas-Fort Worth metropolitan area. The missions represented potential commuter trips, point-to-point trips like sporting events, and randomly generated missions.

Through this case study, nineteen operational challenges are identified that may impact the development, implementation, and operation of an Urban Air Mobility system. After reviewing each reference mission, community acceptance of aircraft noise and take off and landing area availability were identified as the operational constraints likely to cause the greatest challenges for UAM operations in Dallas Fort Worth.

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1. Introduction

This chapter outlines the motivation and objectives for this project. It also introduces the project approach and provides a roadmap walking the reader through each of the upcoming sections.

1.1 Motivation

The concept of Urban Air Mobility (UAM) proposes to develop short-range, point-to-point transportation systems in metropolitan areas using Vertical Takeoff and Landing (VTOL) or Short Takeoff and Landing (STOL) aircraft to overcome increasing levels of surface congestion. Technological advancements have increased the potential for near and far term development of UAM systems. Within the aviation community, there is an emerging interest to provide air transportation services in major metropolitan areas.

Two companies in particular have been focusing on developing a UAM system in the Dallas Fort-Worth Metropolitan area. Bell has released an Urban Air Taxi concept with the aim of expanding the scope of air travel and aviation technology [1]. Bell is a vertically integrated Original Equipment Manufacturer (OEM). The company has a strong history of innovation and is continuing to develop aircraft to serve an aviation community with diverse needs and interests. Bell is collaborating with Uber Technologies and identified Dallas as a launch city that could see initial testing as early as 2020 and initial service offerings as early as 2025 [2]. In addition to Bell and Uber, many companies have begun leveraging these technologies to create aircraft capable of operating in a UAM system. However, technological capabilities alone are not sufficient to sustain a new transportation system. The motivation for this project is to gain a better understanding of the operational considerations vehicle manufactures must consider and how customers view and value those considerations.

1.2 Problem Statement

The primary goal of this thesis is to identify the operational constraints that may impact the implementation of an Urban Air Mobility service in the Dallas-Fort Worth metropolitan area. The concept of Urban Air Mobility is not new, but there has been rapidly increasing interest in providing air transportation services within metropolitan areas.

Advancements in electric aircraft and automation make the market more attractive for vehicle manufactures and transportation companies. Equipment manufactures are interested in identifying potential applications for Urban Air Mobility operations and analyzing the best way to meet customers' needs in a rapidly changing market. These potential applications cannot be based solely on what is technological feasible, but must consider all of the factors in the market. Equipment manufactures must consider how these factors should be incorporated into vehicle and system design.

The problem is then to identify the market and what the most important considerations area. This thesis focuses on the Dallas-Fort Worth metropolitan area in order to limit the scope of the study to one geographic region and because of the possibility that it will be an early adoption market. The objective of this thesis is to understand the Dallas-Fort Worth environment better in two dimensions:

1. Residents current perceptions and values
2. The operational challenges and constraints that exist

The following section provides an overview of the approach that will be used to reach this objective.

1.3 Project Approach

A two phased approached was developed in order to meet the objectives identified above. In the first phase, a questionnaire was developed to examine how residents and potential customers perceived Urban Air Mobility services, how they would use those services, and to assess potential operational challenges. In the second phase, a case study was developed to identify the operational challenges that could impact the implementation of an UAM network in Dallas-Fort Worth metropolitan area. The study approached focused on conducting a systems level analysis by investigating Concept of Operations (ConOps) for UAM systems in multiple missions. By identifying both customer perceptions and mission challenges, this thesis aims to present a thorough understanding of the Dallas-Fort Worth environment and the potential for UAM services.

1.4 Thesis Roadmap

The following chapters walk through this approach and present an analysis of Urban Air Mobility operational considerations and perceived customer value attributes. Chapter 2 provides a history of Urban Air Mobility, describes existing air transportation services, and discusses emerging Urban Air Mobility concepts. Chapter 3 outlines the methodology used to complete the research. Chapter 4 contains the customer survey, method, results, and key findings. Chapter 5 outlines the case study approach and identifies market opportunities in the Dallas-Fort Worth metropolitan area. Chapter 6 identifies each specific reference mission used in the case study. Chapter 7 walks through the Concept of Operations (ConOps) evaluation and operational constrains identification. Chapter 8 discusses final recommendations, conclusions, and possibilities for future research.

2. Background and Literature Review

This chapter provides an overview of the current status of Urban Air Mobility and the recent motivation to change current transportation systems. This chapter will also describe the need to develop an Urban Air Mobility system in Dallas-Fort Worth.

2.1 Urban Air Mobility Overview

Urban Air Mobility (UAM) is a concept that proposes to provide short-range transportation solutions that will enable customers to travel point-to-point more quickly than they can today using cars or public transportation. Recent aviation technologies and concepts have reached a level of maturity that may soon enable UAM systems of aircraft fueled by quiet, efficient, and potentially automated air taxis [3]. These recent developments have generated increased discussion around UAM systems and application.

2.2 Historic and Existing Air Transportation Services

There are many historic examples of helicopter transportation systems. The first commercial helicopter transportation companies started carrying passengers in the 1950s. NASA and DOT identified Short Take Off and Landing (STOL) and Vertical Take Off and Landing (VTOL) systems as early potential solutions to meet growing demand in the short-haul transportation market [4]. Despite early interest, UAM operations were not adopted due to community acceptance issues, accidents, and financial feasibility. Recently, companies have resumed UAM operations using helicopters.

Two recent companies have launched on demand helicopter transportation services in North America. BLADE launched in New York in 2014 and has now expanded to 22 locations within the United States [5]. Voom, a unit of Airbus SE, launched in 2017 in Sao Paulo, expanded to Mexico City, and plan to expand to Rio De Janeiro [6,7]. Both of these companies use helicopters to offer on demand services.

2.3 Emerging Urban Air Mobility Concepts

Beginning in 2010, NASA presented a view for "On-Demand Aviation" that used small electric aircraft to conduct operations [8]. This concept of UAM was expressed in an Uber white paper in 2016. In the paper, Uber portrayed an ambitious vision for the future of UAM operations and identified the following challenges as the most critical to address [9]:

- Aircraft certification
- Battery Technology
- Vehicle Efficiency
- Vehicle Performance and Reliability
- Air Traffic Control (ATC)
- Cost and Affordability
- Safety
- Aircraft Noise
- Emissions
- Vertiport/Vertistop Infrastructure in Cities
- Pilot Training

The paper identified infrastructure development as the most significant operational constraint. Further studies by NASA and MIT provided greater detail into these projected operational constraints [10]. In 2017, NASA published a strategic framework for On-Demand Air Mobility that identifies potential market demand, enabling technologies, and analyzes technological gaps [11]. These challenges similarly aligned with the challenges that Uber identified.

2.4 Uber Elevate and Dallas-Fort Worth

Metropolitan areas in the United States are facing increasing levels of congestion every year. In 2013, the estimated cost of congestion was $124 billion [12]. Without significant action, the cost is expected to increase 50 percent to $186 billion by 2030 [13]. The Dallas Fort-Worth metropolitan area is not immune to this problem. Figure 1 shows the NCTCOG metropolitan area and current congestion levels.

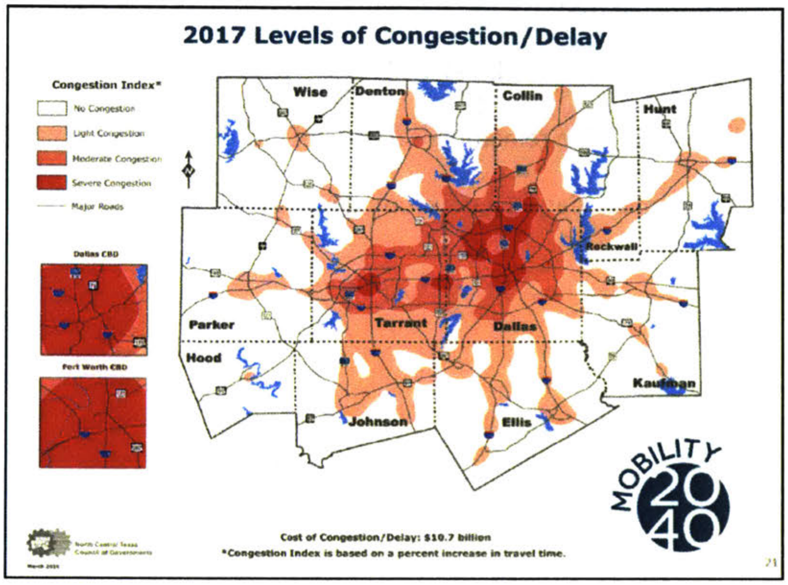

Figure 1. NCTCOG Metropolitan Planning area and 2017 Levels of Congestion [13]

North Central Texas has been experiencing rapid population growth and development in recent years. In the next two decades, the population is expected to grow by 48% [13]. This increase in population brings with it an increase in travel time due to congestion and an associated cost of congestion. The North Central Texas Council of Government (NCTCOG) expects this cost to increase from $10.7 billion in 2017 to $25.3 billion in 2040 [14]. Regional performance measures are summarized in figure 2.

Regional Performance Measures	2017	2040	No-Build
Population	7,235,508	10,676,844	10,676,844
Employment	4,584,235	6,691,449	6,691,449
Vehicle Miles of Travel (Daily)	206,162,076	319,470,644	320,119,945
Hourly Capacity (Miles)	44,334,264	52,655,877	43,872,454
Vehicle Hours Spent in Delay (Daily)	1,521,068	3,587,058	6,198,230
Increase in Travel Time Due to Congestion	38.2%	58.4%	98.2%
Annual Cost of Congestion (Billions)	$10.7	$25.3	$43.9

Figure 2. North Central Texas Regional Performance Measures [14].

Urban Air Mobility presents one possible means to improve the growing traffic congestion problem. In 2017, at the Elevate Summit in Dallas, Uber announced Dallas would be one of the launch cities for Uber's Elevate service [15]. The growing need for transportation services, recent industry interest, and favorable conditions for aviation operations make Dallas-Fort Worth a likely candidate for early development of a UAM system in the United States. The remaining sections of this paper will analyze potential operational constraints and potential customers views on developing a UAM service in Dallas-Fort Worth.

3.0 Methodology

The objective of this thesis is to understand the Dallas-Fort Worth environment for UAM operations better by understanding both the market and operational challenges. First, a boundary area was defined for the scope of the research. Second, a survey of Dallas-Fort Worth residents was conducted to evaluate resident's perceptions and values. Finally, a case study was developed using hypothetical missions to identify operational challenges. This section discusses the methodology used to approach this analysis.

3.1 Boundary Area Identification

The boundary area selected for this study is the boundary of the Dallas-Fort Worth metropolitan planning area as defined by the North Central Texas Council of Governments (NCTCOG). The area includes 12 counties in North Central Texas and covers approximately 9,500 square miles [14]. Figure 3 displays the study boundary area.

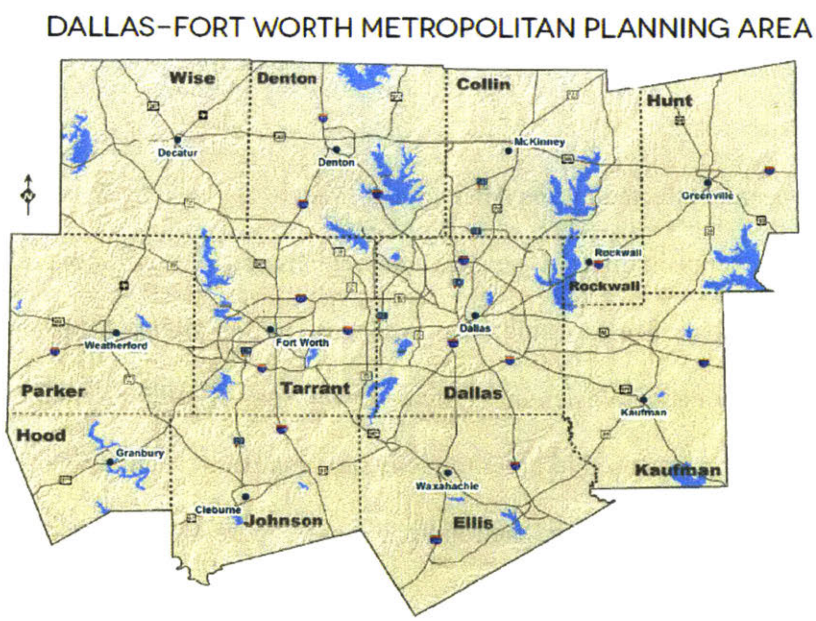

Figure 3. The Dallas-Fort Worth Metropolitan planning area [14].

3.2 Survey Methodology

A questionnaire was developed to examine how residents and potential customers perceived Urban Air Mobility services, how they would use those services, and to identify potential operational challenges. Two trial versions of the survey were launched to target audiences in the Dallas-Fort Worth Metropolitan area to refine the survey questions for clarity, completeness, and respondent understanding. Then, the questionnaire was summited to Dallas-Fort Worth residents using the platform SurveyMonkey [16]. SurveyMonkey's Audience tool was used to recruit respondents in the Dallas-Fort Worth metropolitan area. Respondents were 18 years and older. No gender or income limitations were set.

3.3 Case Study Methodology

The case study was developed to identify the operational constraints that could impact the implementation of an UAM network in Dallas-Fort Worth metropolitan area. The study approached focused on conducting a systems level analysis by investigating Concept of Operations (ConOps) for UAM systems in multiple missions in order to identify potential operations factors that could constrain the implementation or scale up of the service.

Similar studies have been conducted in Los Angeles and Boston. Dallas-Fort Worth was selected in order to evaluate UAM performance in different geographical regions and because of the recent interest discussed in previous sections. The case study reviewed airborne and ground-based operations using the methodology developed by Parker Vasick in "Systems-Level Analysis of On Demand Mobility for Aviation" [10]. This method was used in order to facilitate a comparative analysis of operational constraints in in different geographies and metropolitan areas. Figure 4 shows a block flow diagram of the approached used in this thesis.

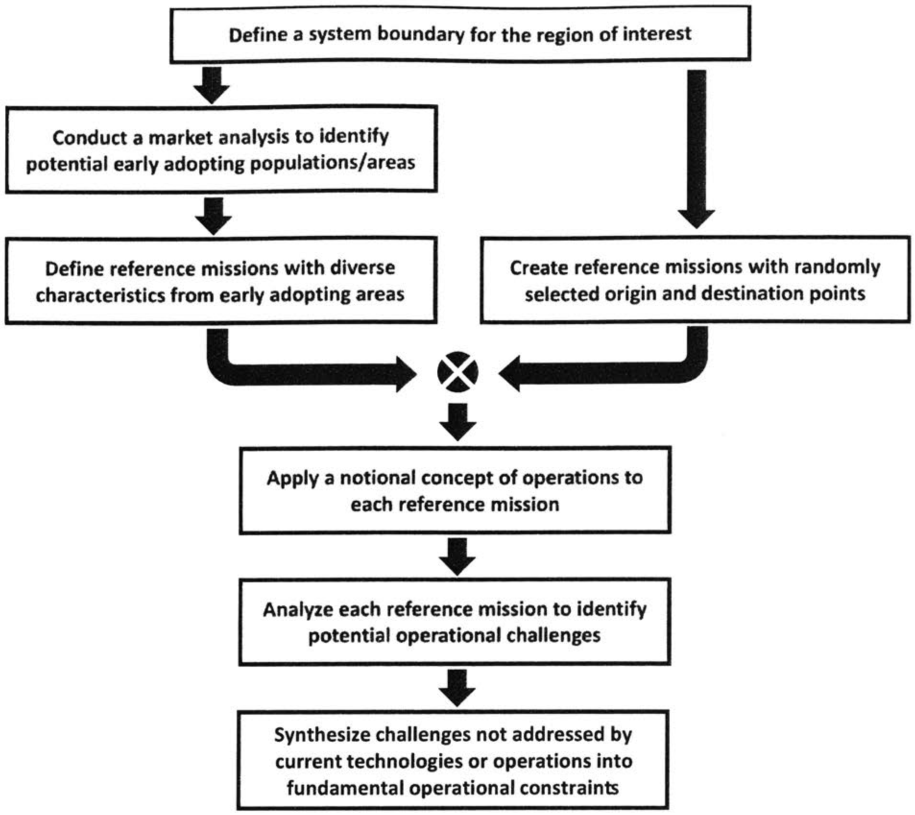

Figure 4. Block diagram of the case study analysis approach [10].

First, a boundary area was defined for the Dallas-Fort Worth metropolitan area including regions that might be served by a UAM system. Five factors were considered to indicated where UAM services were likely to be demanded within the city:

1) Consumer demand based on current transportation flows into, out of, and within the metropolitan area
2) Existing helicopter charter services and helicopter routes
3) Population density of communities in the region
4) Anticipated UAM mission profiles
5) The Metropolitan Transportation Plan for North Central Texas

The factors enabled the identification of potential UAM users and likely transportation patterns and routes. The boundary was drawn to include all census tracts within 100 miles of the primary city center that had a population density of at least 101 people per square mile. This population density was chosen because it notionally represented a population density capable of supporting UAM services. Because DFW is split between Dallas and Fort Worth, a central location between the cities was chosen to serve as the center point. The 100-mile radius was chosen to limit the size of the case study so that proposed near-term UAM vehicles could potentially fulfill the selected mission profiles.

Second, three categories of potential UAM markets were considered for case study analysis:

1) Daily Commute: an aircraft used to transport individuals from their residence to or near their place of employment and back
2) Non-Commute Point to Point: non-commuter trips between to locations such as business to business, recreation events, sporting events, airports, and hospitals
3) Randomly Selected: randomly selected missions were identified to address possible selection bias

Next, a set of 10 reference missions was developed to represent the categories of potential UAM markets. These reference missions were not selected to represent all of the potential market opportunities in the boundary area, but chosen to represent the diversity in the market and mission profiles for UAM services.

Next, a concept of operations (ConOps) was developed for each reference mission. The ConOps defined the activities completed by the customer from the time of ordering the UAM service to arrival at their final destination. The ConOps remained vehicle agnostic.

After the 10 ConOps were defined, each mission was analyzed in order to provide a holistic view of the potential operational challenges UAM networks face. The final step of the analysis identified the challenges and investigated the most severe constraints and evaluated potential mitigation techniques.

4. Customer Value Attributes

4.1 Introduction

This chapter explores community perceptions of an Urban Air Mobility service in Dallas-Fort Worth and attempts to understand the attributes of this service that customers value the most. Previous studies have been conducted in the United States surveying public opinion concerning flying cars [16]. This study focuses specially on Urban Air Mobility and the Dallas-Fort Worth metropolitan area. The operational challenges and likely uses identified in this section are used to develop reference missions and add to the demand estimation, likely use cases, and operational challenges identified in the case study.

4.2 Method

A survey was developed to analyze the Urban Air Mobility system attributes that customers value the most. Two trial versions of the survey were launched to target audiences in the Dallas-Fort Worth Metropolitan area to refine the survey questions for clarity, completeness, and respondent understanding. After refining the survey, the final version was launched in April 2018. A total of 606 people attempted the survey with a completion rate of 91% yielding 552 responses. Average survey completion time was four minutes and 44 seconds. Only fully completed question data is included in the results. The following sections describe the survey instrument used and respondent breakdown.

4.2.1 Survey instrument

The survey was conducted using the platform Survey Monkey [16]. The survey instrument consisted of an introduction, research disclaimer, and 19 questions. The original survey instrument is included in Appendix A. Survey Monkey's "Audience" tool was used to target respondents within the study boundary area of Dallas-Fort Worth. In exchange for completing the survey, each survey respondent who finishes a survey received:

- "A $0.50 donation to the participating charity of their choice. (SurveyMonkey makes this donation on their behalf and has a variety of charity partners which members can choose from.)" [18]

- "An entry into an instant win sweepstakes to win a $100 Amazon gift card. (SurveyMonkey randomly selects one winner per month.)" [18]

The survey was divided into four sections. First, questions regarding respondent familiarity with the concept and concerns for using the service. Second, expected uses for the service. Third, operations questions related to how a respondent would use the service. Finally, questions related to vehicle and system design.

4.2.2 Respondents

SurveyMonkey's Audience tool was used to recruit respondents in the Dallas-Fort Worth metropolitan area. Respondents were 18 years and older. No gender or income limitations were set. Fully completed surveys were received from 552 respondents. The margin of error at the 95% confidence level for the overall results is +/- 4.4%. Demographic breakdown for the respondents are shown in Table 1.

Table 1. Demographic breakdown for survey respondents.

Demographic Breakdown		Percent
Gender	Female	67.0
	Male	33.0
Age group	18 to 29	21.5
	30 to 44	30.1
	45 to 59	24.6
	60 or older	23.7
Income	$0 to $9,999	7.0
	$9,999 to $24,999	10.8
	$25,000 to $49,999	27.4
	$50,000 to $74,999	17.6
	$75,000 to $99,999	12.9
	$100,000 to $124,999	8.2
	$125,000 to $149,999	3.1
	$150,000 to $174,999	2.1
	$175,000 to $199,999	1.6
	$200,000 or more	4.2
	Prefer not to answer	5.1
U.S. Census region	South Central	100.0

The United States Census Bureau reported a median household income of $45,215 and $54,876 for the cities of Dallas and Fort Worth respectively in 2016 [19]. It should be noted that this survey received a higher percentage of female respondents than male respondents and is not necessarily representative of the demographic breakdown of Dallas and Fort Worth. It is unclear if this response rate is due to a specific response factor within the Survey Monkey audience toolkit or in the composition of respondents that received the survey. The survey results provide a demographic breakdown whenever it is applicable.

4.3 Results

This section contains the results of the individual survey questions. The exact question is given in bold text followed by the results for that question.

"Had you heard of an Urban Air Mobility, air taxi, or flying car service before taking this survey?"

Table 2 presents a summary of responses to the question that asked whether or not respondents had heard of an Urban Air Mobility, air taxi, or flying car service before. Less than one-third (28.3%) of respondents were familiar with the concept. The results varied slightly between gender and age groups. Men were slightly more likely to have heard of the concept and respondents between the ages of 30 and 44 were more likely to have heard of the service.

Table 2. Familiarity with Urban Air Mobility concept.

Response	Gender		Age				Total
	Female	Male	18-29	30-44	45-59	60+	
Yes	25.7%	33.5%	27.1%	32.1%	27.4%	25.7%	28.3%
No	74.3%	66.5%	72.9%	67.9%	72.6%	74.3%	71.7%

"If available in your area, how likely would you be to use this service?"

Figure 5 summarizes respondents desire to use an Urban Air Mobility Service. Overall, there is a positive view toward UAM services in Dallas, 49.1% of all respondents said they would like to use the service and 29.1% of users would not like to use the service. Almost one-third respondents were neutral.

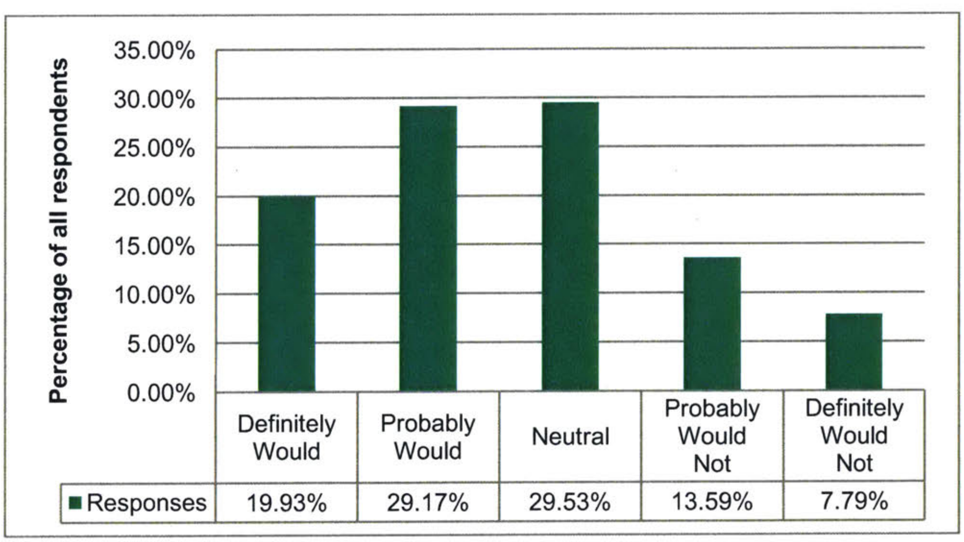

Figure 5. Desire to use an Urban Air Mobility Service.

Table 3 provides a detailed breakdown by demographic group. In general, younger respondents had a more favorable view of UAM services and are more likely early adopters. The percentage of respondents who "definitely would" use the service decreased as age increased.

Table 3. Desire to use and Urban Air Mobility service.

Response	Gender		Age				Total
	Female	Male	18-29	30-44	45-59	60+	
Definitely Would	15.4%	29.1%	30.5%	25.5%	13.3%	9.9%	19.9%
Probably Would	29.0%	29.1%	31.4%	30.9%	31.1%	22.8%	29.2%
Neutral	32.0%	24.7%	24.6%	27.9%	31.1%	37.6%	29.5%
Probably Would Not	15.2%	10.4%	8.5%	10.9%	15.6%	17.8%	13.6%
Definitely Would Not	8.4%	6.6%	5.1%	4.8%	8.9%	11.9%	7.8%

"Would you have any concerns about using this service? If so, please select any that apply."

Figure 6 summarizes the findings for users concerns about using a UAM service. The response percentages show the percentage of all respondents that selected a specific concern. For example, 69% of all respondents were concerned about price. Price and safety were the most common concerns. In the free response option: other concerns included availability, accessibility, number of passengers, and family use with small children, and fear of flying.

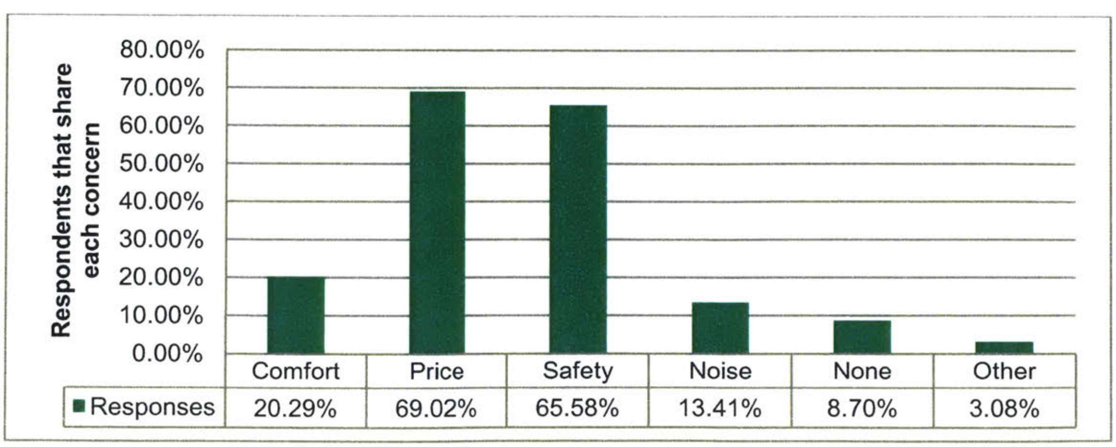

Figure 6. Concerns about using an Urban Air Mobility service.

"What type of trips would you like to use this service for? Please select all that apply."

Figure 7 summarizes likely uses for UAM services. Respondents were asked what type of trips they would like to use the service for. The response percentages show the percentage of all respondents that selected a specific use. Of the potential use cases identified in the case study methodology, it appears that users are more likely to use the service for point-to-point missions (special events and trips to the airport) than daily commute missions.

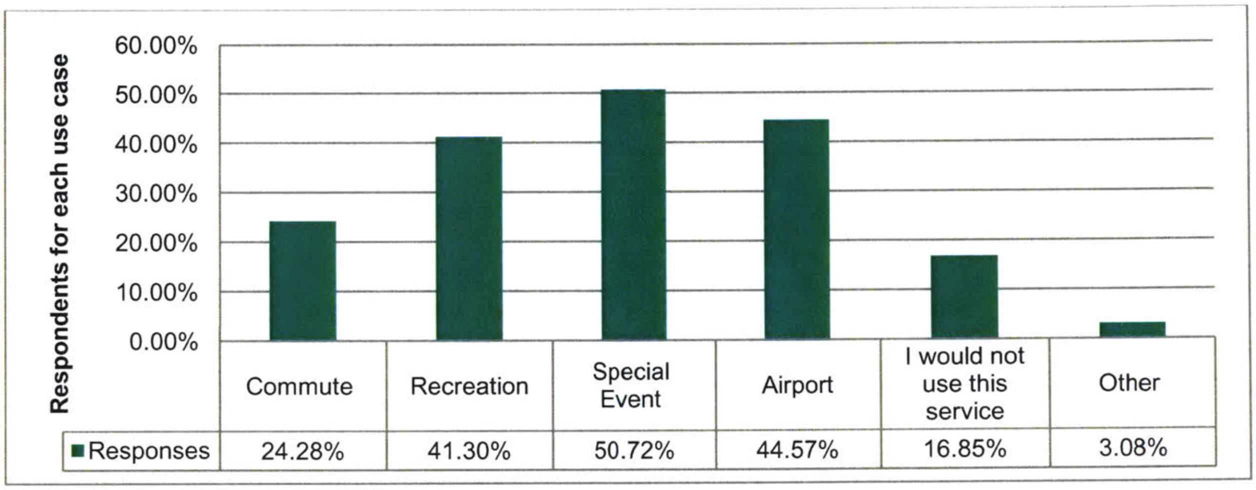

Figure 7. Desired uses for a UAM service.

"What would you expect the likely benefits of this service to be? Please select all that apply."

Figure 8 summarizes the benefits that users expect from a UAM service. Respondents were allowed to select all of the expected likely benefits of a UAM service. The majority of users (78%) expected a UAM service to provide shorter travel time from origin to destination.

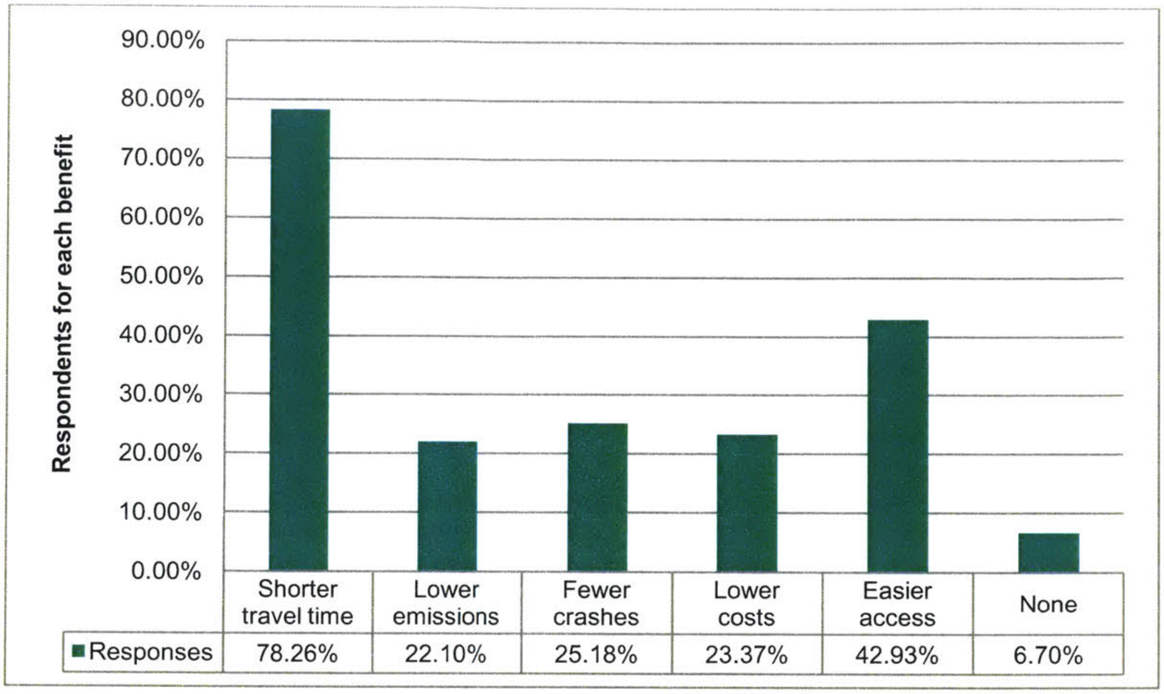

Figure 8. Expected likely benefits of a UAM service.

"How many people would you normally want to travel with?"

Figure 9 summarizes respondent's preferences for the number of people they would normally want to travel with. The majority (87.3%) of respondents needs could be meet with a vehicle that could hold three occupants.

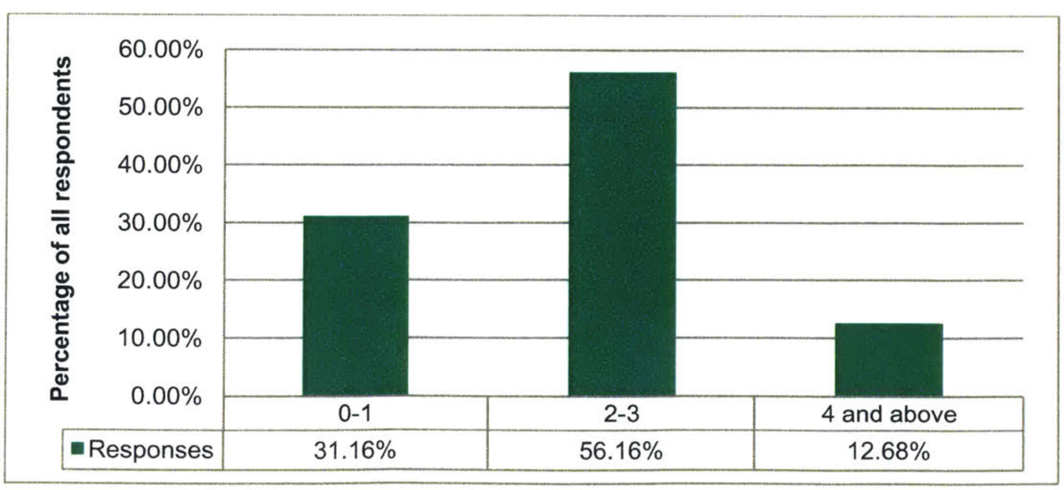

Figure 9. Seating capacity requirements.

The following questions were asked together and consisted of multiple responses:

"Please enter a trip you would use this service for (please enter a specific location)

- **Origin:**
- **Destination:**
- **Approximate Distance (miles):**

How much would you expect to pay for this service? (Approximate price in US Dollas)
How much would you be willing to pay for this service? (Approximate price in US Dollars)"

Full responses were received from 461 respondents. The question was designed as an open ended question so that users would not be anchored to any distance or price point. The origin and destination question yielded a broad range of responses that were not possible to correlate to specific locations. This question did yield responses for the approximate distance that users would like to use the service for and how much they would expect and be willing to pay for that service. Figure 10 displays the Cumulative Density Function (CDF) for users response to the approximate distance they would use the service for. Responses ranged from zero to 500,000 miles. In Dallas-Fort Worth, 50% of respondents selected trips less than 30 miles and 77.8% of all users selected missions less than 100 miles.

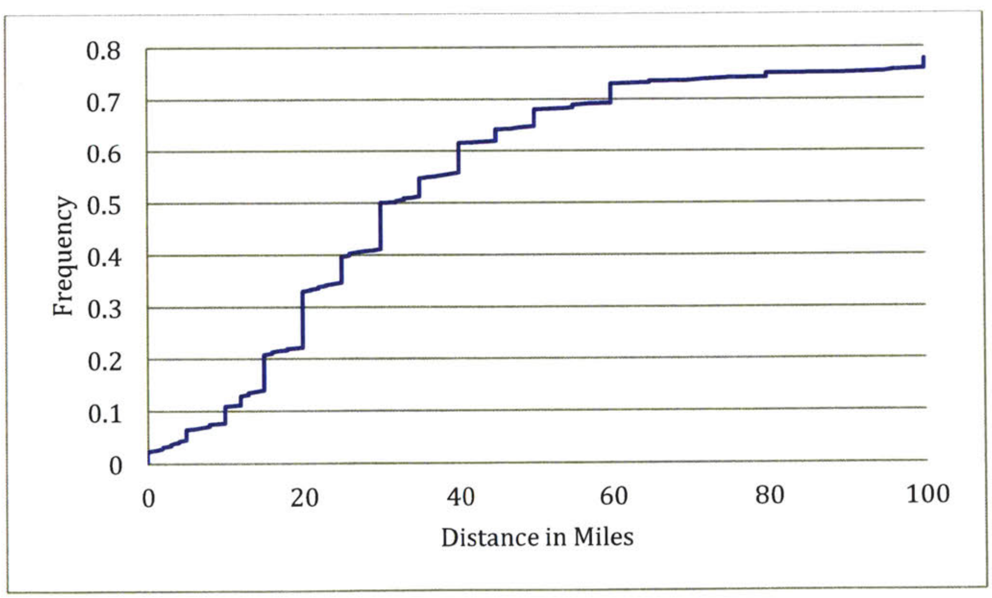

Figure 10. Distance that users desire to travel using an UAM service

Respondents were then asked how much they would expect to pay and how much they would be willing to pay for this service. Figure 11 displays the Cumulative Density Function (CDF) for users response regarding price. Both responses yielded similar trends, but users expectation to pay exceeded willingness to pay. This can been seen in Figure 11 where a greater percentage of respondents are willing to pay a lower price. The CDF is divided in order to display two potential groups of consumers. On the left side, 70% of respondents are willing to pay less than $2/passenger mile for UAM services. On the right side, there is a portion of users that are willing to pay higher rates. For example, 9.2% of respondents are willing to pay more than $5/passenger mile. This indicates that there are multiple markets for UAM services and customers that are potential early adopters at a higher price point.

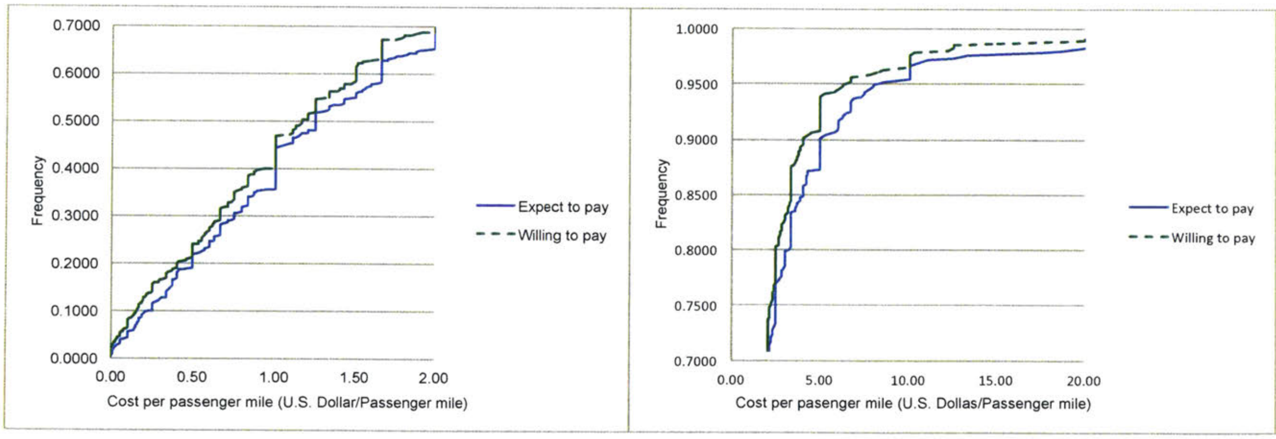

Figure 11. Customer expectation and willingness to pay (U.S. Dollar/Passenger mile)

"Which of the following modes of ground transportation would you expect to use for getting to and from a take off and landing area?"

Figure 12 summaries how users would likely commute to a take off and landing area. Almost two-thirds of respondents (71.4%) would use a personal car to travel to a TOLA. This creates a potential operational challenge due the availability of parking at potential take off and landing areas.

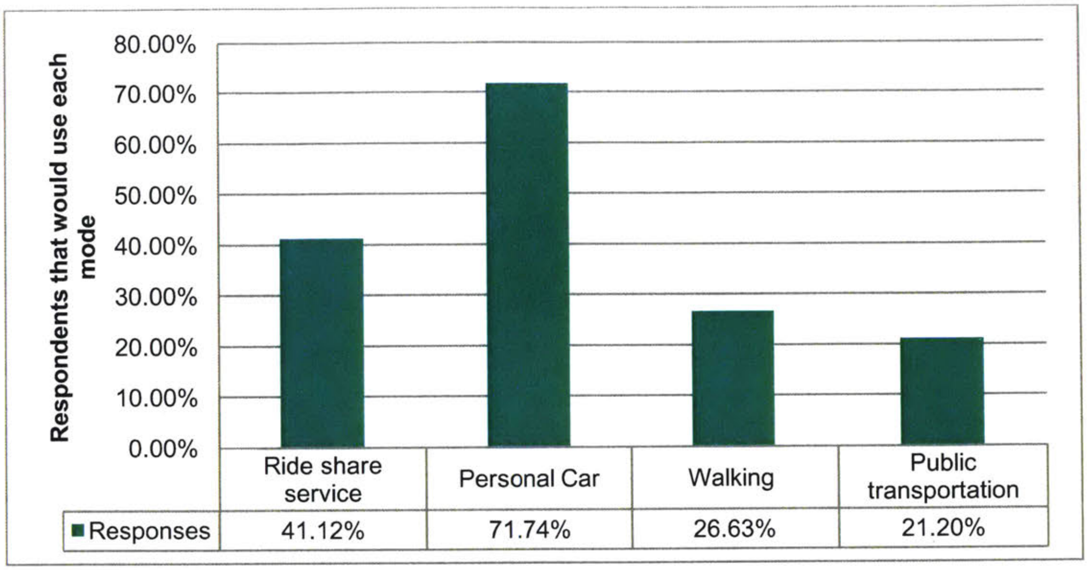

Figure 12. Transportation to Take Off and Landing Areas.

"I would not use this service if the Take Off and Landing Area is more than _____ miles from my starting or destination point."

The availability of ground infrastructure is a potential challenge that could limit customers to desire to use a UAM service. This question was designed to determine how far customers would be willing to travel to a Take Off and Landing Area. The question used an open response format so that respondents were not anchored to certain distances. Figure 13 displays the Cumulative Density Function (CDF) of responses to this question. In Dallas-Fort Worth, 90.6% of all respondents were willing to travel less than one mile and 60.4% of all respondents were willing to travel less than 10 miles to reach a TOLA. There are pronounced steps at 1, 5, 10, 15, and 20 miles where respondents willingness to travel drops.

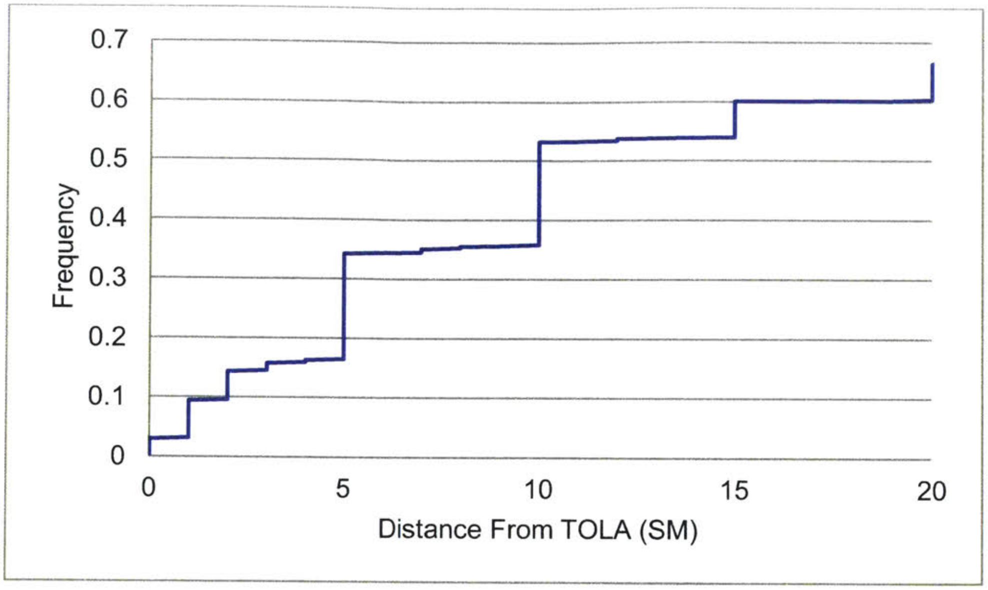

Figure 13. Respondent willingness to travel to a TOLA

"Would you be willing to share your ride with other passengers?"

Figure 14 summaries the findings concerning users acceptance to share their ride with other users. The majority (83.7%) stated they would be willing to share their ride with other passengers.

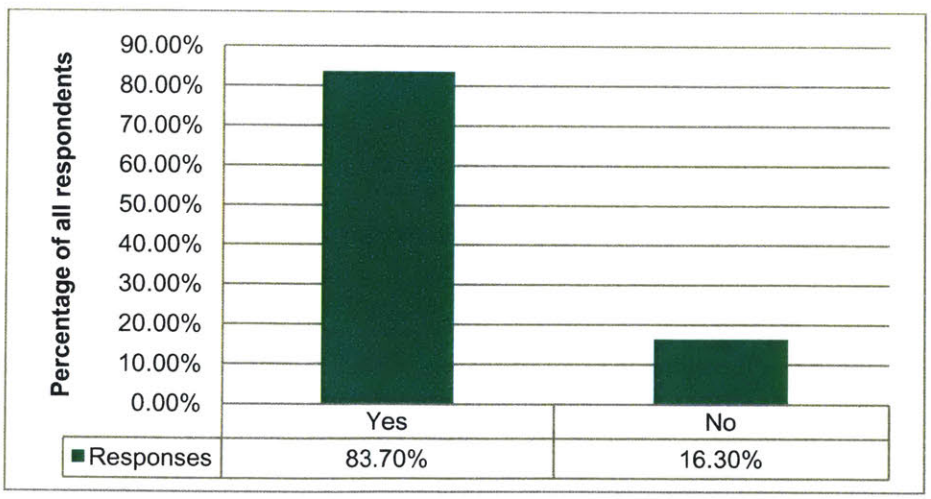

Figure 14. Users willingness to share with other passengers.

"Would you prefer to schedule your ride the day prior, or order on demand the day of?"

Figure 15 summarizes the findings concerning users desire to schedule the service the day prior or the day of. In Dallas-Fort Worth, the majority of users (69.4%) prefer to schedule the service at least one day prior to use. This indicates that service providers may be able to anticipate demand the day prior to service offerings and may offer increase predictability as the service scales.

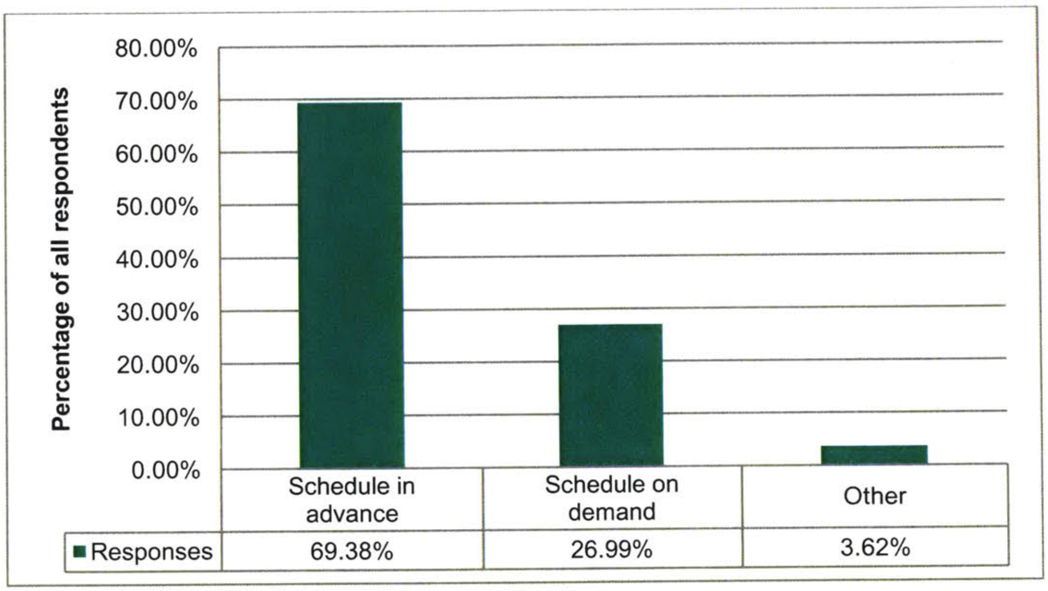

Figure 15. Respondents scheduling preferences.

"Which source of energy would you prefer for this service to use?"

Figure 16 summaries the findings concerning users preferred energy source. In this case, 42.8% of respondents preferred a gasoline or diesel energy sources versus 26.8% that preferred a fully electric vehicle. Based on these results, there does not appear to be strong market demand for electric or hybrid vehicle configurations in the Dallas-Fort Worth market. This gives equipment manufactures flexibility in vehicle design based on passenger requirements.

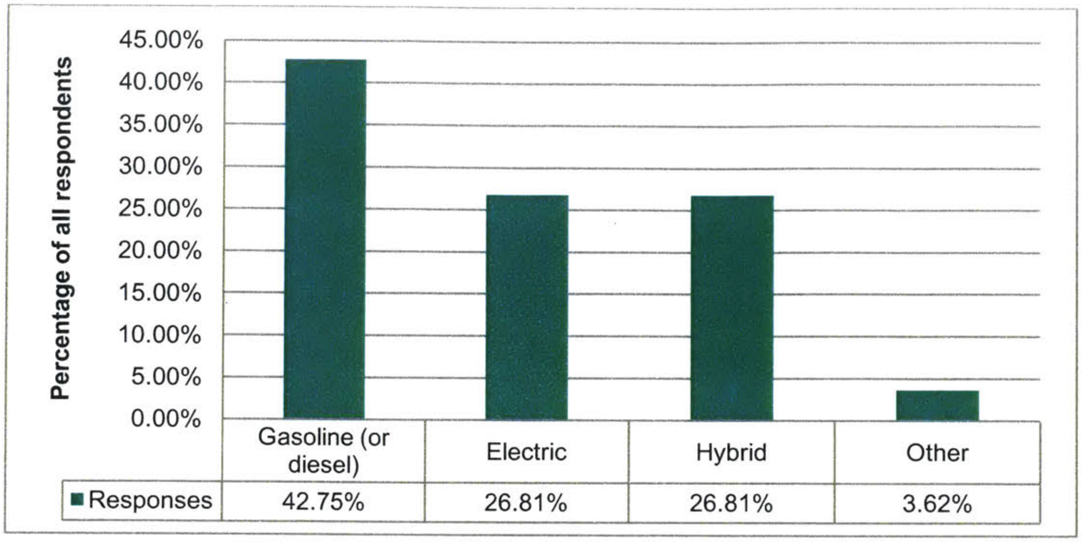

Figure 16. Energy preference for vehicle configurations

"Would you be willing to ride if the aircraft was flown automatically?"

Figure 17 summaries the findings concerning users preference for automatically flown vehicles to human piloted aircraft. In Dallas-Fort Worth, 43.3% of respondents indicated that they would be willing to use an automatically flown vehicle. This is a high level of confidence in a technology that is not currently used to carry passengers and does not have a performance or safety record. Acceptance of autonomous vehicles would give equipment manufactures more flexibility in vehicle design that could lead to increased utilization and decreased operating costs.

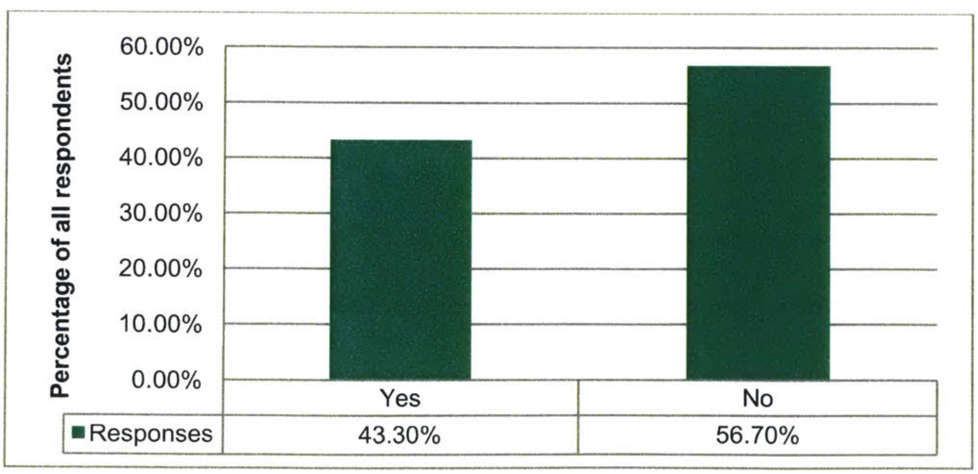

Figure 17.Would users fly in an automatically flown aircraft

"If this service were located in your neighborhood, would you have any concerns? If yes, please select all that apply:"

Figure 18 summarizes respondents concerns if this service was operated in their neighborhood. Users primary concerns were safety (59.2%) and noise (41.7%). Other concerns included the time the service would be operated.

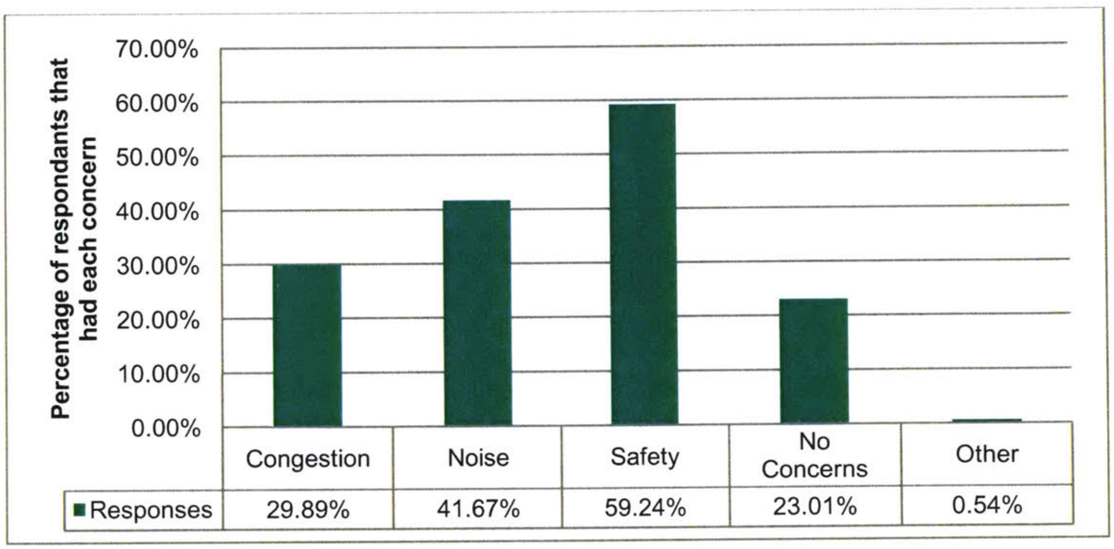

Figure 18. Residents concerns for local operation

"Please enter any additional questions or comments that you have about this concept and service."

The final question allowed respondents a free response to add any additional points. The most common responses involved questions and concerns about safety and price. Several questions were also raised regarding vehicle capabilities. Respondents asked if the vehicle would accommodate families with small children and passengers with disabilities. Additional responses asked about luggage storage and the ability to change destination during a trip.

4.4 Key Findings

The first section of the survey accessed respondent's familiarity with the concept of Urban Air Mobility and concerns for using the service. Less than one-third (28.3%) of respondents were familiar with the concept of Urban Air Mobility, air taxis, or flying cars. Despite not being familiar with the service, almost half (49.1%) of respondents said they would like to use an Urban Air Mobility service. When asked about concerns, price and safety were the most common responses. These concerns were shared by approximately two-thirds of users (69.0% and 65.6% respectively). The survey identified that respondents in Dallas-Fort Worth were not familiar with the service, but may be receptive to using UAM services.

The next section of the survey accessed how customers would prefer to use the service. Point-to-point missions (airport and special events) were the most desired UAM mission type followed by commuter missions. Shorter travel time was the most anticipated benefit of a UAM service (shared by 78.3% of respondents). Additional, A majority of respondents (69.4%) would prefer to schedule their ride in advance. It is possible in that congestion during special events in Dallas-Fort Worth could be perceived as more difficult than daily commute traffic. Cities that experience higher commuter congestion penalties may see different user responses.

The next section focused on operational challenges based on how respondents desired to use the service. In Dallas-Fort Worth, 90.6% of all respondents were willing to travel less than one mile and 60.4% of all respondents were willing to travel less than 10 miles to reach a TOLA. Over two-thirds of respondents (71.7%) would use their personal car to travel to the TOLA site. Additionally, A majority of respondents (83.7%) would be willing to share their ride with other passengers. These results indicate that respondents are likely to use the service, but will use their personal vehicle to travel to the TOLA location. Availability of take off and landing areas and parking are likely operational challenges that may result.

The fourth section focused on factors that might influence vehicle and system design. One important consideration is the aircraft propulsion system. Based on these results, there does not appear to be strong market demand for electric or hybrid vehicle configurations in the Dallas-Fort Worth market. Forty-two percent of respondents indicated that gasoline or diesel was their preferred energy source. Hybrid and electric followed and was evening split at 26.8% each. This give equipment manufactures more flexibility in aircraft design.

One particularly interesting result is that 43.3% of respondents indicated that they would be willing to use an automatically flown vehicle. This is a high level of confidence in a technology that is not currently used to carry passengers and does not have a performance or safety record. Acceptance of autonomous vehicles would give equipment manufactures more flexibility in vehicle design that could lead to increased utilization and decreased operating costs. For example, another question found that a seating capacity for three passengers meets 87.3% of respondents normal travel needs. Removing the pilot from the aircraft has the potential to make this requirement easier to meet.

Respondents were also asked how far they would like to travel and how much they would be willing to pay for that service. In Dallas-Fort Worth, 50% of respondents selected trips less than 30 miles and 77.8% of all users selected missions less than 100 miles. In analyzing customer willingness to pay, 70% of respondents are willing to pay less than $2/passenger mile for UAM services. There was a portion of the population (9.2%) that is willing to pay more than $5/passenger mile. This indicates that there are potential customers that will be willing to pay higher prices and could be potential early adopters as the service starts. Higher levels of utilization will require lower costs.

Each of the survey sections provides respondent insight into potential operational challenges that may impact implementation into UAM operations in Dallas-Fort Worth. Not included in the individual sections, men tended to have a stronger desire to use the service than females and overall positive feelings decreased with age. Of all respondents, safety and noise (59.2% and 41.7% respectively) are the primary concerns regarding UAM services operating in local areas. The results of this survey analysis are used in the following sections to develop reference missions and identify potential operational challenges that exist in those missions.

5. Case Study Approach and Market Opportunities

There have been many potential market opportunities identified for UAM services. The case study approach, market opportunities, and reference mission sections use the approach and methodology developed by Parker Vascik at the Massachusetts Institute of Technology [10]. Vascik applied this approach to case studies in Los Angeles and Boston. The same approach and methodology is used in order to compare geographically diverse regions for UAM services. This study considers two potential UAM markets in the analysis:

1. Daily Commuter: an aircraft is utilized during business days to take a passenger from or near their residence to their place of employment and return at the end of their workday.
2. Non-Commute Point to Point: an aircraft is utilized to transport a passenger on a non-commuter trip between two locations such as a major entertainment event, a major transportation hub, or a recreational trip.

While there are many applications for UAM services, these missions were not considered for potential early adoption analysis because they were perceived to have less revenue potential and were not deemed as interesting to near term service providers.

Four consumer groups were identified as potential early adopters of UAM services. First, individuals with long distance commutes or those traveling through areas of severe congestion on a daily basis. Second, individuals traveling to events that expect to encounter significant delays (such as a major sporting event). Third, wealthy consumers that may be willing to pay for decreased travel time and convenience. Finally, those consumers with tight travel timelines and consequences for missed deadlines, such as travel to airports and hospitals. The travel demand patterns of each consumer group were analyzed through commuter transportation flows, consumer income data, and regional population density.

5.1 Dallas Fort-Worth Boundary Area Identification

The Dallas Fort-Worth metropolitan area was selected for a UAM service case study because of the expectation that the metropolitan area is uniquely suited as an early adopter market. The metropolitan area has experience rapid growth and is expected to continue to grow rapidly for the foreseeable future. Congestion problems have not been as severe as other large metropolitan areas; however, increase in travel time due to congestion is expected to increase almost 100% over the next two decades with no improvements. [1] The potential increase in demand combined with a large consumer base, existing helipad infrastructure, and mild weather make the city suited to become an early adopter market.

Five factors were investigated in order to define the case study system boundary. The factors are:

1. Commuter transportation flows within the metropolitan area
2. Current helicopter charter services
3. Regional population densities
4. Anticipated UAM mission profiles
5. The Metropolitan Transportation Plan for North Central Texas

First, commuter transportation flows were estimated using US Census LEDH Origin-Destination Employment Statistics (LODES) for six cities in the Dallas-Fort Worth metropolitan areas. [2] This data provided the distance and direction that commuters travel to and from work on a daily basis. From this data, it was recognized that commuters travel both into the city centers and out of the city center. This occurs because of the regionally distributed nature of the metropolitan area with multiple city centers.

Second, current helicopter charter services were analyzed as the nearest representation of intra-urban UAM services. These services are summarized in Table 4.

Table 4. Dallas-Fort Worth helicopter charter companies

Helicopter Charter Companies	Services
Epic Helicopters	Charters, scheduled flights
FLYDAR Air Services	Charters, police
Texas Helicopter Experiences	Tours
Fort Worth/Dallas Helicopter Charters	Charters
Air Center Helicopters	Tours
Longhorn Helicopters	Charters, Tours
Sky Helicopters	Charters, scheduled flights, surveying

Seven helicopter charter companies currently operate in the Dallas-Fort Worth metropolitan area. The primary services offered are helicopter tours, including city tours and trips to local scenic destinations, and scheduled charter services.

Third, regional population densities were considered. A notional threshold population density of at least 101 people per square mile was chosen to represent a community with sufficient population to support UAM services.

Forth, anticipated UAM mission profiles were considered based on a review of the characteristics of proposed UAM missions and projections of UAM aircraft range capabilities. Because of the distributed nature of the Dallas-Fort Worth Metropolitan area, both inter-urban and intra-urban flights must be considered. This boundary area limitation also considers the existing boundary of the North Central Texas Council of Governments (NCTCOG) metropolitan planning area, which includes the 10 counties surrounding Tarrant and Dallas County. Figure 2 shows the metropolitan planning area for North Central Texas.

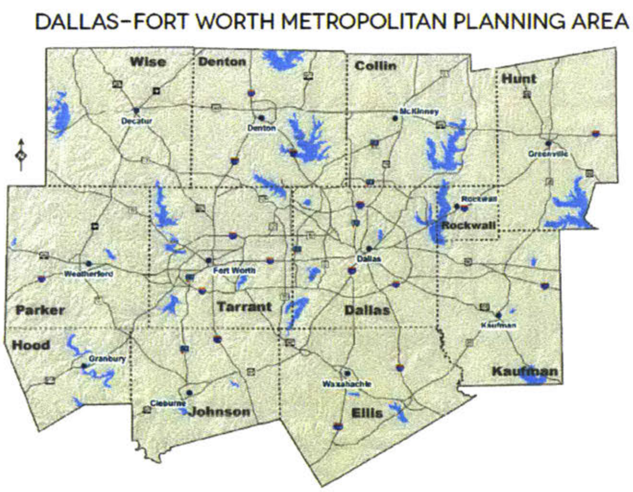

Figure 19. NCTCOG Metropolitan Planning area [13].

6. Dallas-Fort Worth Case Study Reference Mission Definition

This chapter focuses on the third step of the case study methodology by defining 10 reference missions for which ConOps may be developed and analyzed. The 10 reference missions in this case study were selected to capture the diversity of potential missions in the Dallas-Fort Worth metropolitan area. The missions represent multiple types of markets with diverse ranges, duration, demand, and airspace constraints. The missions also account for different levels of ground infrastructure and flight profiles. Eight of the missions were selected to represent potential early adoption markets and two of the flights were randomly selected to account for selection bias. The randomly selected missions also serve as a means to capture previously unidentified challenges and constrains. These missions cover a diverse range of potential consumer needs and mission requirements from both the daily commute and non-commute point –to-point mission categories. The 10 missions defined in this chapter are summarized in Table 5.

Table 5. Summary and characteristics of the 10 reference missions

Mission Category	Mission Number	Mission Origin and Destination Point	
		Origin	Destination
Daily Commute Missions	1	Frisco Square	American Airline Center
	2	Dallas Downtown (US)	McKinnney
	3	Westlake	Dallas City Center
	4	Fort Worth (Sundance Square)	Union Station (Dallas Downtown)
Point to Point Missions	5	DFW	Frisco Station
	6	Dallas Downtown (US)	DFW International Airport
	7	Plano	Cowboys Stadium (Arlington)
	8	Meacham Airfield	Texas Motor Speedway
Randomly Selected Missions	9	Ferris	Irving
	10	Mansfield	Plano

6.1 Reference Mission Definition Approach

The 10 missions listed above were selected to represent the potential breadth of system-level requirements that may emerge concerning aspects such as mission, range, and the consumer groups the mission would serve. The first step was to select origin and destination points for the potential UAM services. These were selected based on the potential early adopter markets identified in the previous section. A representative address was selected in each origin and destination location (such as a neighborhood or business location).

The validity of the commuter reference mission origins and destinations was analyzed using the U.S. Census Bureau Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) 2014 data sets [20]. The LODES data was used to develop a "laborshed" mapping for the reference missions origin area. This mapping typically displays where workers in a specific reference area live and commute to work. This data does not capture the commuting pattern of every individual in the area and cannot be considered a precise estimation of consumer demand. In this case study, the tool is used to confirm potential commuter routes to identify potential missions for UAM services. Figure 20 shows an example of analysis of Frisco, TX displaying the share of jobs for given distances and directions from the city.

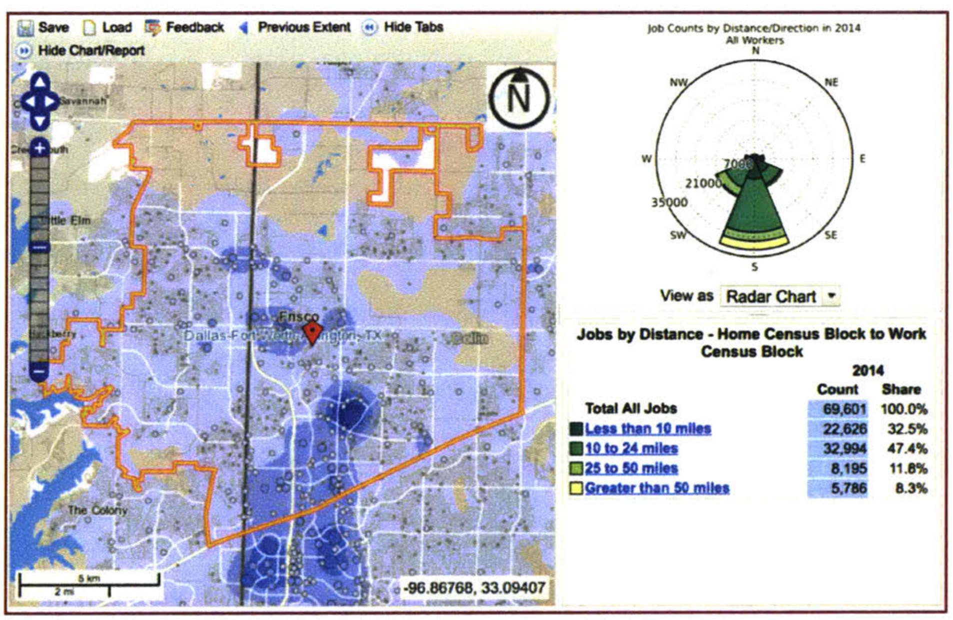

Figure 20: Frisco, TX, LODES Workers Distance/Direction Analysis Home to Work [20]

This tool only provided useful data for the daily commuter missions. It did not provide insight for non-commute point-to-point missions or the randomly selected missions.

Next, a ground transportation study was conducted for each reference mission. This study used predicted times for ground automobile traffic using Google Maps™ travel prediction tool. The results provided an estimate of transportation time and the severity of congestion along the reference routes. Google uses sophisticated travel prediction algorithms that draw upon official speed limits, recommended speeds, likely speeds based on road type, historical data (adjusted for time and day), and actual travel time from users [21]. Travel patterns very during the week and have a different travel pattern than weekend travel. Tuesday was selected a representative day for weekday travel and is used to estimate travel times in each reference mission.

Finally, potential take off and landing areas were identified for UAM aircraft to use in each reference mission. For this case study, locations were considered if they were assessed as being capable of supporting helicopter take off and landing.

6.2 Daily Commute Reference Missions

The daily commuter reference missions cover the scenario where a UAM aircraft is utilized to transport individuals to and their place of employment during a standard business day. This study uses Tuesday, 14 November 2017 to represent a standard day. Each day of the week exhibits a slightly different travel profile, but travel predictions for Tuesday appeared to be most representative of a mean travel day. This research proposes that early adopters of UAM services will most likely be where users experience the longest delays in daily commute. The Dallas Fort-Worth metropolitan area exhibits few geographical barriers to travel. The primary means of delay is due to congestion during peak travel periods. The following four reference missions are introduced in the following sub-sections.

6.2.1 Frisco Square to American Airlines Center

The Frisco Square reference mission captures a likely commuter market with no alternative ground transportation options. Frisco is a growing city North of the Dallas city center. Commuters travel from Frisco into the Dallas city center for work each day. Although the primary route is only 26.7 miles and an average of 31.5 minutes during non-peak traffic, travel time can increase to a high of 70 minutes and an average of 55 minutes during peak traffic incurring an average congestion penalty of 87%. While there are alternative routes, those routes are not available until the last third of the trip where commuters are likely to face similar congestion penalties using alternative routes. Figure 21 displays the primary route from Frisco Square to American Airlines Center.

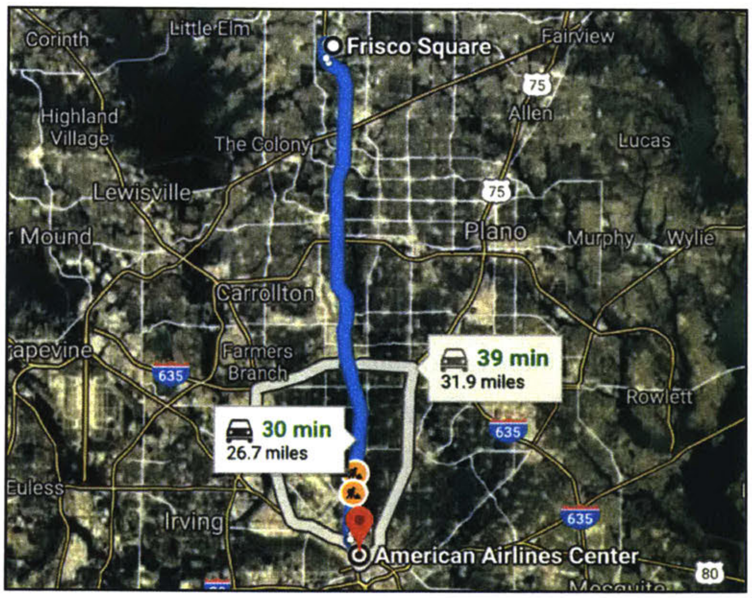

Figure 21. Frisco Square to American Airlines Center
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 6 displays the specifications for the Frisco to American Airlines Center reference mission. The origin point was chosen as Frisco Square. Frisco Square is in the center of Frisco with access to parking for commuting residents. American Airlines Center is on the northern edge of the city of Dallas, home of the Dallas Mavericks, and has access to many businesses in Downtown Dallas. While there are suitable takeoff and landing areas at the origin and destination, no helipads exist at the current sites.

Table 6. Frisco to American Airlines Center reference mission specifications.

Type:	Commuter			
Origin:	Frisco Square: 8874 Coleman Blvd, Dallas, TX 75034			
2017 Origin Helipad:	TX80 (2.75 miles)			
Destination:	American Airlines Center: 2500 Victory Ave, Dallas, TX 75219			
Destination Helipad:	9TA4 (0.88 miles)			
Driving Distance:	26.6	mi primary ground	31.8	mi secondary ground
2017 ODM Distance:	2.75	mi to helipad	25.0	mi LOS flight

Table 7 presents the ground transportation study for the Frisco to American Airlines Center reference mission. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 12:00 PM inbound and 1:00 AM to 8:00 PM outbound for the Frisco Square to American Airlines Center reference mission. The total travel time was recorded as well and the low, high, and average travel time. Ground transportation study data was collected for each reference missions using the format presented in Table 4 and summarized in Figure 6. The following reference missions only include the summary data.

Table 7. Frisco to American Airlines Center ground transportation study.

		Travel Time (minutes)					Avg. Speed (MPH)
	Date	**Time**	**Low**	**High**	**Average**	**+/-**	
Inbound	Tuesday, Nov 14, 2017	5:00	28	35	31.5	3.5	51
Inbound	Tuesday, Nov 14, 2017	6:00	28	35	31.5	3.5	51
Inbound	Tuesday, Nov 14, 2017	7:00	30	55	42.5	12.5	38
Inbound	Tuesday, Nov 14, 2017	8:00	40	70	55	15	29
Inbound	Tuesday, Nov 14, 2017	9:00	30	45	37.5	7.5	43
Inbound	Tuesday, Nov 14, 2017	10:00	28	40	34	6	47
Inbound	Tuesday, Nov 14, 2017	11:00	28	40	34	6	47
Inbound	Tuesday, Nov 14, 2017	12:00	28	40	34	6	47
Outbound	Tuesday, Nov 14, 2017	13:00	28	40	34	6	47
Outbound	Tuesday, Nov 14, 2017	14:00	26	35	30.5	4.5	52
Outbound	Tuesday, Nov 14, 2017	15:00	28	35	31.5	3.5	51
Outbound	Tuesday, Nov 14, 2017	16:00	30	50	40	10	40
Outbound	Tuesday, Nov 14, 2017	17:00	40	65	52.5	12.5	30
Outbound	Tuesday, Nov 14, 2017	18:00	35	50	42.5	7.5	38
Outbound	Tuesday, Nov 14, 2017	19:00	28	40	34	6	47
Outbound	Tuesday, Nov 14, 2017	20:00	28	40	34	6	47

Figure 22 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 12:00 PM and "outbound" captured from 1:00 PM to 8:00 PM as displayed in the ground transportation study in Table 4. The travel time bounds are often quite large, often varying by +/- 50% of the total travel time.

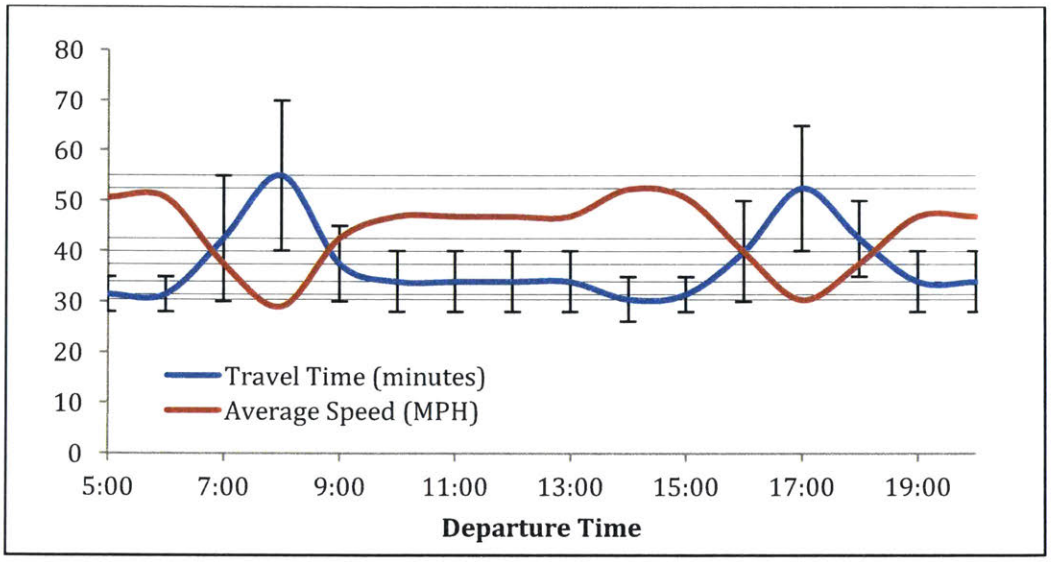

Figure 22. Frisco to American Airlines Center travel time and speed distribution.

6.2.2 Union Station to McKinney

The Union Station to McKinney reference missions capture a potential commuter market for commuters who desire to live near the Dallas city center and commute to nearby cities. Several cities north of Dallas receive commuter traffic from the Dallas city center (Plano, Allen, and McKinney). McKinney is the northern most city and the commute route includes the cities of Allen and Plano. As these cities continue to grow, McKinney appeared to be representative of an early adopter market. Highway 75 is the primary route from Dallas to McKinney and there no alternate routes that do not lead to significantly increased millage and travel times. Figure 23 shows the primary route from Union Station to McKinney.

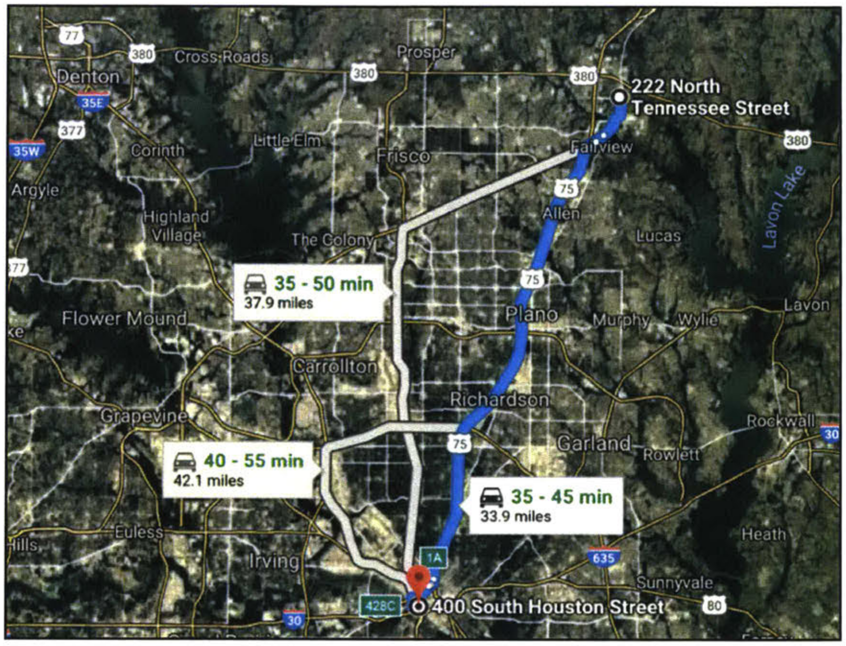

Figure 23. Union Station to McKinney
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 8 displays the specifications for the Union Station to McKinney reference mission. Union Station is a transportation hub into the center of downtown Dallas. Multiple ground transportation systems link into the station and an on-site helipad make the station a likely site for UAM services. The nearest helipad to the McKinney city center is a privately owned helipad 1.3 miles from the mission destination.

Table 8. Union Station to McKinney reference mission specifications.

Type:	Commuter			
Origin:	Union Station: 400 S Houston St. Dallas, TX 75202			
2017 Origin Helipad:	49T (0.41 miles)			
Destination:	McKinney, City Hall: 222 N Tennessee St, Mckinney, TX 75069			
Destination Helipad:	TE66, LMC Heliport (1.38 miles)			
Driving Distance:	33.9	mi primary ground	37.9	mi secondary ground
2017 ODM Distance:	1.38	mi to helipad	31.2	mi LOS flight

Ground transportation times predicted by the Google Maps^{TM} mapping service were collection from 5:00 AM to 12:00 PM inbound and 1:00 AM to 8:00 PM outbound. The reference mission is 33.9 miles on the primary ground route and takes 35 min during off-peak ground time. During peak travel times, this increases to a maximum travel time of 100 min incurring a congestion penalty of 186%. There is a secondary ground route to leave Union Station from downtown Dallas, but this secondary route then connects to the primary ground route and leaves no viable alternate route to bypass traffic during peak hours. Figure 24 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 12:00 PM and "outbound" captured from 1:00 PM to 8:00 PM as displayed in the ground transportation.

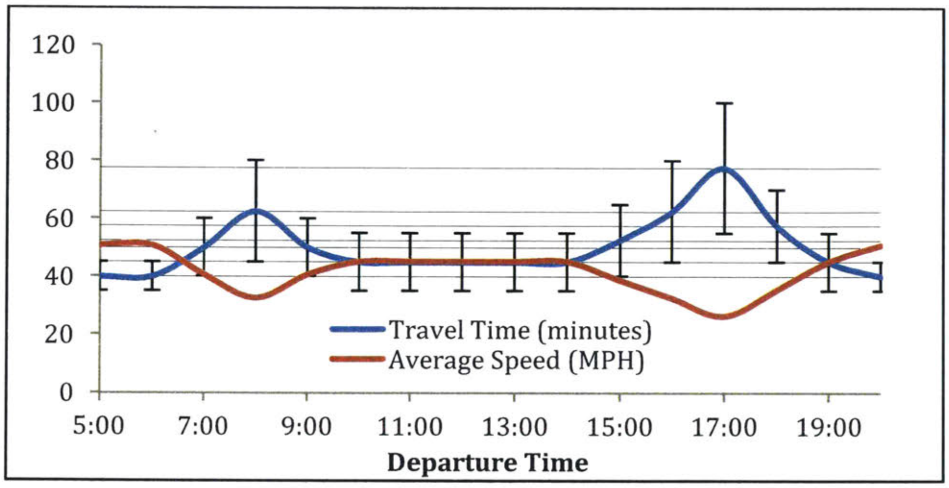

Figure 24. Union Station to McKinney travel time average speed distribution.

6.2.3 Westlake to Dallas City Center

The Westlake to Dallas city center reference commute captures a potential wealthy commuter market. The town of Westlake is located northwest of Dallas and had the highest median home value for the Dallas-Fort Worth metropolitan area. Westlake is also home to multiple corporate campuses and training facilities that generate increased traffic to and from the town. The town center is roughly 30 miles from the Dallas city center and multiple alternate routes exist between the two locations. Because of Westlake's location between Dallas and Fort Worth, commuters are subject to increased congestion and traffic flows both inbound and outbound. Figure 25 shows the primary route from Westlake to the Dallas City Center.

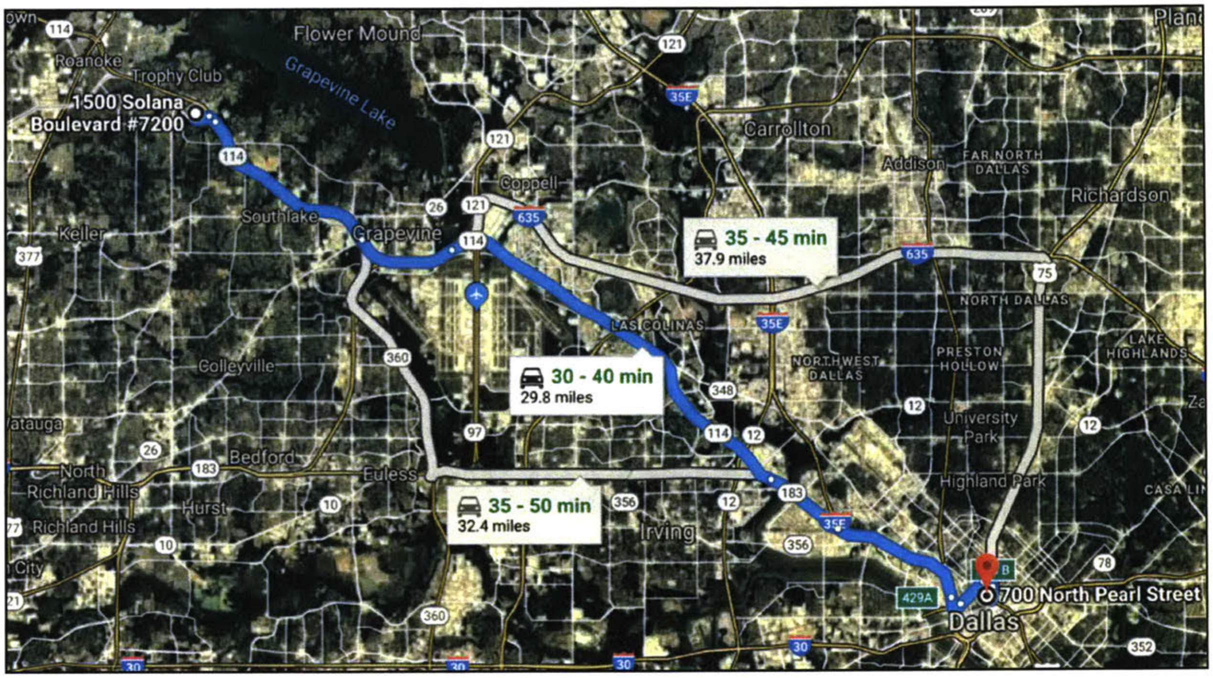

Figure 25. Westlake to Dallas City Center
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 9 displays the specifications for the Westlake to Dallas City Center reference mission. Westlake town hall has an on-site heliport and convenient parking to facilitate commuter traffic. The mission destination, Plaza of the Americas, is located in the Dallas City Center near the financial district and has an on-site heliport.

Table 9. Westlake to Dallas City Center reference mission specifications.

Type:	Wealthy Commuter			
Origin:	Westlake Town Hall: 1500 Solana Blvd #7200, TX 76262			
2016 Origin Helipad:	on-site			
Destination:	Plaza of the Americas: 700 N Pearl St. Dallas, TX 75201			
Destination Helipad:	9TA4 (0.38 miles)			
Driving Distance:	29.8	mi primary ground	37.9	mi secondary ground
Future ODM Distance:	0.38	mi (min) to helipad	25.9	mi LOS flight

Figure 26 displays the results of the Westlake to Dallas City Center ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 12:00 PM inbound and 1:00 AM to 8:00 PM outbound. The reference mission is 29.8 miles on the primary ground route and takes 30 min during off-peak ground time. During peak travel times, this increases to a maximum travel time of 75 min incurring a congestion penalty of 150%. Figure 10 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 12:00 PM and "outbound" captured from 1:00 PM to 8:00 PM as displayed in the ground transportation study.

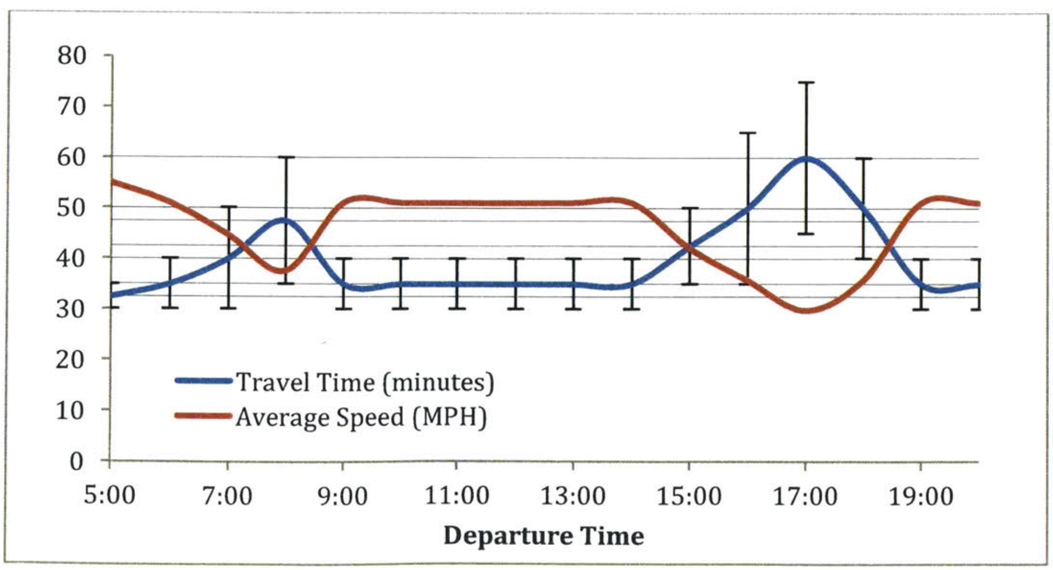

Figure 26. Westlake to Dallas City Center travel time average speed distribution.

6.2.4 Fort Worth City Center to Union Station

The Fort Worth City Center to Union Station reference mission captures commuters that live in Fort Worth and Commute to Dallas. Fort Worth is home to over 850,000 residents. While many of those residents work in Fort Worth, many of them and those from the surrounding cities commute to Dallas on a daily basis. There are three primary routes from Fort Worth to Dallas. Figure 27 shows the primary route from the Fort Worth City Center to Union Station.

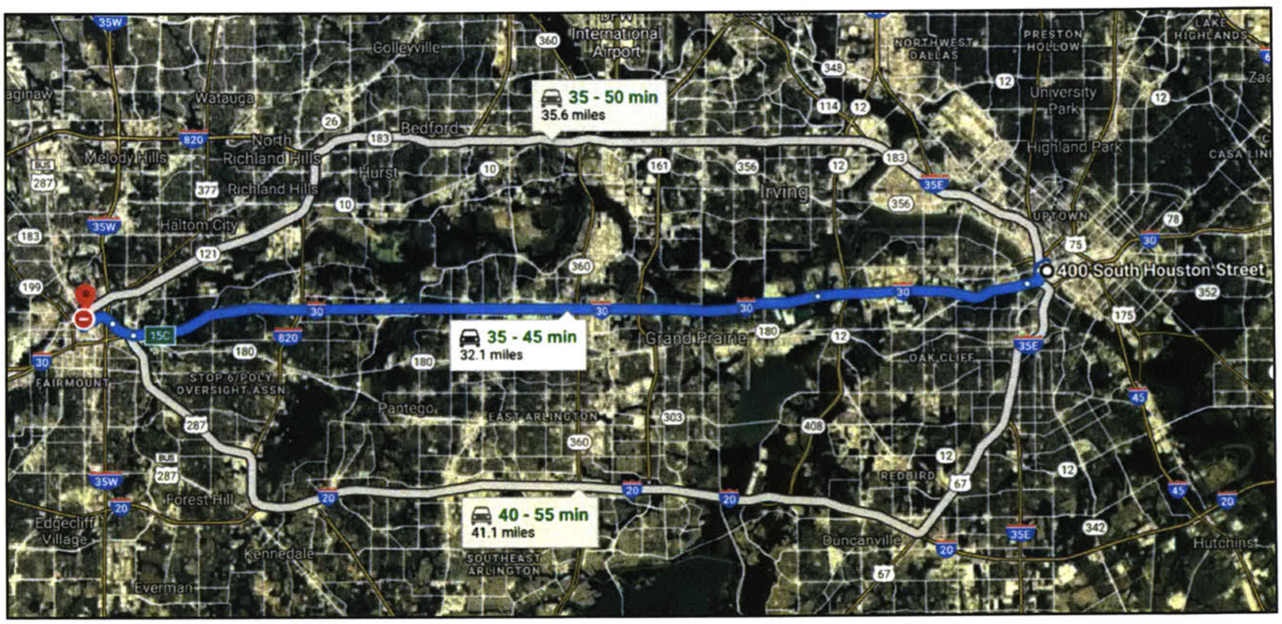

Figure 27. Fort Worth City Center to Union Station
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 10 displays the specifications for the Fort Worth to Union Station reference mission. Union Station is a transportation hub into the center of downtown Dallas. Multiple ground transportation systems link into the station and an on-site helipad make the station a likely site for UAM services. The nearest helipad to the Fort Worth City Center is the Mallick Tower Heliport and is 0.6 miles from the city center.

Table 10. Fort Worth City Center to Union Station reference mission specifications.

Type:	Commuter			
Origin:	Sundance Square: 420 Main St. Fort Worth, TX 76102			
2016 Origin Helipad:	TX77, Mallick Tower Heliport (0.6 miles)			
Destination:	Union Station: 400 S Houston St. Dallas, TX 75202			
Destination Helipad:	49T (0.41 miles)			
Driving Distance:	31.7	mi primary ground	35.5	mi secondary ground
Future ODM Distance:	0.6	mi (min) to helipad	30.5	mi LOS flight

Figure 12 displays the results of the Fort Worth City Center to Union Station ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 12:00 PM inbound and 1:00 AM to 8:00 PM outbound. The reference mission is 32 miles on the primary ground route and takes 30 min during off-peak ground time. During peak travel times, this increases to a maximum travel time of 70 min incurring a congestion penalty of 133%. Figure 28 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 12:00 PM and "outbound" captured from 1:00 PM to 8:00 PM as displayed in the ground transportation study.

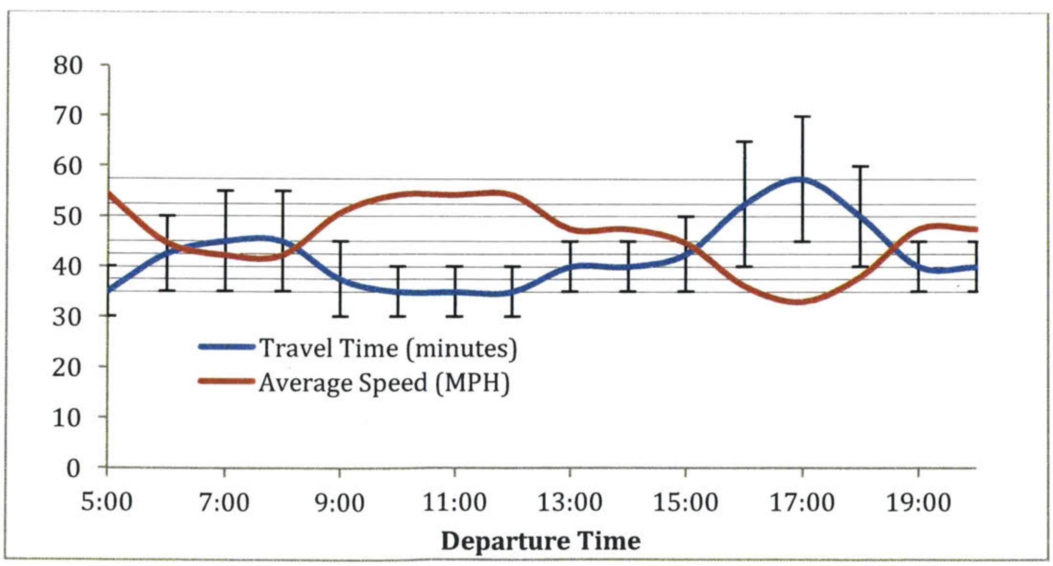

Figure 28. Fort Worth City Center to Union Station travel time average speed distribution.

6.3 Non-Commute Point-to-Point Reference Missions

Non-commute point-to-point missions cover scenarios where an aircraft is utilized to transport non-commuting individuals between two locations. These scenarios include situations like business trips between company locations, recreational trips in and out of the city, trips to sporting events, hospitals visit, and airport travel. Unlike commuting demand, these point-to-point missions are unlikely to follow the same peak inbound and outbound traffic patterns as commuter missions.

The first category of point-to-point mission involves travel between city centers and the Dallas-Fort Worth International Airport. The first, Dallas to Frisco Station was chosen because of the recent interest from Uber to conduct a "Uber Elevate" demonstration mission from DFW to Frisco Station. The Union Station to DFW mission captures likely point-to-point traffic from a central ground transportation hub in downtown Dallas to the airport.

The second category of point-to-point mission includes missions to popular events that are likely to draw customers will to pay for UAM services and that desire to avoid the increased congestion that accompanies these events. The first, Plano Station to Cowboys Stadium captures traffic from North Dallas cities to the Cowboys Stadium. The Second, Meacham Airfield to Texas Motor Speedway covers traffic for customers that desire to avoid traffic. Existing helicopter charter services already transport customers from the airfield to the speedway. Existing ground infrastructure and demand make it a likely early adoption location.

One additional set of point-to-point missions to consider is travel from one city center to another city center (inter-city missions). These services are currently offered in several cities for large businesses that may have locations in multiple cities in a geographic region. This service is also offered for travel over significant geological features, such a large body of water or mountain range. In this case study, this scenario is included in commuter missions. The Dallas-Fort Worth metropolitan area connects multiple city centers and is not separated by any significant geological features. As a result, commuter traffic between cities is common and more accurately captured by a commuter mission than a point-to-point mission. The following sections include the development and analysis of each mission.

6.3.1 DFW Airport to Frisco Station

The Dallas-Fort Worth International Airport (DFW) to Frisco Station reference mission covers a short distance mission from a major transportation hub to a suburban area. Demand for this type of mission is heighted due to the high cost associated with travel delays and willingness to offset the costs of airport parking. Frisco Station is the home to the training center for the Dallas Cowboys and has access to several Dallas Suburbs. The reference mission is 24 miles and can be completed in as little as 26 minutes without congestion. However, during peak congestion periods the trip may take as long as 40 minutes incurring a congestion penalty of 54%. This suggests that demand for this UAM mission may exist throughout the day and especially during peak travel times. Figure 29 shows the ground route from DFW Airport to Frisco Station.

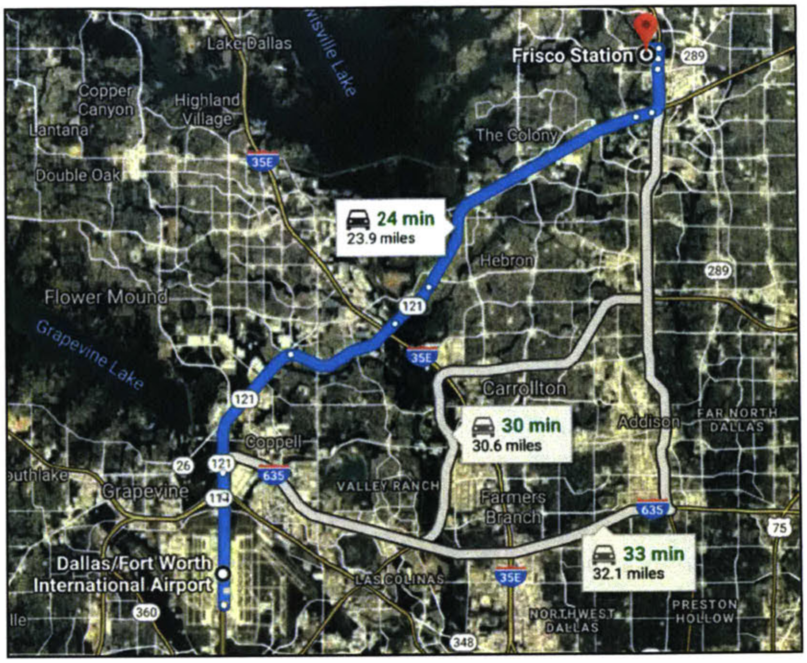

Figure 29. DFW Airport to Frisco Station

Table 11 displays the specifications for the DFW Airport to Frisco Station reference mission. Both locations have an on-site helipad and easy access for customer parking.

Table 11. DFW Airport to Frisco Station reference mission specifications.

Type:	Point to Point			
Origin:	DFW Airport: 2400 Aviation Drive, Dallas, TX 75261			
2017 Origin Helipad:	on-site			
Destination:	Frisco Station: 4141 Frisco Green Avenue, Frisco, TX 75034			
Destination Helipad:	on-site			
Driving Distance:	23.9	mi primary ground	30.6	mi secondary ground
2017 ODM Distance:	0	mi (min) to helipad	19.3	mi LOS flight

Figure 30 displays the results of the DFW Airport to Frisco Station ground transportation study. Ground transportation times predicted by the Google Maps^{TM} mapping service were collection from 5:00 AM to 8:00 PM. Figure 14 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 8:00 PM as displayed in the ground transportation study.

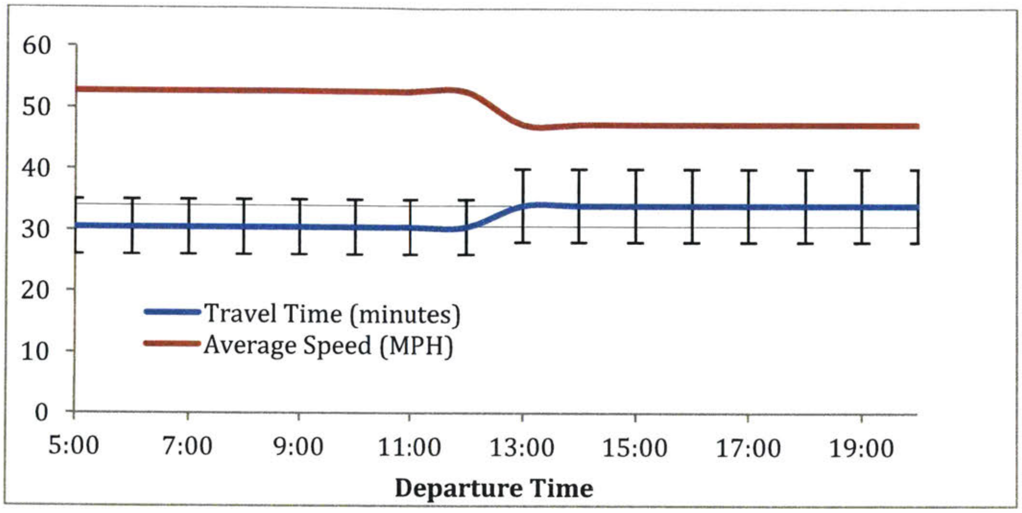

Figure 30. DFW Airport to Frisco Station travel time average speed distribution.

6.3.2 Union Station to DFW Airport

The Union Station to DFW Airport reference mission captures travel from a central business district in Downtown Dallas to a major transportation hub. Demand for this type of mission is heighted due to increased congestion along all primary travel routes and the large number of business travel customers likely to use this route. Union Station provides convenient access to many downtown locations. The reference mission is 19 miles and can be completed in 20 minutes with during off peak time. During peak congestion, this time can increase to 45 minutes incurring a 125% congestion penalty. Figure 31 shows the primary ground route from Union Station to DFW Airport.

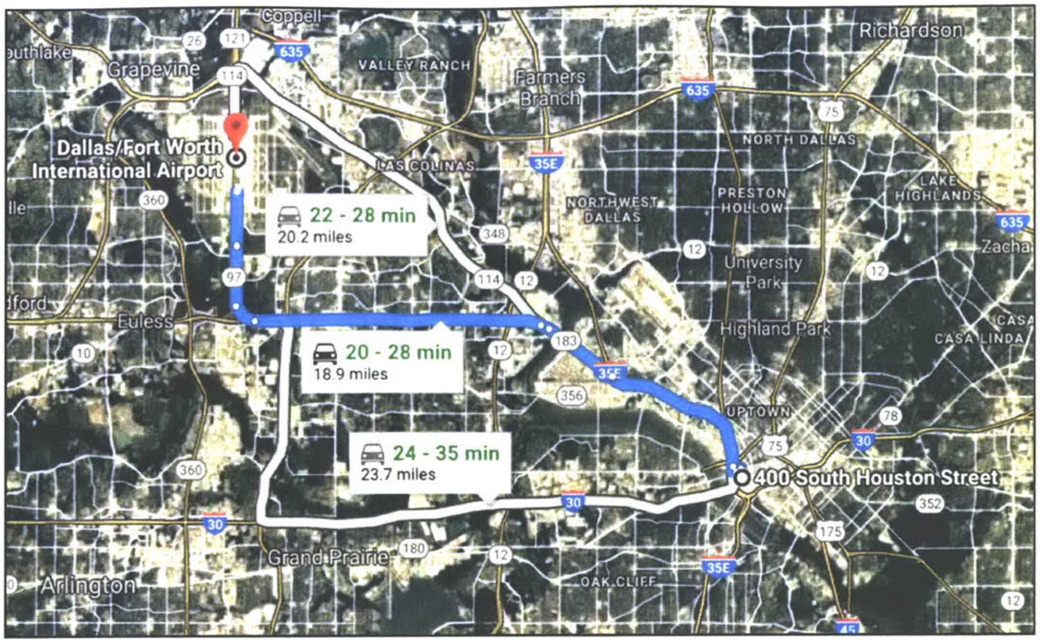

Figure 31. DFW Airport to Frisco Station
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 12 displays the specifications for the Union Station to DFW Airport reference mission. Both locations have on-site helipads and access to parking for ground transportation.

Table 12. Union Station to DFW Airport reference mission specifications.

Type:	Point to Point			
Origin:	Union Station– 400 S Houston St. Dallas, TX 75202			
2017 Origin Helipad:	49T (0.41 miles)			
Destination:	DFW Airport: 2400 Aviation Drive, Dallas, TX 75261			
Destination Helipad:	On-site			
Driving Distance:	18.9	mi primary ground	20.2	mi secondary ground
2017 ODM Distance:	0.41	mi (min) to helipad	15.9	mi LOS flight

Figure 32 displays the results of the Union Station to DFW Airport ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 8:00 PM. Figure 16 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 8:00 PM as displayed in the ground transportation study.

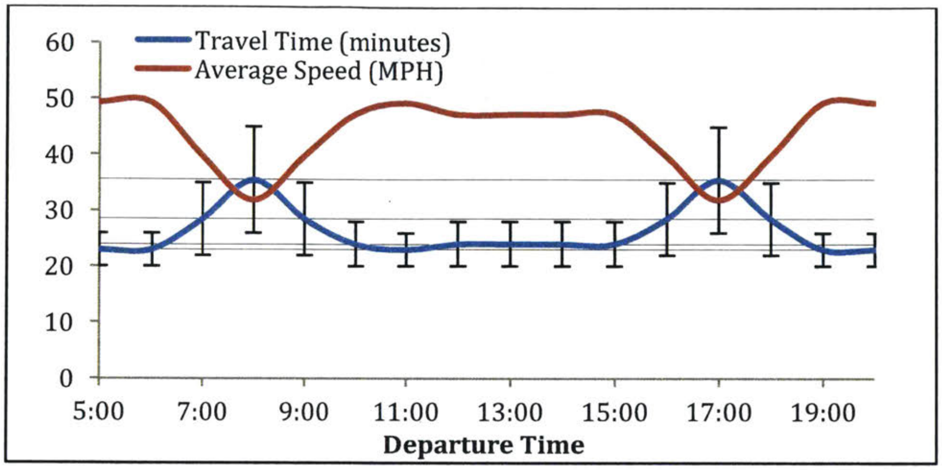

Figure 32. Union Station to DFW Airport travel time average speed distribution.

6.3.3 Plano to Cowboys Stadium

The Plano to Cowboys Stadium reference mission captures the mission from a suburban area to a major sporting venue. The nearly 100,000 fans that travel to the stadium during major sporting events increase demand for the mission. The customers in this mission will also have to cross several major transportation routes that can contain normal congestion from commuter traffic. This is true for residents living north of Dallas and also customers traveling through DFW Airport. The total trip is 39 miles and can take 35 minutes during off peak hours. During peak congestion, travel time can increase to 80 minutes incurring a congestion penalty of 129%. However, it should be noted that Google Maps^{TM} mapping service does not predict travel times during major sporting events. Travel times were calculated using the same standard day as the other time travel studies. Actual congestion during sporting is likely much higher. Figure 33 shows the primary route from Plano to Cowboys stadium.

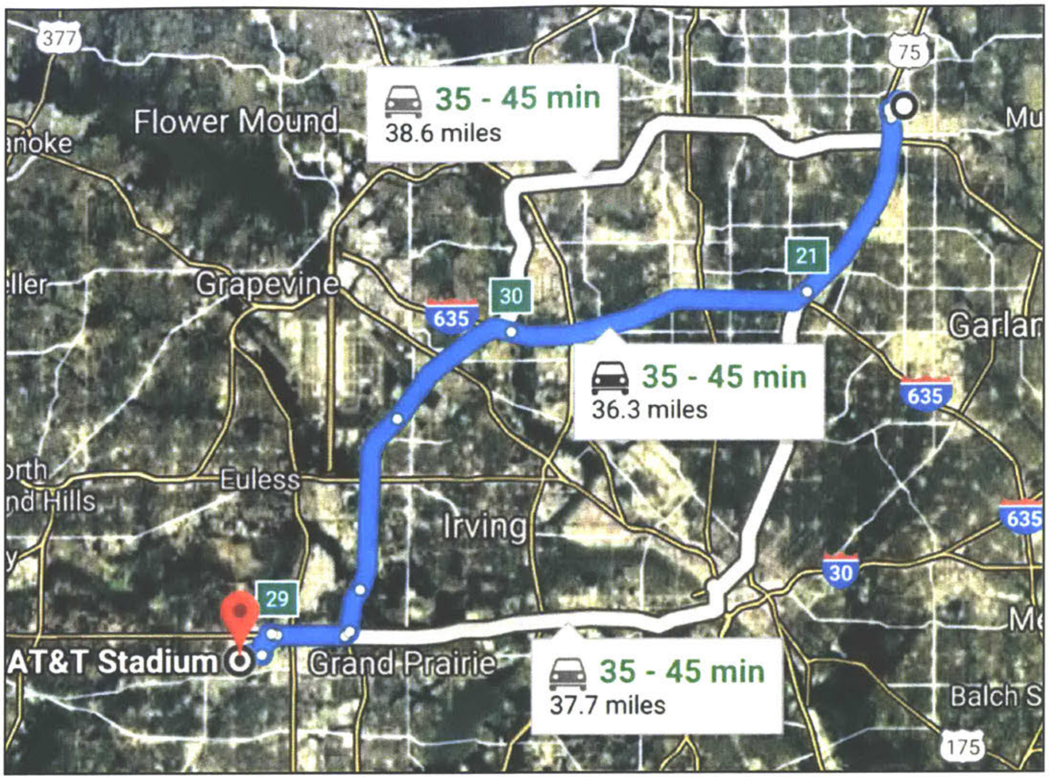

Figure 33. Plano to Cowboys Stadium primary route
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 13 displays the specifications for the Plano to Cowboys Stadium reference mission. The Plano city center has a helipad located 1.7 miles from origin location. Dallas Cowboys stadium has an on-site heliport adjacent to the stadium.

Table 13. Plano to Cowboys Stadium reference mission specifications.

Type:	Point to Point			
Origin:	1001 E 16th St, Plano, TX 75074			
2017 Origin Helipad:	1TS4 (1.94 mi)			
Destination:	Cowboys Stadium: 1 AT&T Way, Arlington, TX 76011			
Destination Helipad:	on-site			
Driving Distance:	38.6	mi primary ground	36.3	mi secondary ground
2017 ODM Distance:	1.94	mi (min) to helipad	29.5	mi LOS flight

Figure 18 displays the results of the Plano to Cowboys Stadium ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to

8:00 PM. Figure 34 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 8:00 PM as displayed in the ground transportation study.

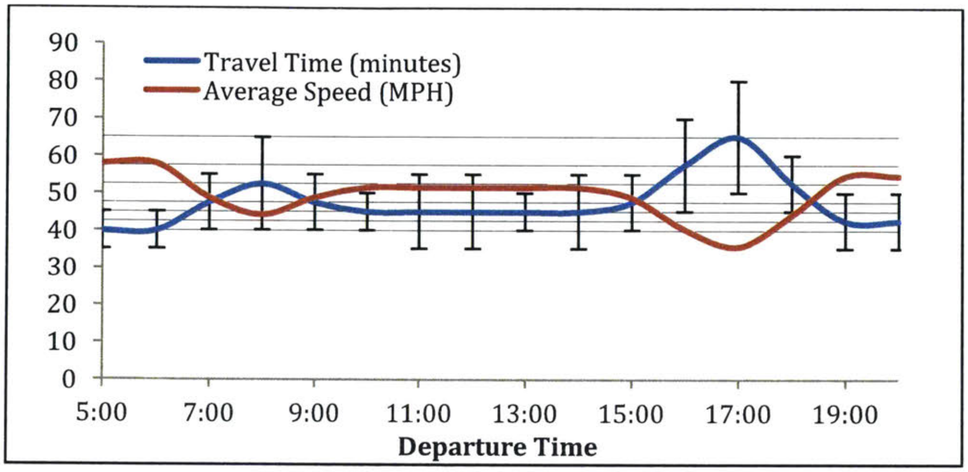

Figure 34. Plano to Cowboys Station travel time average speed distribution.

6.3.4 Meacham Airfield to Texas Motor Speedway

The Meacham Airfield to Texas Motor Speedway reference mission captures a short distance mission for wealthy customers traveling to sporting events. Meacham Airfield allows access to private plans and helicopter transport and several helicopter charter services offer transportation from the airfield to the racetrack during events. The total trip is 19 miles and takes 22 minutes during non-peak travel times. Total trip time increases to 50 minutes during peak travel incurring a congestion penalty of 127%. As with the mission to Cowboys Stadium, it should be noted that Google Maps™ mapping service does not predict travel times during major sporting events. Travel times were calculated using the same standard day as the other time travel studies. Actual congestion during sporting is likely much higher. Figure 35 shows the primary route from Meacham Airfield to Texas Motor Speedway.

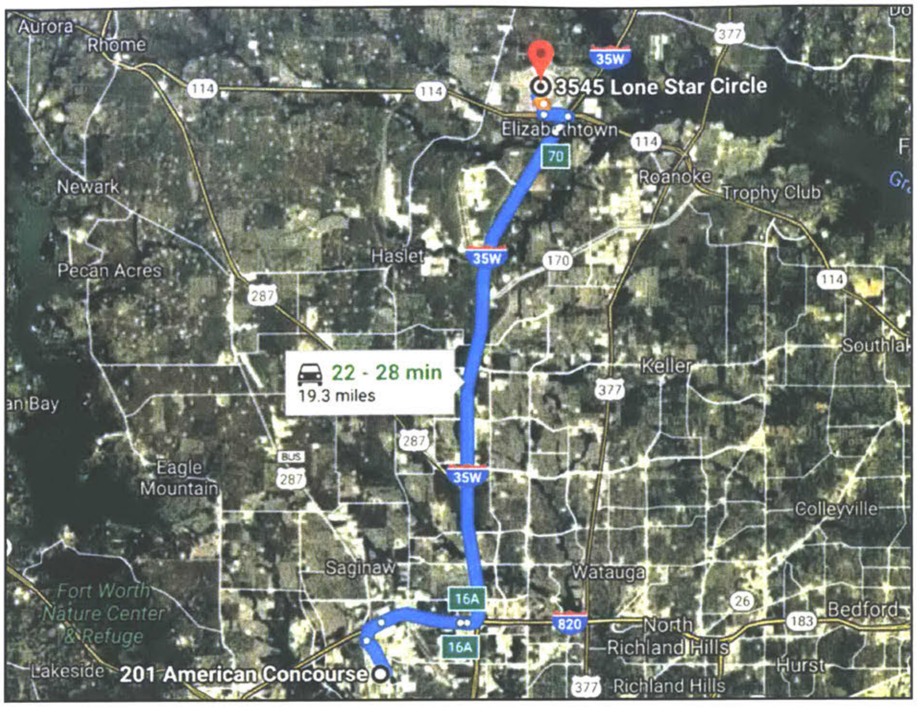

Figure 35. Meacham Airfield to Texas Motor Speedway primary route
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 14 displays the specifications for the Meacham Airfield to Texas Motor Speedway reference mission. Both the origin and destination have helipads on-site.

Table 14. Meacham Airfield to Texas Motor Speedway reference mission specifications.

Type:	Point to Point			
Origin:	201 American Concourse, Fort Worth, TX 76106			
2017 Origin Helipad:	on-site			
Destination:	3545 Lone Star Cir, Fort Worth, TX 76177			
Destination Helipad:	on-site			
Driving Distance:	19.3	mi primary ground	23	mi secondary ground
2017 ODM Distance:	0	mi (min) to helipad	14.6	mi LOS flight

Figure 20 displays the results of the Meacham to Texas Motor Speedway ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 8:00 PM.

Figure 36 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 8:00 PM as displayed in the ground transportation study.

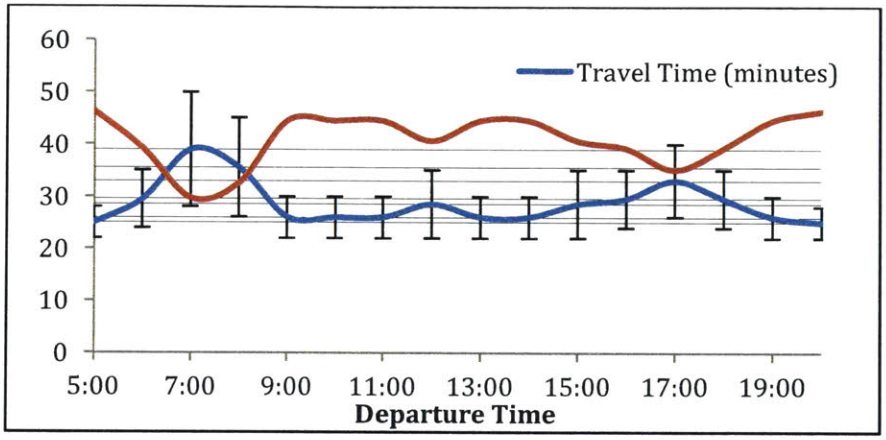

Figure 36. Meacham Airfield to Texas Motor Speedway travel time average speed distribution.

6.4 Randomly Selected Reference Missions

In addition to demand based commuter and point-to-point reference missions, a set of randomly selected reference missions were also evaluated. The purpose of the randomly selected missions is to reduce the effect of any potential selection that the author may have experienced in the previous sections. Additionally, randomly selected missions may reveal unique mission profile characteristics that that were not apparent in the other mission sets. Origin and destination points were determined by randomly generating addresses within a defined region. The region approximately represents that 12 counties included in the North Central Texas Council of Governments (NCTCOG) metropolitan planning area [13]. The addresses corresponded to positions mapped in the Google Street View program. The development and analysis of each reference mission is shown in the following two sections.

6.4.1 Ferris to Irving

The Ferris to Irving reference mission is shown in Figure 37. The origin is a rural area south of the Dallas metropolitan area. Commuter traffic from south of Dallas into the metropolitan area is common. The destination is between the Dallas City Center and DFW Airport. The reference mission is 44 miles and takes 44 minutes during off peak times. During peak congestion, this increases to 80 minutes incurring an 82% congestion penalty. This mission is longer than the typical commuter or point-to-point missions evaluated in the earlier sections. It can also serve to demonstrate missions for rural customers traveling into the metropolitan area that has longer commute distances, but may not experience as much congestion.

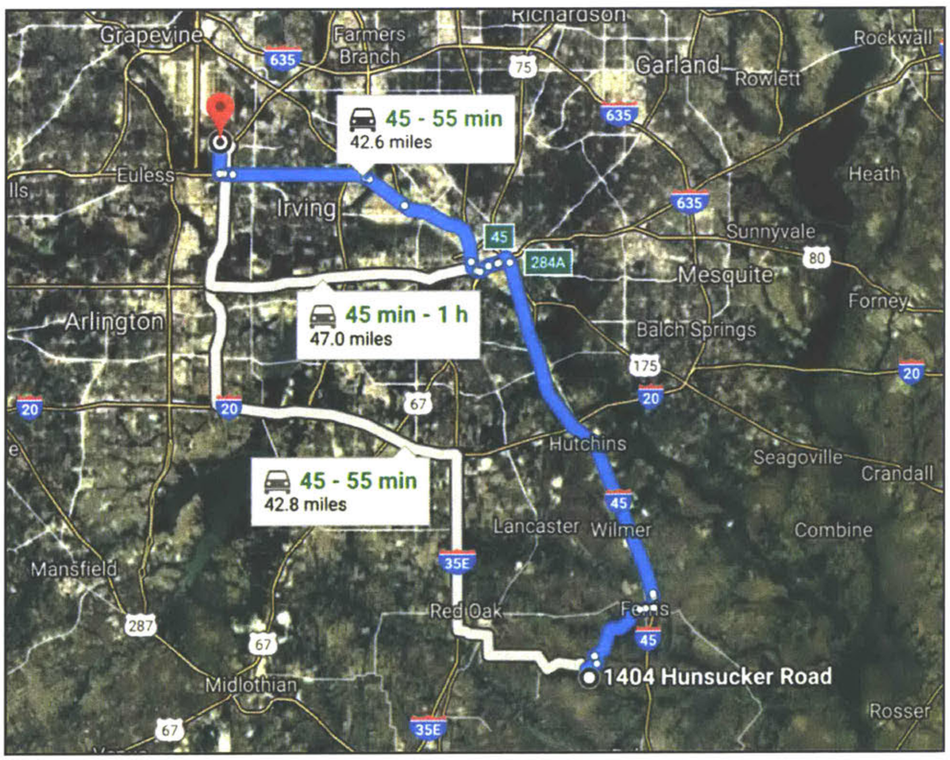

Figure 37. Ferris to Irving primary route
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 15 displays the specifications for the Ferris to Irving reference mission.

Table 15. Ferris to Irving reference mission specifications.

Type:	Random			
Origin:	1404 Hunsucker Rd, Ferris, TX 75125, USA			
2017 Origin Helipad:	Dallas South Port, Airfield (1.65)			
Destination:	4056-4102 Valley View Ln, Irving, TX 75038, USA			
Destination Helipad:	DFW Airport (2.88)			
Driving Distance:	44.3	mi primary ground	42.6	mi secondary ground
2017 ODM Distance:	2.88	mi (min) to helipad	31.3	mi LOS flight

Figure 22 displays the results of the Ferris to Irving ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 12:00 PM inbound and 1:00 PM to 8:00PM outbound. Figure 38 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 12:00 PM and "outbound" captured from 1:00 PM to 8:00 PM as displayed in the ground transportation study.

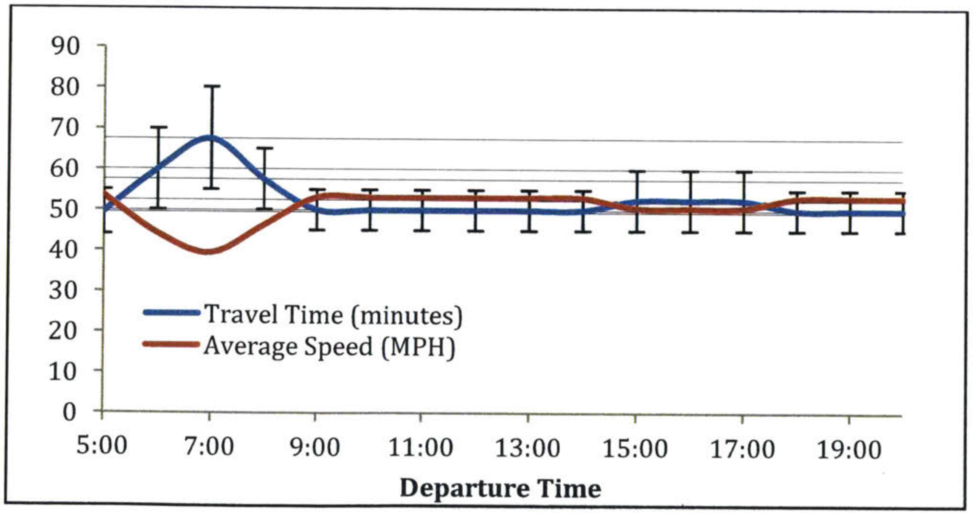

Figure 38. Ferris to Irving travel time average speed distribution.

6.4.2 Mansfield to Plano

The Mansfield to Plano reference mission is shown in Figure 39. The origin is in a rural area south of both Dallas and Fort Worth, while the destination is in a more populated suburb north of the two cities. The total trip is 53 miles and takes 55 minutes during non-peak travel times. During peak congestion, travel time increases to 130 minutes incurring a 136% congestion penalty. This mission is longer than the previously defined reference missions and crosses through several previously defined mission routes.

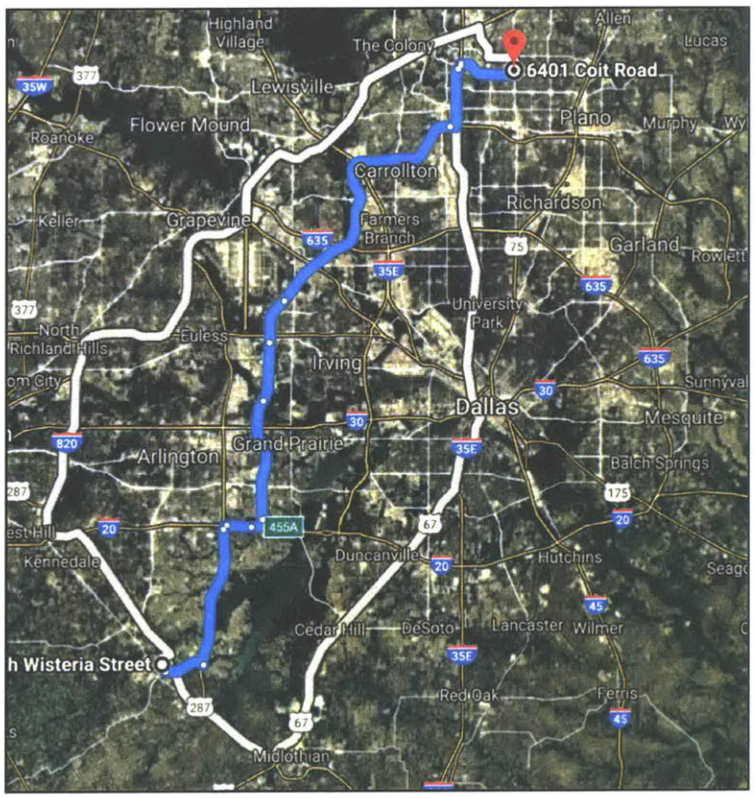

Figure 39. Mansfield to Plano primary route
© 2018 Google, Map Data: SIO, NOAA, U.S. Navy, NGA, GEBCO, USGS.

Table 16 displays the specifications for the Mansfield to Plano reference mission.

Table 16. Mansfield to Plano reference mission specifications.

Type:	Random			
Origin:	468 S Wisteria St, Mansfield, TX 76063, USA			
2017 Origin Helipad:	Flying L Airpark (1.59)			
Destination:	6401-6409 Coit Rd, Plano, TX 75024, USA			
Destination Helipad:	1TS4 (1.94)			
Driving Distance:	53	mi primary ground	61.2	mi secondary ground
2017 ODM Distance:	1.94	mi (min) to helipad	40.0	mi LOS flight

Figure 40 displays the results of the Mansfield to Plano ground transportation study. Ground transportation times predicted by the Google Maps™ mapping service were collection from 5:00 AM to 12:00 PM inbound and 1:00 PM to 8:00PM outbound. Figure 24 presents a diagram of the average travel time and average speed distribution. The diagram shows both the average travel time and average speed based on departure time. The diagram displays both the morning and afternoon peak travel times with "inbound" travel captured from 5:00 AM to 12:00 PM and "outbound" captured from 1:00 PM to 8:00 PM as displayed in the ground transportation study.

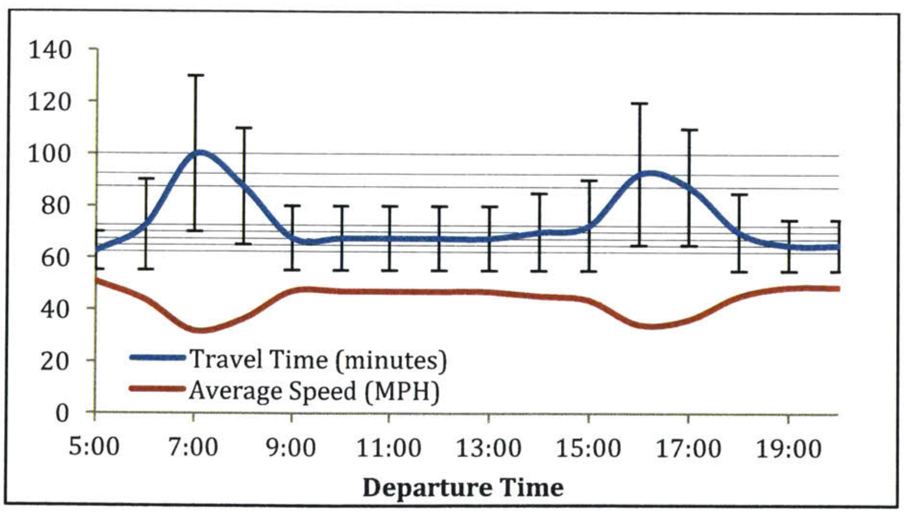

Figure 40. Mansfield to Plano travel time average speed distribution.

6.5 Dallas-Fort Worth Reference Mission Definition Summary

This section present 10 reference missions to capture the variety of missions proposed for UAM services in the Dallas-Fort Worth Metropolitan Area. Eight of the missions were chosen to represent customers that are likely early adopters of UAM services.

Section 4.2 introduced four daily commute missions. The potential demand for UAM services was validated by the significant congestion penalties experienced in each route. The maximum penalty incurred ranged from 132 – 186% on the four routes. It should be noted that these maximum congestion penalties occurred during peak congestion periods and not during the duration of the day. This suggests that demand for UAS services may also occur during those peak congestion periods.

Section 4.3 introduced four point-to-point reference missions. Among these missions, travel to and from major transportation hubs like DFW Airport and major events were found to represent potential high value markets. These missions are not aligned with traditional commuter hours and represent the potential for additional demand throughout the day.

Section 4.4 introduced randomly assigned missions. These missions were not assigned to identify potential early adoption or high value markets, but may reveal additional constraints or opportunities not present in the other missions. Table 17 displays a summary of the 10 reference missions. The average ground distance, off and on peak travel times, and maximum congestion penalty is summarized.

Table 17. Reference mission summary.

	Daily Commute Missions	Ground Distance (mi)	Line-of-Sight Distance (mi)	Off-Peak Ground Time (min)	Peak Ground Time (min)	Congestion Penalty
1	Frisco Square to AA Center	26.6	25.0	28.0	65.0	132%
2	Union Station to McKinney	33.6	31.2	35.0	100.0	186%
3	Westlake to Dallas City Center	29.8	25.9	30.0	75.0	150%
4	Fort Worth to Union Station	31.7	30.5	30.0	70.0	133%
	Point to Point Missions					
5	DFW Airport to Frisco Station	26.8	19.3	26.0	40.0	54%
6	Dallas Downtown to DFW Airport	18.9	15.9	20.0	45.0	125%
7	Plano to Cowboys Stadium*	38.6	29.5	35.0	80.0	129%
8	Meacham Airfield to TMS*	19.3	14.6	22.0	50.0	127%
	Randomly Generated Missions					
9	Ferris to Irving	44.3	31.3	44.0	80.0	82%
10	Mansfield to Plano	53.0	40.0	55.0	130.0	136%

*Event day penalty not considered

The 10 reference missions defined in the case studies represented a diverse combination of market demand, infrastructure attributes, and flight profiles. Table 18 presents a summary of the key mission attributes.

Table 18. Attributes exhibited by reference mission

Attribute	Description	Sampled Range
Mission Length	Line-of-sight mileage from origin to destination	16-40 mi
Surface Congestion Penalty	Ratio of peak congestion to free flow surface travel time	54% -186%
Population Over flight	Population densities of census tracts under the flight path	0-100K per mi^2
Airspace Interaction	The number and types of airspaces entered along flight path	All classes
Infrastructure Availability	Proximity of the O-D points to existing aviation infrastructure	on-site - 2.9 mi
Surface Route Efficiency	Ratio of surface route distance to line-of-sight distance	104% -141%
High Income Community	Household income or valuation above city-specific threshold	40% of missions
Arrival Time Deadline	Trip with a strict arrival deadline (ex. airport, sporting event)	30% of missions

The reference mission analysis completed in this section will be used to complete UAM Concept of Operations (ConOps) for potential UAM missions in order to identify potential operational challenges that may exist during the development, operation, and scaling of a UAM system.

7. UAM ConOps and Operational Constraints Identification

7.1 Introduction

The section conducts a step-by-step evaluation of the notional UAM Concept of Operations (ConOps) for each reference mission. It follows the same methodology developed by Vasick as discussed in previous sections. In his study of Los Angeles, Vasick identified nineteen operational challenges that may impact the development, implementation, or operation of a UAM system [10]. This study will analyze Dallas-Fort Worth in order to determine if the challenges that Vasick identified exist in a different geographic region and to determine if any additional challenges exist. The study uses the same set of evaluation metrics use in the Los Angeles study [22]. These metrics are included in Appendix B. To begin, a notional ConOp was developed for each reference mission. The ConOps walk through each mission and evaluate all steps that a potential customer would take from the time that they order the service until the time that they arrive at their destination. The ConOps include ground transportation, aircraft preflight, customer boarding, flight planning, air traffic control interaction, and aircraft preparation for future flights.

Figure 41 and Table 25 identify a notional aircraft ConOps and outline the associated steps [10]. The same ConOps steps and methodology is used in this case study in order to facilitate constraint comparisons for different geographical regions. The acronym "TOLA" in Table 1 stands for "Take off and Landing Area" and refers to any location that a UAM aircraft may depart from or arrive at. Figure one shows a notional aircraft ConOps for an UAM aviation mission.

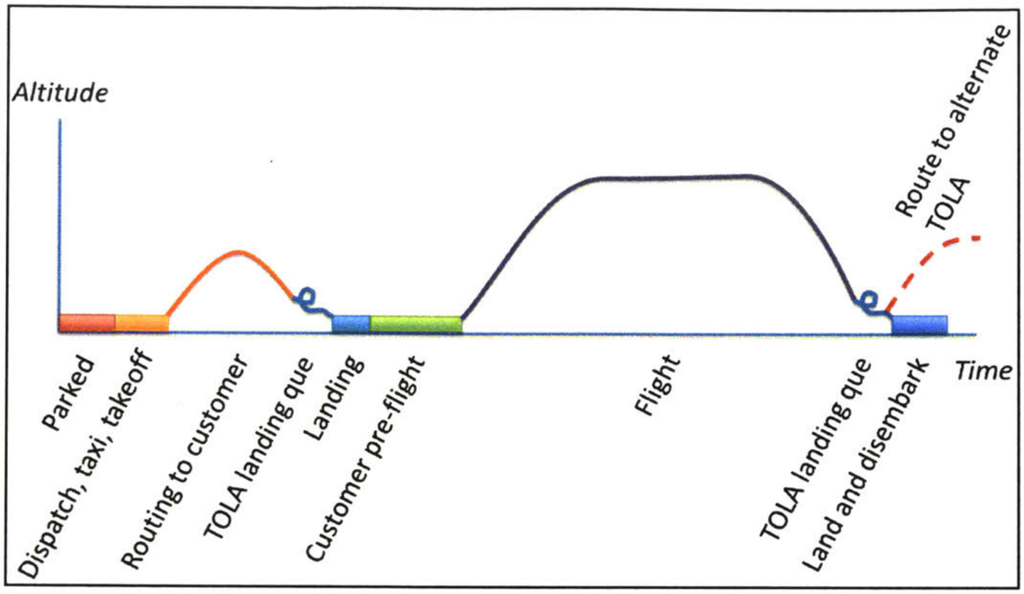

Figure 41. Notional aircraft ConOps for an UAM Aviation Mission [10]

Table 19 outlines eight steps for UAM reference missions. The ConOps steps were applied to each reference mission in order to develop a hypothetical timeline and identity potential operational challenges.

Table 19 Notional Mission ConOps for UAM [10]

ConOps Step	Description
Initiation	Customer submits a travel request
1	Aircraft pre-flight
2	Aircraft routed to the TOLA nearest to the customer origin
3	Customer takes ground transportation from origin to TOLA
4	Customer and aircraft are prepared for takeoff
5	Flight segment
6	Aircraft arrives at destination and customer disembarks
7	Customer takes ground transportation to final destination
8	Aircraft turn (charging, cleaning, flight crew swapping)

A step-by-step evaluation of each reference mission was conducted to identify potential operational challenges. The results from each reference mission were then compared to the results of the Boston and

Los Angeles case studies to determine if any additional potential operating challenges existed or if the challenges identified in Dallas-Fort Worth differed from those identified in the previous studies.

Each ConOps step is discussed in the following sections and potential operating challenges are identified in each step discussed.

7.1.1 Aircraft Preflight

A wide variety of activities must be performed in order to ensure that UAM aircraft are ready for flight and capable of safely completing the mission. One of these activities is to check the local weather to ensure that the aircraft will be able to successfully complete the mission based on the conditions that it is likely to encounter. To evaluate the possible effect of weather on UAM aircraft performance, data from METAR weather observations was collected from July 1, 2016 through June 30, 2017. Information on visibility, ceiling, winds, precipitation, temperature, and convective action was extracted from the reports. Figure 42 displays Cumulative Density Functions (CDFs) for temperature, visibility, and wind conditions in the Dallas-Fort Worth case study. Visual Flight Rule (VFR) and special VFR (SVFR) visibility minimums, 3 statute miles and 1 statute mile respectively, are indicated within the visibility sub-plot.

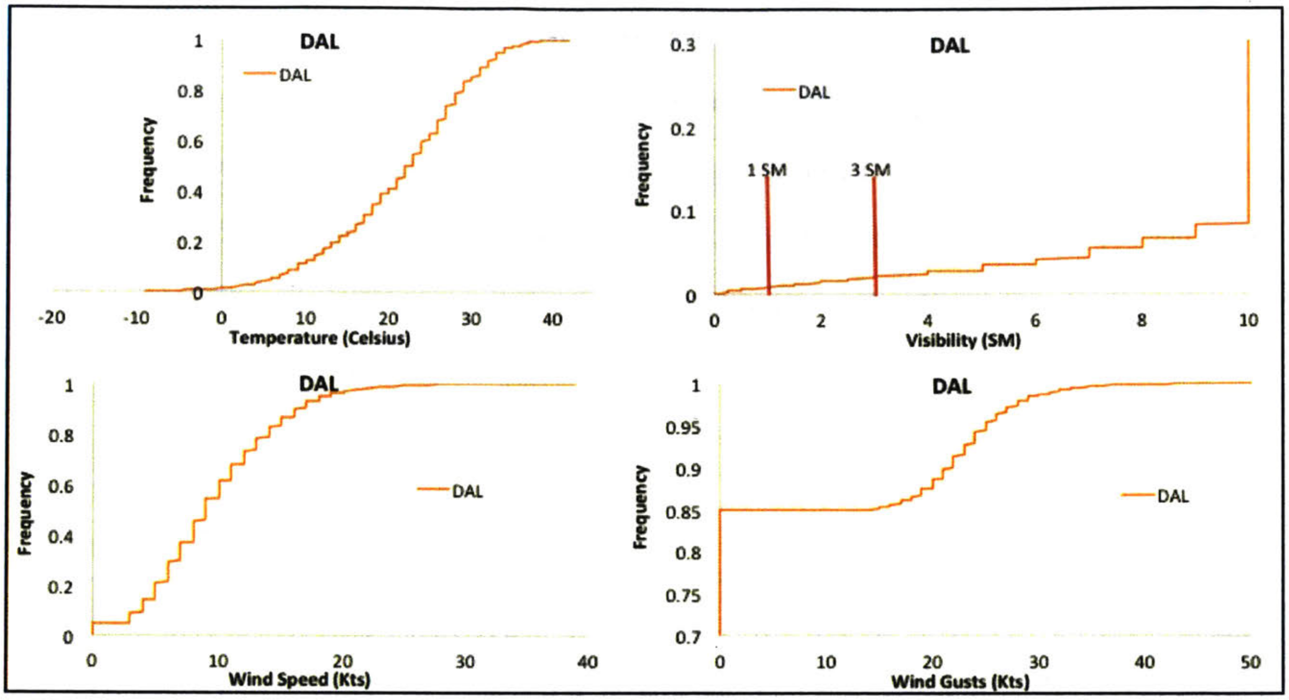

Figure 42. Weather Characteristics for Dallas-Fort Worth [22]

Visibility dropped below three statue miles less than two present of the time reported. Dallas-Fort Worth does experience wind greater than 15 knots and wind gusts greater than 20 knots 13% and 11% of the time respectively. While visibility does not appear to be a potential constraint, small aircraft may be more sensitive to wind conditions than traditional helicopters. Additionally, due to the wide variety of potential vehicle configurations, UAM operations may be limited during periods of extreme cold or extreme heat. Dallas experienced temperatures greater than 35° C for 3% of the time and very rarely experienced temperatures below freezing. Weather conditions were assessed for all 10 reference missions.

The challenges identified in this ConOp step are consistent with those identified in Boston and Los Angeles. There is a difference in the severity of the impact. Dallas-Fort Worth and Los Angeles exhibit more favorable weather conditions for UAM operations. Pilot staffing is a common challenge in each case.

7.1.2 Aircraft routed to the TOLA nearest to the customer origin

Once the customer travel request is submitted to the UAM system provider, the provider must identify and available TOLA near the customer pick up point. If an aircraft is not already located on the selected pickup site, it must be routed to the location. Similarly, if the customer was not located at the TOLA site, they must take ground transportation from their origin to the pick-up point. These two activities may require a network of TOLAs that have sufficient aircraft staging capacity and customer throughput capacity that are in closer proximity to the customer's origin point.

Table 20 displays a summary of existing ground infrastructure in the Dallas-Fort Worth metropolitan area. They Google Earth symbols on the left side of the table are used to display the different TOLA types in figure 27.

Table 20 Existing TOLA by type in Dallas-Fort Worth

Symbol	**TOLA Type**	**Dallas-Fort Worth**
	Emergency Helicopter Landing Facility	1
	Private Heliport	79
	Government Heliport	3
	Medical Heliport	53
	Public Use Heliport	4
	Airport	174

Figure 43 presents the location of the existing ground infrastructure in the Dallas-Fort Worth case study boundary area.

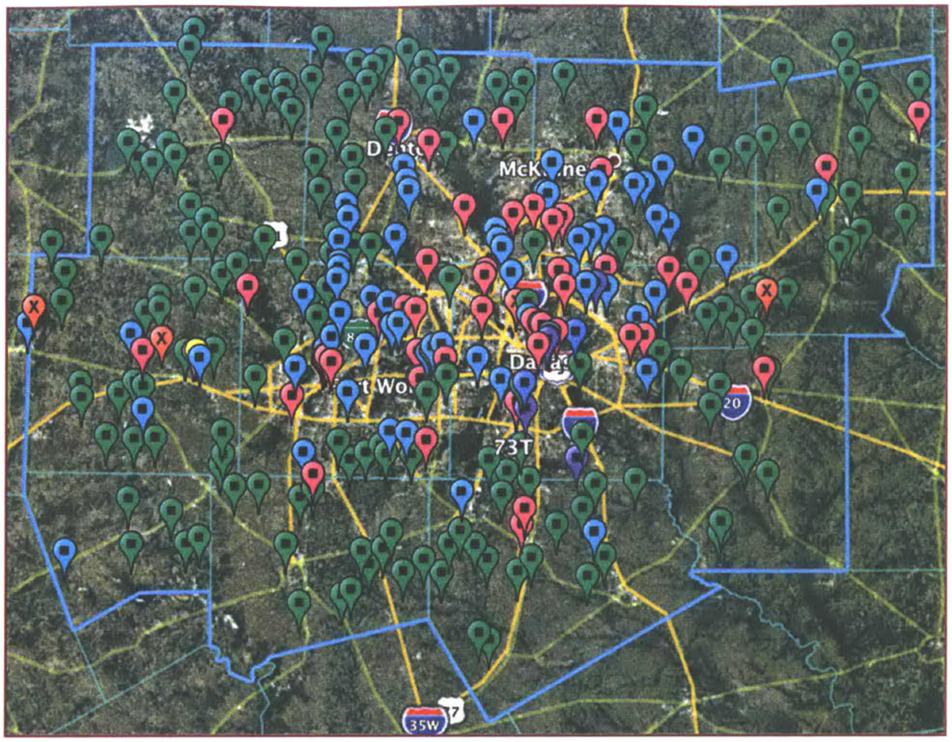

Figure 43. Existing heliport and airport infrastructure in Dallas-Fort Worth. Map Data © 2017 Google

The large number of available TOLAs, regional airports, and a high-capacity public heliport near the city center make the Dallas-Fort Worth metropolitan area more favorable than other large metropolitan areas for UAM operation. Of the 10 reference missions, 35% had an on-site TOLA at the origin or destination. Of the missions, 100% had a TOLA within three miles of the origin and destination points. In Dallas-Fort Worth, 84.3% of potential users indicated that they would be willing to travel three miles to reach a TOLA. As a result, TOLA proximity to customer origin is not assessed to be an operational challenge in any of the 10 reference missions analyzed. It is still assessed as an overall operational challenge for Dallas-Fort Worth.

Take off and landing area throughput and prioritization was identified as an operational challenge during this stage. This challenge applied to five of the reference missions analyzed in Dallas-Fort Worth. These

TOLAs can only support single aircraft operation increasing turn time and reducing aircraft throughput. This can lead to capacity constraints as the UAM system attempts to scale.

The challenges identified in this ConOp step are consistent with those identified in Boston and Los Angeles. There is more available for aircraft staging, but throughput and use prioritizing is an issue for half of the missions. This potentially due to larger amounts of available space for infrastructure, but the infrastructure that exists primarily supports one aircraft at a time. Dispatch regulations for electric aircraft is assessed to be a ubiquitous challenge across all three cases.

7.1.3 Customer takes ground transportation from origin to TOLA

The majority of TOLAs used in these reference missions are located near city centers and major transportation hubs. As a result, customers do not begin and end their travel at the TOLA location. They must use additional means of ground transportation to cover the "first mile" and "last mile" of the trip. These additional transportation requirements create two additional challenges. The first is customer parking. In Dallas-Fort Worth, 71.74% of residents indicated that they would use their personal car to travel to the TOLA location. While Dallas-Fort Worth has more convenient parking that many large metropolitan areas, this creates challenges when the UAM system scales and customer parking becomes more of a challenge.

A second operational challenge is the TOLA proximity to the customer origin point. As a rule of thumb, customers will only walk a quarter to half mile to reach a transportation mode [10]. Beyond this distance, customers are likely to need an additional source of transportation to reach the TOLA. In each reference mission where the TOLA is not located on-site, the origin is located greater than the half mile customers are likely to walk. This will create an increased demand for parking and add to the first operational challenge identified in this section.

In the 10 reference missions analyzed, the average distance to TOLA was 0.86 miles from the origin or destination. TOLA proximity to customer origin was a challenge in 50% of the reference missions and ground transportation to the TOLA was a challenge in 70% of the reference missions analyzed. These challenges are consistent with the challenges identified in Boston and Los Angeles.

7.1.4 Customer and aircraft are prepared for takeoff

Once the customer arrives at the TOLA, the customer and vehicle must be prepared for flight. These activities may include:

- Customer identification
- Security Check
- Customer and luggage loading into the aircraft
- Aircraft performance calculations
- Pre-flight safety review
- Aircraft start up, taxi, and takeoff

Completing all of these steps will take a significant amount of time and add to the total trip duration. These steps may also require increased on-site personal at the TOLA area. These steps lead to a potential operational challenge of the duration of the aircraft occupancy time at the landing surface. The challenge becomes even more significant when TOLAs only have a single touchdown surface. Delays in completing this process can also lead to delays for aircraft in route and make flight scheduling more complicated.

Customer physical access to the TOLA, aircraft time on TOLA, and TOLA safety and security, were identified as potential operating challenges during this phase. Customer physical access to the TOLA was assessed as a challenge in 50% of the reference missions analyzed. Aircraft time on the TOLA was a ubiquitous challenge. TOLA safety and security was a challenge in 90% of reference missions. These results are consistent with the challenges identified in Boston and Los Angeles and no new challenges were identified.

7.1.5 Flight segment

Departure, enroute, and approach paths were evaluated for each of the reference missions. Multiple departure and arrival procedures were considered for each reference mission and up to four potential flight trajectories were evaluated for each mission. Each trajectory was reviewed to identify required aircraft performance, ATC interactions, and population over flight, and other conditions such as flight over open water or restricted areas.

The first challenge identified was UAM aircraft interaction with Air Traffic Control (ATC). Flight through controlled airspace and special use airspace incurs additional requires concerning communication with ATC, aircraft equipage, and flight procedures. In this case study, 90% of reference missions used a pick up or drop off TOLA within a surface level class B, C, or D controlled airspace. These requirements add to operator workload for both the ATC operator and UAM service operator. As UAM operations increase, increased flight densities will likely strain or exceed the capabilities of existing ATC capabilities. Access to controlled airspace and interaction with ATC were assessed as challenges in 90% of the reference missions analyzed. These challenges will be present for any flight that required entry into controlled airspace.

Two additional operational challenges were identified concerning the approach and departure phases of the flight. Some TOLAs were identified to have clearways where obstacles or procedures from nearby airports penetrated the approach and departure or transitional surfaces of the TOLA. Access to the TOLAs may require extended vertical flight segments, steep approach or departure angles, or restricted hours of operations. May proposed UAM vehicle configurations are smaller lightweight aircraft that may also be more subject to ambient weather and wind conditions. These conditions may necessitate changing the approach and departure paths from a given TOLA location in order to maintain a safe operating profile. The safety of vertical flight segments was considered an operational challenge because the majority of proposed aircraft do not have autorotation capability. Safety of flight with increased traffic was assessed to be a challenge in 40% of Dallas-Fort Worth reference missions.

The final operational considerations identified were community noise exposure to UAM operations, approach and departure path clearance, and safety of vertical flight segment. Dallas-Fort Worth has two major airports, several smaller airports, and helicopter traffic from many commercial and private operators. However, UAM operations propose to conduct frequent operations within communities that have traditionally not experienced levels of airport noise. TOLA locations near city centers and within suburban communities will lead to increased noise and vehicle over flight. Noise exposure was assessed as a challenge for all reference missions. Approach and departure path clearance was not assessed as an operational challenge in the 10 reference missions analyzed. It remains a potential challenge because it will be an important planning factor for TOLAs if other missions are used. Finally, safety of vertical flight segment was assessed as an operational challenge in 90% of the missions analyzed.

The operational challenges identified in this section are consistent with the challenges identified in Boston and Los Angeles.

7.1.6 Aircraft arrives at destination, customer disembarks and takes ground transportation to final destination

Many of same operational challenges identified in sections 7.1.3 and 7.1.4 customer arrive and preparation for flight a contained in this section. These included aircraft throughput, customer egress, safety, security, and aircraft turn time.

7.1.7 Aircraft turn (charging, cleaning, flight crew swapping)

The final step in the notional UAM ConOps is preparation for follow on missions. The three operational challenges identified in this section are aircraft charge time, TOLA infrastructure requirements, and aircraft and pilot demand requirements. Traditional aircraft turn times typically include refueling, servicing, potential crew swapping, and cleaning. With eVOTL or hybrid-electric aircraft an additional operational challenge is battery charging and charging facility development. In the reference missions analyzed, aircraft charge time was identified as a constraint in 90% missions. TOLA infrastructure requirements are a challenge in every mission and aircraft and pilot demand requirements were challenges in 70% of missions. These challenges are consistent with the challenges identified in Boston and Los Angeles.

7.2 Results of the Reference Mission ConOps Evaluation

Through the evaluation of the 10 reference missions, 19 potential UAM operational challenges were identified. These challenges are summarized in Table 21 ground with the missions ConOps step they were identified with.

Table 21. Potential UAM operational challenges [22]

Mission ConOps Step(s)	Potential Operating Challenge
Aircraft pre-flight	1. Weather Restrictions 2. Pilot Staffing
Aircraft routed to the TOLA nearest to the customer origin	3. Aircraft staging 4. Dispatch regulations for electric aircraft 5. TOLA throughput and prioritization
Customer takes ground transportation from origin to TOLA	6. TOLA proximity to customer origin 7. Ground transportation to TOLA
Customer and aircraft are prepared for takeoff	8. Customer physical access to TOLA 9. Aircraft time on TOLA 10. TOLA safety and security
Flight segment	11. Access to controlled airspace 12. Interaction with ATC 13. Safety of flight with increased traffic 14. Noise exposure 15. Approach and departure path clearance 16. Safety of vertical flight segment
Aircraft arrives at destination	Previously identified
Aircraft turn (charging, clearing, flight crew swapping)	17. Aircraft charge time 18. TOLA infrastructure requirements 19. Aircraft and pilot demand requirements

Of the operational constraints identified, aircraft noise, takeoff and landing area availability, and air traffic control scalability were perceived to be the most likely to cause the greatest issues to UAM system scalability. Table 22 presents a summary of the operational challenges identified in Table 21 and the reference mission they apply to. The 19 operational challenges corresponded to the challenges identified in Table 21 above.

Table 22. Operational challenges identified through reference mission ConOps analysis

Reference Mission	Operational Challenge																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1 Frisco Square to American Airlines Center	■	■	■	■	■	■	□	□	■	■	■	■	■	■	□	■	■	■	■
2 Union Station to McKinney	■	■	□	■	□	□	□	■	□	■	■	■	□	■	□	■	□	■	■
3 Westlake to Dallas City Center	■	■	■	■	□	□	□	□	□	■	■	■	■	■	□	■	■	■	■
4 Fort Worth to Union Station	■	■	□	■	■	■	□	□	■	■	■	■	■	■	□	■	□	■	■
5 DFW Airport to Frisco Station	■	■	□	■	□	□	□	■	■	■	■	■	□	■	□	■	□	■	■
6 Dallas Downtown to DFW Airport	■	■	□	■	□	□	□	■	□	■	■	■	□	■	□	■	□	■	□
7 Plano to Cowboys Stadium	■	■	■	■	■	■	■	□	■	■	■	■	□	■	□	■	■	■	□
8 Meacham Airfield to TMS	■	■	□	■	□	□	□	■	□	■	■	■	□	■	□	□	□	■	■
9 Ferris to Irving	■	■	□	■	■	■	■	■	■	■	■	■	■	■	□	■	■	■	□
10 Mansfield to Plano	■	■	□	■	■	■	■	□	■	■	□	□	□	■	□	■	■	■	■

Legend	
□	Does Not Apply
■	Applies

This case study is consistent with previous studies in that it identified the same operational challenges in those studies. There are differences in the frequency and severity of each challenge in the different geographic regions. When compared to other large metropolitan areas, Dallas-Fort Worth is less geographically constrained. Aircraft staging, safety of vertical flight segments, community noise exposure, and approach and departure clearways are constraints that present operational challenges, but are not deemed as binding as other large cities. This section provides an introduction to the constraint analysis applied to near term UAM operations in Los Angeles, Boston, and Dallas. A complete analysis of all three city cases studies is available for a more comprehensive review [22].

8. Conclusion

This thesis investigated potential operational challenges for Urban Air Mobility in Dallas-Fort Worth. The thesis introduced two tools used to understand the environment better. First, a survey of community members and potential early adopters was conducted to determine the customer's perceptions of a UAM system, identify UAM markets, and identify operational challenges. Second, operational challenges and constraints were identified through a review of the Concept of Operations for 10 reference missions projected to serve UAM markets in Dallas-Fort Worth. Nineteen operational challenges were identified that may impact the development, implementation, and operation of an Urban Air Mobility system. Community acceptance of aircraft noise, takeoff and landing area availability, and air traffic control scalability were assessed to be the most significant challenges to UAM systems development. The following section identifies key findings from Dallas-Fort Worth study.

8.1 Key Findings

The case study identified commuter trips and point-to-point trips missions as possible use cases. The customer survey identified that a greater percentage of respondents anticipated using the service for point-to-point missions than commuter travel. This may be representative of the city of Dallas where commuters experience less traffic congestion than other larger cities. If users are less likely to use the service for commuter travel, it may make it difficult for a UAM aircraft to maintain a high level of utilization during off peak hours.

Weather restrictions and pilot staffing were identified as potential operating challenges. The case study revealed that weather in Dallas-Fort Worth was not a binding constraint for near team operation, but that other cities may have more significant impact on operations due to weather. The challenge of pilot staffing is likely to be a key consideration in any market. One proposed solution is to transition from a pilot aircraft to an autonomous aircraft as a UAM system scales. Survey results in Dallas-Fort Worth indicate that residents are receptive to flying in fully autonomous vehicles.

Aircraft charge time and TOLA infrastructure requirements were identified as additional operational challenges. Based on these results, there does not appear to be strong market demand for electric or hybrid vehicle configurations in the Dallas-Fort Worth market. This indicates the users in Dallas-Fort Worth may be accepting of traditional, hybrid, and eclectic vehicles as a UAM system develops. While this may help the charge time constraint, it could add increased infrastructure requirements to support vehicles developed by different manufactures with different fuel requirements.

Ground transportation to the TOLA and TOLA proximity to the origin were identified as operational constraints. As a UAM system is designed, the location of TOLA infrastructure will be critical. The Dallas-Fort Worth metropolitan area does have a large amount of existing infrastructure in place. In the 10 reference missions studied, the average TOLA was less than one mile from the origin and destination point. The survey results suggested that residents would be willing to travel to reach a TOLA under one mile with 90.6% of all respondents were willing to travel less than one mile and 60.4% of all respondents were willing to travel less than 10 miles. Existing ground infrastructure and residents willing to travel to a TOLA location support Dallas-Fort Worth as an early adoption city.

Take Off and Landing Area safety, security, and overall noise exposure were also identified as operational challenges. Respondent data verified these challenges with a majority of respondents citing noise and safety as primary concerns for aircraft operating in their neighborhoods. This indicates that while Dallas-Fort Worth users may not be as concerned about propulsion systems and travel distance to TOLAs, safety and noise are two issues that manufactures must address.

The study revealed some additional findings that may be interesting to equipment manufactures. In Dallas-Fort Worth, an aircraft capable of carrying 2-3 passengers could meet a majority of users (87.3%) normal travel requirements. Additionally, a majority of users (83.7%) were willing to share a ride with other passengers and most users (69.4%) preferred to schedule a trip the day prior to use.

Respondents were also asked how far they would like to travel and how much they would be willing to pay for that service. In Dallas-Fort Worth, 50% of respondents selected trips less than 30 miles and 77.8% of all users selected missions less than 100 miles. In analyzing customer willingness to pay, 70% of respondents are willing to pay less than $2/passenger mile for UAM services. There was a portion of the population (9.2%) that is willing to pay greater than $5/passenger mile. This indicates that there are potential customers that will be willing to pay higher prices and could be potential early adopters as the service starts. Higher levels of utilization will require lower costs to reach more customers. Both of these price points are lower than current helicopter charter services and indicates that cost will be a critical consideration for equipment manufactures.

8.2 Opportunities for Additional Research

There are a number of opportunities for additional research based on the topics explored in this thesis. First, each of the potential operating challenges identified would be valuable to explore in order to fully understand the impact of these challenges. Of the most significant challenges, takeoff and landing area availability and air traffic control scalability will be important problems to investigate for UAM system development in Dallas-Fort Worth. Second, case studies have been completed in Dallas, Los Angeles, and Boston. Additional cities and metropolitan areas could be studied to identify new challenges and further understand existing challenges. Finally, this study focuses on U.S. metropolitan areas. Exploring international metropolitan markets as well as U.S. and international rural markets would lead to different challenges and opportunities.

8.3 Summary

This chapter outlined the key findings for the Dallas-Fort Worth Urban Air Mobility market. The findings used hypothetical UAM missions to identify the key operational challenges and link them to perceived customers values where applicable. The findings can be used by equipment manufactures to identify current challenges and perceptions that must be addressed in developing vehicles that may operate in an Urban Air Mobility system.

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Appendix A: Customer Survey

Urban Air Mobility Survey

Uber and Bell Helicopter are working to launch an "Air Taxi" service in Dallas-Fort Worth. These "Air Taxis" operate similar to helicopters but are likely smaller and quieter. The idea is for the aircraft to operate from "vertiports" located throughout the Dallas-Fort Worth metro area and fly straight-line distances as fast or faster than a cars avoiding ground traffic.

There are many potential uses for this service. This survey attempts to understand people's opinions and preferences concerning this service.

This Survey is part of a MIT scientific research project. Your decision to complete this survey is voluntary. There is no way for us to identify you. The only information we will have, in addition to your responses, is the time at which you completed the survey. The results of the research may be presented at scientific meetings or published in scientific journals. Clicking on the 'Submit' button on the bottom of this page indicates that you are at least 18 years of age and agree to complete this survey voluntarily.

1. What is your approximate household income?

- ○ $0-$9,999
- ○ $10,000-$24,999
- ○ $25,000-$49,999
- ○ $50,000-$74,999
- ○ $75,000-$99,999
- ○ $100,000-$124,999
- ○ $125,000-$149,000
- ○ $150,000-$174,999
- ○ $175,000-$199,999
- ○ $200,000+
- ○ Prefer not to answer

* 2. Had you heard of an Urban Air Mobility, air taxi, or flying car service before taking this survey?

- ○ Yes
- ○ No

* 3. If available in your area, how likely would you be to use this service?

- ○ Definitely Would
- ○ Probably Would
- ○ Neutral
- ○ Probably Would Not
- ○ Definitely Would Not

* 4. Would you have any concerns about using this service? If so, please select any that apply.

- [ ] Comfort
- [ ] Price
- [ ] Safety
- [ ] Noise
- [ ] None
- [ ] Other (please specify)

* 5. What type of trips would you like to use this service for? Please select all that apply.

- [ ] Commute (work)
- [ ] Recreation
- [ ] Special Event (like a football game)
- [ ] Airport
- [ ] I would not use this service
- [ ] Other (please specify)

* 6. What would you expect the likely benefits of this service to be? Please select all that apply.

- [ ] Shorter travel time
- [ ] Lower emissions
- [ ] Fewer crashes
- [ ] Lower transportation costs
- [ ] Easier access
- [ ] None

* 7. How many people would you normally want to travel with?

- ○ 0-1
- ○ 2-3
- ○ 4 and above

*** 8. Please enter a trip you would use this service for (please enter a specific location)**

Origin:

Destination:

Approximate Distance (miles):

*** 9. How much would you expect to pay for this service? (Approximate price in US Dollars)**

*** 10. How much would you be willing to pay for this service? (Approximate price in US Dollars)**

* 11. Which of the following modes of ground transportation would you expect to use for getting to and from a take off and landing area?

- [ ] Ride Share service (Uber, Lyft)
- [ ] My Car
- [ ] Walking (less than 10 min)
- [ ] Public transportation

* 12. I would not use this service if the Take Off and Landing Area is more than _________ miles from my starting or destination point.

* 13. Would you be willing to share your ride with other passengers?

○ Yes

○ No

* 14. Would you prefer to schedule your ride the day prior, or order on demand the day of?

○ schedule in advance (the day prior)

○ schedule on demand (anytime the day of)

○ Other (please specify)

* 15. Which source of energy would you prefer for this service to use?

- ◯ Gasoline (or diesel)
- ◯ Electric
- ◯ Hybrid
- ◯ Other (please specify)

* 16. Would you be willing to ride if the aircraft was flown automatically?

- ◯ Yes
- ◯ No

* 17. If this service were located in your neighborhood, would you have any concerns? If yes, please select all that apply:

- ☐ Congestion
- ☐ Noise
- ☐ Safety
- ☐ No Concerns
- ☐ Other (please specify)

* 18. Using the slider below, please indicate how much you generally want to use an Air Taxi service?

0 100

* 19. Please enter any additional questions or comments that you have about this concept and service.

Appendix B: Operational challenge evaluation metrics

Potential Operational Challenge	Reference Mission Evaluation Metric *(challenge exists in mission if metric evaluates positive)*
1. Weather restrictions	1. Do convective weather, IMC, or sub-freezing conditions occur during >10% of the year
2. Pilot staffing	2. Potential challenge for all missions
3. Aircraft staging	3. Can ≤5 aircraft be staged within 5 mi of the origin TOLA
4. Dispatch regulations for electric aircraft	4. Potential challenge for all missions
5. TOLA throughput and use prioritization	5. Does either TOLA lack a second Touchdown and Liftoff (TLOF) surface onsite or another TOLA within 0.5 miles
6. TOLA proximity to customer origin	6. Does the duration of first/last mile transport require >30% of the nominal non-UAM driving transportation time
7. TOLA integration with ground transportation	7. Does either TOLA lack onsite public transit or parking
8. Customer physical access to TOLA	8. Is either TOLA in an area not accessible to the public
9. Aircraft occupancy time on TLOF	9. Does either TOLA have only one onsite TLOF
10. TOLA and aircraft security	10. Potential challenge for all missions
11. Access to controlled airspace	11. Does the flight enter class B, C, D or special use airspace
12. Autonomous aircraft interaction with ATC	12. Potential challenge for all flights in controlled airspace
13. Safety of flight in areas of concentrated aircraft or UAS activity	13. Does the flight use an SFRA, helicopter or VFR route
14. Community noise exposure	14. Does flight <500 ft occur in residential or tourist areas
15. Approach and departure clearways	15. Do approach or departure clearways contain obstructions or interact with the procedures of nearby facilities
16. Safety of vertical flight segments	16. Is a vertical flight segment required during the flight
17. Aircraft charge time	17. Is mission range >50 miles necessitating extensive charge
18. TOLA charging infrastructure	18. Does the destination TOLA lack electric aircraft chargers
19. Balance of aircraft/pilots with demand	19. Is either TOLA >25 miles from the primary city center

These reference missions were developed by Vascik for case studies in Los Angles and Boston [22].