Noise Impact Analysis for Urban Air Mobility in Dallas-Fort Worth Metroplex

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This study supports re-design of airspace and procedures for management of Urban Air Mobility (UAM) fleet operations in a given metropolitan area. A goal of UAM is to maintain geographic separation of UAM flight tracks from densely populated areas in order to reduce the potential negative community impact of UAM and manage flight trajectory in anticipation of allowable noise levels and current land use. A UAM route inventory and a demographic-data-optimized topographic map are developed for the Dallas-Fort Worth metroplex to identify routes or baseline route segments for reduction of noise impact. Noise contours are computed for baseline route and alternative route design given the desired UAM demand level. The impact of UAM fleet noise is predicted based on predicted number of people and noise-sensitive facilities located inside the noise contours.

I. Introduction

Mitigating the noise impact of Urban Air Mobility (UAM) vehicles will be critical to public acceptance of UAM operations. Aircraft equipped with satellite-based navigation systems can fly more precise flight paths. UAM aircraft are likely to be concentrated on cost-efficient routes. Aircraft noise accumulated over time could have a major impact to the communities located under the flight path. Some geographic areas (e.g., hospitals, schools, residential areas) are densely populated or more sensitive to noise than others (e.g., highways, large parking lots). System noise prediction tools such as the FAA Aviation Environmental Design Tool (AEDT)[1] and NASA's AIRNOISEUAM[2] integrate all elements of the source-path-observer paradigm to compute noise levels at the receptor location. Hence an important aspect of UAM airspace design is the development of routes and multiple alternatives for UAM fleet operations that strikes an appropriate balance between flight efficiency (e.g., travel time, energy consumption) and noise impact.

Recent exploration[3] of routes and procedures for UAM in the Dallas-Fort Worth (DFW) metroplex used modified current-day helicopter routes with different communication procedures for assessment of controller workload and average aircraft separation given various UAM demand scenarios. In general, current helicopter route networks in the DFW metroplex overlie the network of highways for visual reference of pilot's location and have no speed or altitude restrictions. Virginia Tech developed three UAM demand scenarios[4] in this area. NASA recently developed an appropriate UAM conceptual aircraft noise model[5] that is integrated into UAM noise assessment software AIRNOISEUAM for the development of UAM noise exposure maps[6] following FAA's noise compliance planning regulation. The UAM stakeholders in DFW metroplex require identification of entry and exit waypoints of existing helicopter networks, feasible route options, and usable UAM airspace for flight planning and noise analysis. Mitigation strategies have not been considered for reducing the impact of UAM aircraft noise.

This paper describes a study that supports re-design of airspace and procedures for management of Urban Air Mobility (UAM) fleet operations in a given metropolitan area. Given a demand level and the baseline route structure, potential noise impact on the population by the UAM aircraft fleet is assessed and compared to the potential noise impact on the population using an alternate routing network. AIRNOISEUAM computes noise levels of UAM aircraft fleet at the predicted receptor locations with population numbers based on United States Geological Survey (USGS) Census database[7]. The baseline scenarios are based on the UAM demand levels predicted by Virginia Tech and routes used for NASA's X2 and X3 engineering evaluations[3] with industry partners. UAM routes defined for NASA's X3 engineering evaluation using modified current-day helicopter routes are incorporated into the baseline UAM route structure. A multiple-path, dynamic-programming-based routing algorithm, which is developed to generate an

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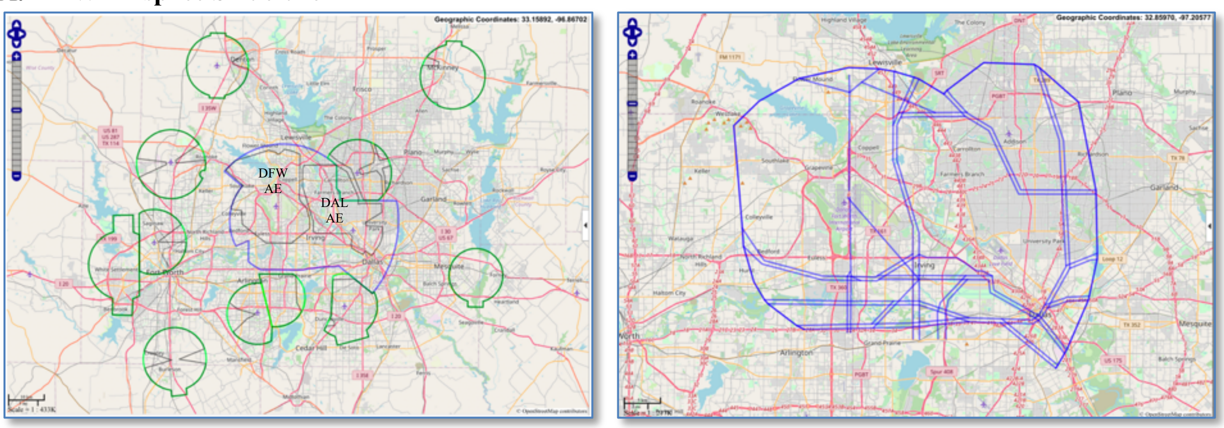
inventory of route options for UAM flights, enables development of alternative routing structures for trade-off analysis of the noise impact. Noise mitigation strategies are considered through selection from the route inventory a set of appropriate routes that reduce the number of people under the flight path and dispenses the flights to alternate routes to reduce the recurrence of the noise events to the same receptors.

Section II introduces baseline airspace structures, relevant data for modeling noise impact, and the noise mitigation considerations. The analytical approaches for designing noise-aware routing are presented in Section III. Section IV provides an assessment of the noise impacts and the trade-off analyses between the reduction of people exposed to noise and additional trip distance flown. Concluding remarks are presented in Section V.

II. Baseline UAM Models and Noise Mitigation Considerations

FAA Advisory Circular[8] 150/5020-1 discusses control actions and provides useful insights on the philosophy of noise abatement and mitigation. This study develops and uses alternative flight paths to overfly compatible land use, and management of number and time of operations (day vs. night). This section introduces the baseline airspace structures, demographic database, and UAM scenarios that are used in this simulation study for the prediction and mitigation of UAM fleet noise in DFW metroplex.

A. DFW Airspace Structure



(a) (b)

[1]Figure 1. Airspace boundaries (a) and UAM airways (b) for DFW metroplex

The baseline airspace structures are modeled as route constraints for the design of noise-aware route options in the DFW metroplex. In figure 1(a), the Class B airspace boundary is outlined by a blue contour, and the surrounding Class D airspace boundaries are shown as green polygons. Based on the Instrument Approach Procedure FAA 8260.46G and the historical air traffic patterns[9], the ATM environment (AE) regions that cannot be used for UAM operations in the engineering evaluation are depicted by the dark-grey polygons inside each controlled airspace. The AE regions were determined based on an assumed standard separation requirement of 1,000 ft vertical or 2,500 ft horizontal from the historical traffic pattern required for a controller to provide wake turbulence advisories to the UAM and traditional traffic. The DFW AE and DAL AE regions are valid only for south flow configurations. Each AE region within the Class D airspace (i.e., inside the green polygons) is independent of airport configuration. The AE regions are modeled as route constraints in this study.

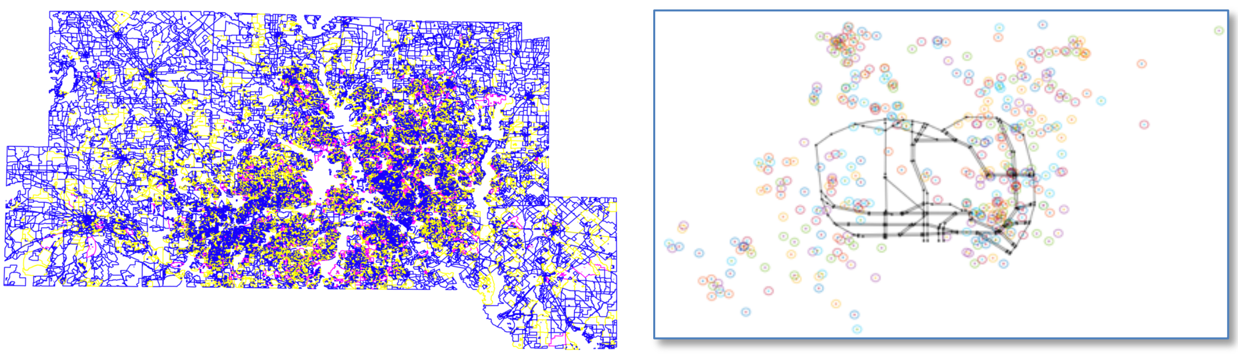
Figure 1(b) depicts the UAM airways within the Class B airspace and Class D airspace. They are based on modifications applied to the current-day helicopter routes in the Dallas area based on NASA's recent exploration of routes and procedures for UAM operations. Some parts of the UAM airway network are overlie the highway network, providing pilots with a visual reference to follow. The network is comprised of 43 unidirectional airways at 900ft, 1000ft, 1100ft and 1600ft above Mean Sea Level (MSL). The network contains 338 predetermined waypoints specified by latitude, longitude and altitude with directional linkage to neighboring waypoints for construction of UAM aircraft flight plans. To keep communication procedures simple and reduce controller workload, the current

[1] Underlying map data is © OpenStreetMap contributors. https://www.openstreetmap.org/copyright.

study assumes that, for the near-term future, UAM aircraft will fly along the airways after entering the controlled airspace.

B. Demographic Data: Population model & Noise-sensitive Landmarks

For the purposes of UAM noise compatibility planning, the goal is to reduce incompatibilities between aircraft noise and nearby communities. This requires information on local land use patterns. This section introduces the United States Geological Survey's (USGS) Census database that provides the demographic data used in this study for assessing and reducing potential population size affected by UAM aircraft fleet noise. AIRNOISEUAM also uses the data for development of noise exposure maps[6] for UAM following FAA's noise compliance planning regulation. Demographic information for more than 100,000 census blocks in the DFW metroplex, which includes county code, population number, and latitude, longitude, and elevation of each census block centroid, is extracted for modeling the number and location of the noise receptors on the ground. Figure 2(a) outlines the census blocks in blue, yellow, and magenta color, with population numbers no greater than 100, 500, and 6362, respectively. The noise-aware routing algorithm seeks possible ground tracks with reduced total accumulated number of people under the flight path. Figure 2(b) depicts the operational-representative routes used for an engineering evaluation in black lines. The locations of noise-sensitive facilities such as hospitals, places of worship, and schools are queried using Google map Application Programming Interface as shown in Fig. 2(b) for identification of facilities potentially impacted by various noise levels.



(a) (b)

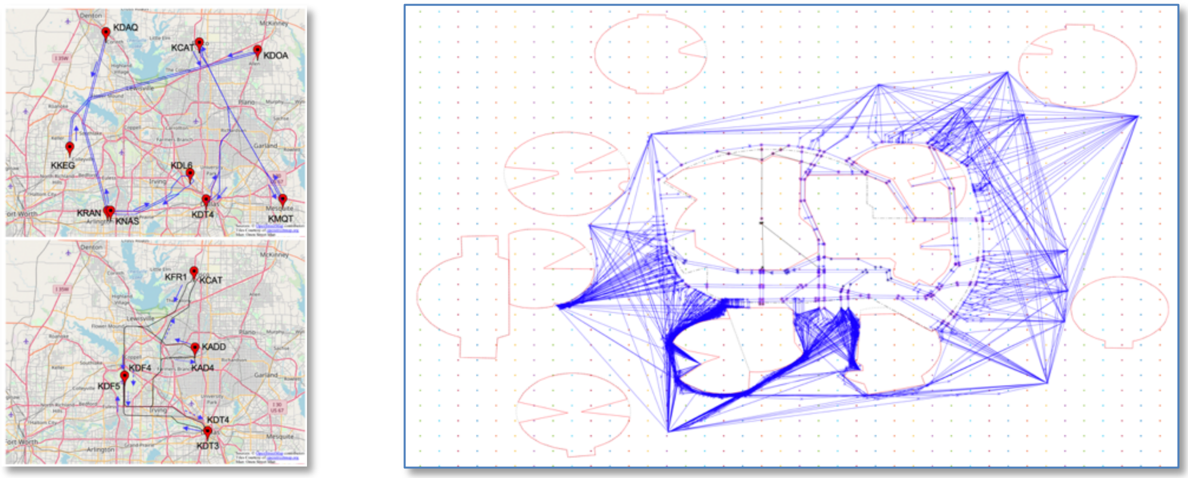
Figure 2. Census blocks with populations (0, 100] depicted in blue, (100, 500] yellow, and (500, 6362] magenta polygons (a) and UAM routes depicted in black lines and noise-sensitive facilities depicted as circles (b)

C. Noise Mitigation Considerations for the UAM Scenarios

Noise impacts of UAM operations can be reduced by increasing the distance between the aircraft noise source and the receptors located on the ground. This can be done by increasing flight altitude and/or increasing the geographic separation between the populated area and the ground tracks of UAM aircraft, giving due consideration to airspace constraints and performance metrics such as flight time. The strategy is to develop multiple feasible routes for a given origin-destination pair and compare the selected baseline route against the identified alternatives to decide whether to fly along the cost-optimal path or a noise-aware path. The decision is made based on the considerations of additional operational cost and the potential reduction in the accumulated number of people and noise-sensitive facilities located along the ground track.

The Day Night average sound Level (DNL) is the current noise metric used for regulatory compliance of aviation noise. DNL depends on both the Sound Exposure Level (SEL) of noise source to noise receptors and the number of occurrences. Given the level of UAM demand for an origin-destination pair, DNL can be reduced by allocating flights to different routes and thus reduce the recurrence of noise exposure to the same set of receptors. These potential strategies to reduce noise impact require the development of alternative route options for each selected UAM flight.

The routes used for NASA's engineering evaluations are collected in this study as part of the baseline UAM route options for assessment of the UAM aircraft fleet noise. There was a total of 16 routes defined for the X2 engineering evaluation. Of those 16, 10 origin-destination pairs were bi-directional as shown in the upper part of Fig. 3(a). The lower part of Fig. 3(a) shows the route network for the remaining 6 unidirectional origin-destination pairs. Figure 3(b) plots all the routes designed for the X3 engineering evaluation based on a low UAM demand level[4] for DFW metroplex. There are 50 vertiports and 2,450 unique origin-destination vertiport pairs. The baseline routes will be compared with noise-aware route options for testing and evaluation of the algorithms leading to the development of an inventory of UAM routes in the Dallas area.

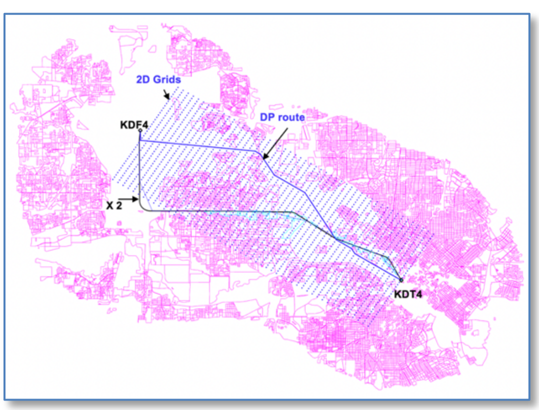


(a) (b)

[2]Figure 3. UAM routes for X2 in (a) and for X3 in (b)

III. Dynamic Programming Approach for Noise-Aware Routing

This study developed routing algorithms to generate noise-aware route options as alternatives to the baseline route inventory for analysis of trade-off between additional trip distance and reduction in impact of noise on the local population. Popular routing algorithms such as Dijkstra's[10] algorithm, and the A*[11]algorithm, find one optimal path per origin and destination pair specified in a graph. A past study[12] developed a flight path search algorithm based on Dynamic Programming (DP) with nodes and links grouped into subsequent stages to reduce computational time. This study used the same algorithm to generate all optimal flight paths to the destination from the origin and all nodes in a graph composed of user-defined regular nodes and links. Figure 4(a) depicts a set of nodes with blue dots within a two-dimensional search plane for flights from origin-KDF4 to destination-KDT4. The magenta polygons are the boundaries of census blocks in the area. The baseline X2 route and the DP route from KDT4 to KDF4 are plotted by the black line and blue line, respectively. The DP route avoids interception of the census blocks en-route, thereby reducing the accumulated number of people located under the flight path. Figure 4(b) summarizes the DP algorithm. The optimal cost-to-go values at all of the nodes are utilized to construct an optimal-cost-specific topographic map for use as a reference comparison between any baseline route overlay and the computed optimal routes. This is done to identify potential benefits and baseline route segments for alternations aiming for noise impact reduction.



for each origin and destination pair,
1. Define a set of grids $x_{i,j}$ for the search space.
for each tentative departure time period,
2. Calculate $t^{min}_{i,j}$ and $t^{max}_{i,j}$ for all $t_{i,j}$ which is the estimated aircraft arrival time at $x_{i,j}$.
3. Define the set of admissible controls $U_{i,j}$.
for each stage (starting from the last stage),
for each admissible state and admissible link,
4. Calculate the population exposure,
5. Calculate the optimal cost-to-go $J(x_{i,j}(t_{i,j}))$.
end for
end for
6. Find the optimal path by minimizing the total cost over all stages.
end for
end for

(a) (b)

Figure 4. Minimum population-of-flyover from KDF4 to KDT4 via Dynamic Programming

[2] Underlying map data is © OpenStreetMap contributors. https://www.openstreetmap.org/copyright.

Multiple cost-conscious routes are needed to enable the analysis of their impact to different sets of noise receptors. The aforementioned algorithm is extended to search for multiple paths between an origin and a destination for a network of predefined nodes and links. The process of searching for *m* multiple paths starts backward from the destination. All nodes reachable from the previous stage are kept for each stage of the search. A path is collected if the origin is reached, and the search process terminates when *m* paths are found or the predefined maximum number of stages is exceeded.

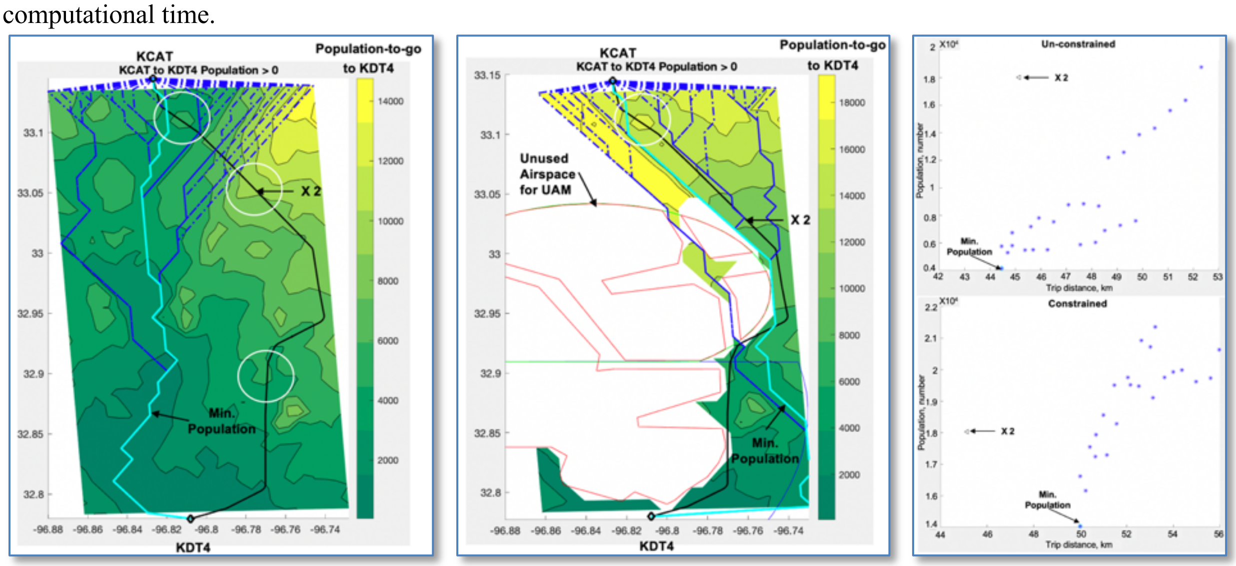
This algorithm is further extended to search for multiple paths between an origin and a destination for a graph that is composed of predefined networks and user-defined regular nodes and links. Similarly, the search process starts backward from the destination and terminates if the origin is reached or the predefined maximum number of stages is exceeded. For each stage in the search, this algorithm retains a constant number *n*, which is greater than or equal to 1, of optimal routes form each node within the stage to the destination. To enhance computational efficiency, a heuristic cost is assigned to each node to guide the search process by only maintaining a set of *o* nodes that are sorted according to the heuristic cost values for each of the *o* nodes to the origin. Only the set of *o* nodes within each stage remains open for subsequent search.

IV. Noise Impact Analysis

The results of the noise impact analyses conducted in this work are presented in this section. Section IV.A. presents the application of the DP routing algorithm for the X2 route enhancement. Section IV.B. presents the routes that overfly fewer people to DFW given a gridded network. Section IV.C. presents the route patterns from 35 UAM airway entry points to DFW. Section IV.D. presents the results for the selected UAM demand scenarios. Section IV.E. utilizes AIRNOISEUAM for noise compliance analysis.

A. **Minimize Population-to-go for Baseline Route Enhancement**

This subsection illustrates an application of the DP routing algorithm to generate alternative route options and an optimal-cost-specific topographic map for a given route. The goal is to identify routes or baseline route segments for alternations to reduce the potential noise impact. Specially, alternate route options are generated between KCAT and KDT4 that overfly fewer people. This is expressed in a cost function by summing the population value of each overflown census block between KCAT and KTD4. Currently, all the census blocks are considered. A strategy of considering only census blocks with a population larger than a chosen threshold can be adopted in future to reduce the computational time.



(a) (b) (c)

Figure 5. Contours plot for minimized population-of-flyover to KDT4, and the route option from KCAT to KDT4 without airspace constraints in (a), incorporating unused UAM airspace in (b); and the plots for possible tradeoff between impacting fewer people and incurring additional trip distance in (c)

Figure 5a depicts the baseline X2 route in black and the optimal route in cyan. The route option also contains a set of 22 alternative routes in addition to the cyan route from KCAT to KDT4. Each route overflies a different grid point at the first stage of the searching process. Note that the optimal route and the optimal cost-to-go value from each grid point at the subsequent stages to KDT4 are also computed. The topographic map in Figure 5a is constructed using the optimal cost-to-go value (i.e. minimized summation of population overflown at each of the grid points to KDT4). The color represents the size of the population overflown in the area to the destination along their optimal routes. The optimal-cost-specific topographic map is used to compare with any baseline routes to identify route segments that could be optimized to reduce the number of people potentially impacted by UAM operations. These route segments are identified in the white circles.

Figure 5(b) plots similarly the re-generated results after incorporating the AE regions that are depicted in red polygons. Figure 5(c) plots the trip distance on the x-axis and the impacted population size on the y-axis for the DP routes and the X2 route. The results for the X2 route are plotted as black triangles; the data points along the optimal route and the 22 alternative routes are plotted as cyan asterisks and blue asterisks, respectively. This example estimates that UAM operations along the optimal route could potentially impact 17% fewer people at the cost of an additional 11% in trip distance.

B. Reduce Population-of-flyover to DFW Given Over 10,000 Potential Origins

This subsection extends the application of the DP routing algorithm to generate an optimal-cost-specific topographic map for reducing number of people potentially impacted by UAM aircraft noise in DFW metroplex. The map is designed based on the minimized population-of-flyover costs and the optimal routes from all grid points to provide reference route segments to DFW airport**.** The search process started at the nearest waypoint on UAM airways to the DFW airport that is assumed to be the major hub for UAM aircraft to connect passengers to commercial airliners. The search process steps backward and expands to the surrounding neighborhoods for more than 10,000 potential origin nodes. These nodes are assumed to be the grid point locations of the High Resolution Rapid Refresh (HRRR) weather system for future exploration of historical weather impacts. The topographic map is used to estimate the number of people overflown by the optimal flight paths from the grids in the area to the destination. They provide policy makers with noise-relevant insights for the placement of vertiports, design of route segments, and flight altitude restrictions.

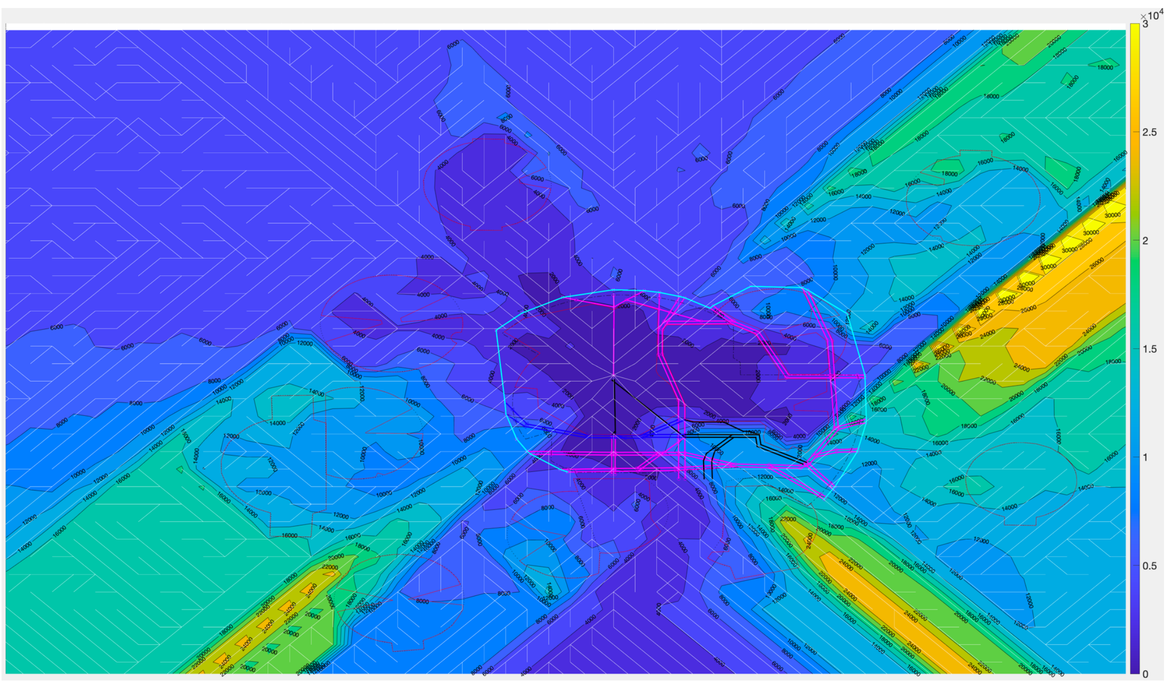


Figure 6. Topographic map based on minimized population-of-flyover to DFW airport and the route segments from all the potential origins

Figure 6 presents a topographic map for the DFW metroplex based on minimizing the overflown population. The light-colored polygons represent areas with a larger accumulated number of people potentially impacted by UAM aircraft along their optimal routes. The structure of the optimal route segments is depicted with white lines. It shows where the UAM flight might be entering the controlled airspaces and the directional characteristics. Note that the UAM airways are plotted using various colors in Fig. 6 as a reference. The information supports design and determination of entry points to the UAM airways without the need of making specific assumptions about future UAM demand over the DFW metroplex. In general, the placement of waypoints and links of a network of routes for UAM traffic at lower altitudes should avoid the warmer-colored areas. This is an example in preparation for exploration of UAM network development with uncertain origin locations. The next section presents the results when UAM aircraft enter the controlled airspace utilizing the UAM airways based on the existing helicopter route network.

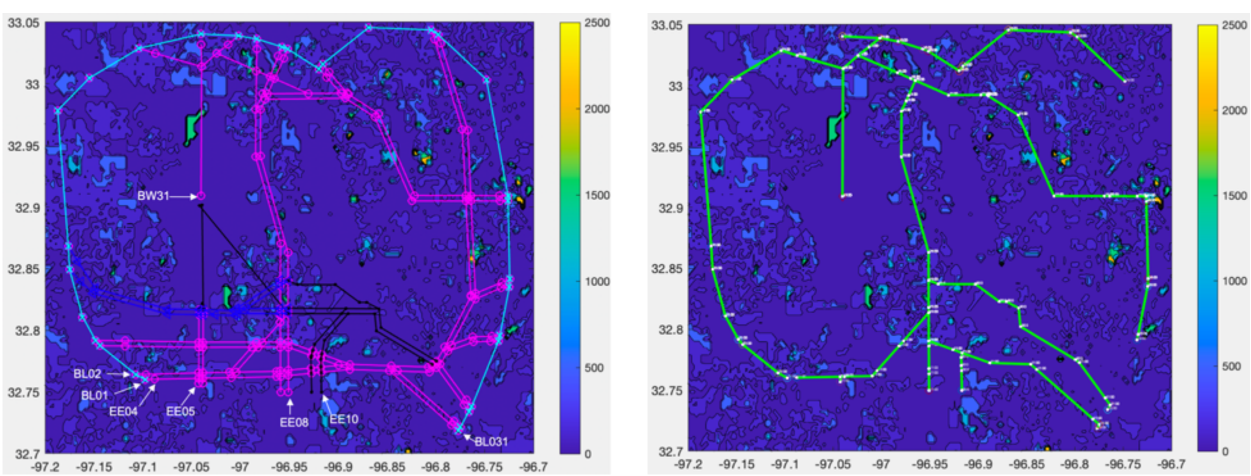
C. Reduce Noise Impacts from 35 UAM Airway Entry Points to DFW

The prediction of noise impact and the potential mitigation needs of UAM flights with the origin or destination outside the controlled airspace requires identification of entry and exit waypoints on the UAM airways and the route options. This study assumes that UAM aircraft can choose to enter and exit UAM airways for operations inside the Class B airspace or Class D airspace at the designated waypoints. Each flight path is a combination of airway segments inside the controlled airspace and predefined links within the gridded search space when outside the controlled airspace in the area. The impact of UAM aircraft fleet noise is predicted based on the possible number of people located inside noise contours of various sound levels.

AIRNOISEUAM is utilized to compute contours of noise levels for the selected route design given a UAM demand level and the aircraft type. It was developed for noise impact prediction of UAM vehicles with NASA Revolutionary Vertical Lift Technology (RVLT)'s Gen-1 Noise Power Distance (NPD) database[2] that models rotor propeller noise using blade loading and motion data. The Gen-1 NPD database was used as input to FAA's AEDT and AIRNOISEUAM software to compute UAM vehicle noise metrics (e.g., SELs, DNLs). Extensive validation of AIRNOISEUAM with the FAA's AEDT software has been conducted, and results from AIRNOISEUAM consistency match with those from AEDT with maximum difference being less than 0.1dB[2]. The validation was done for a Robinson 66 helicopter (R66) and NASA's concept quadrotor UAM vehicle[5].

In this example, the routing algorithm calculates route options for UAM flights going to BW31, which is the closest waypoint to DFW airport given a south flow airport configuration. It is assumed that all UAM flights that operate outside the networks/controlled airspace will enter from one of the 35 entry waypoints (i.e., BL01, BL02, …, BL31, EE04, EE05, EE08 and EE10). Figure 7(a) depicts the locations of the destination and entry waypoints on the cyan line and the magenta line. They are selected here to capture flights entering from all directions. The warmer-colored polygons in Fig. 7(a) represent areas with larger population size. One hundred routes are calculated for each entry waypoint to provide an inventory of routes for the development of potential noise mitigation strategies. The number of potentially impacted people and the trip distance are calculated and ranked for the 3,500 routes. The route with minimum total trip distance and the route with minimum number of impacted people for each entry waypoint are also identified.

Each route is assessed to select one that overflies fewer people. Figure 7(b) depicts the route pattern composed of the minimum-distance route from each of the entry waypoints to the destination. The total trip distance is approximately 1500km, and the number of potential impacted people (calculated by summing the population number of all the intercepted census blocks) is around 800,000.

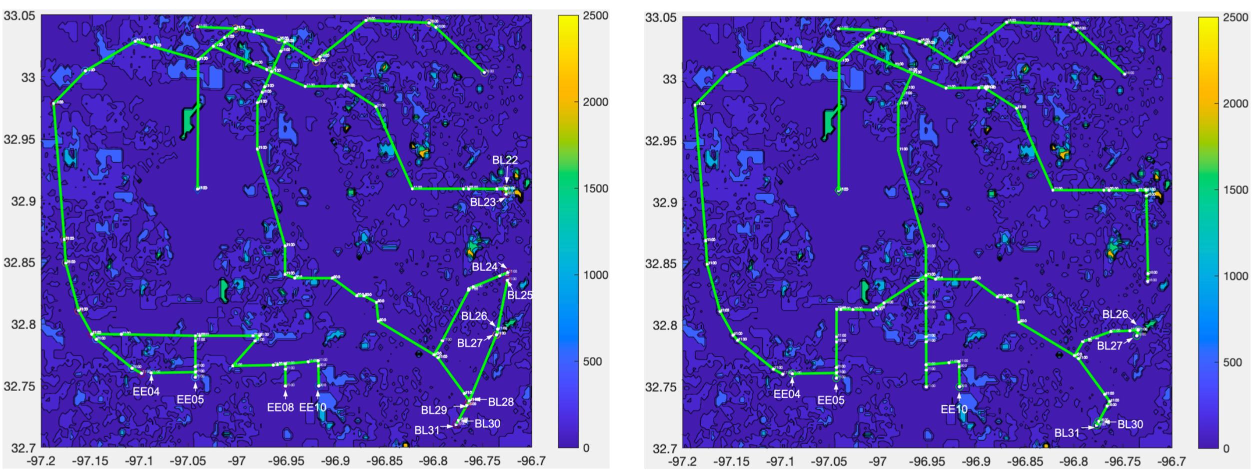


(a) (b)

Figure 7. UAM airway with 35 selected entry points to DFW in (a) and minimum-distance routes in (b)

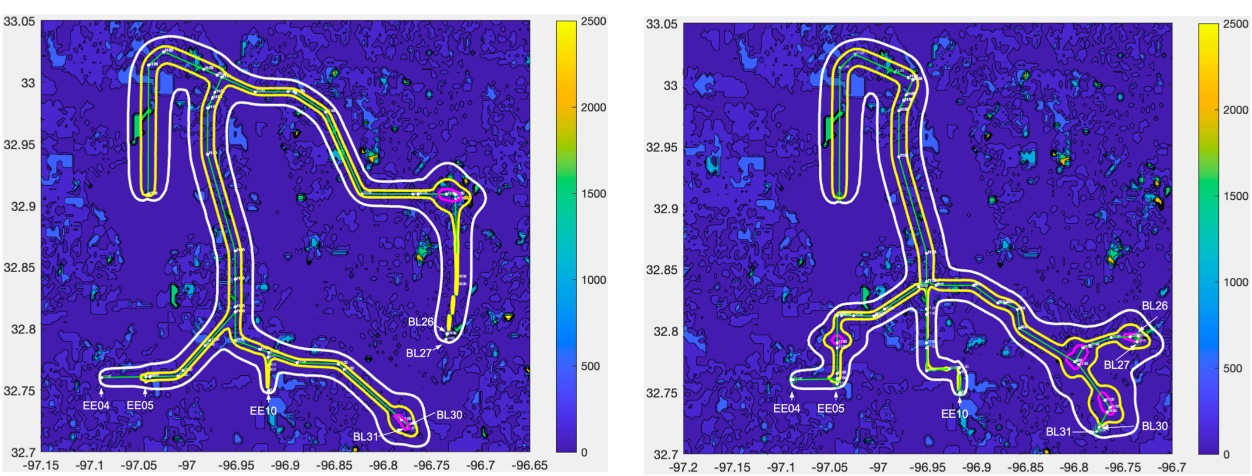
For this UAM rout network, 21 out of 35 entry points have minimum-distance routes that are the same as the minimized population-of-flyover routes. Other routes within the route option set were found to increase both trip distance and number of impacted people. For these entry points, increasing the operational altitude of the airway segments that are predicted to exceed a noise threshold could reduce the noise impact, since it would increase the distance between the noise sources and receptors. The route options developed for these 21 entry points could still have utility, though. By distributing some fraction of flights among the alternate routes, noise metrics such as DNL could be reduced, albeit incurring some additional travel distance.

Fourteen of the 35 entry points have minimum-distance routes that are different than the minimized population-of-flyover routes. Figure 8(a) plots the route pattern when the minimized population-of-flyover route is selected for each of the 14 entry waypoints. The additional trip distance is approximately 90km for one flight along all of the 14 alternative routes, and the potential reduction in the number of people impacted is approximately 70,000. This would require an average of 14% additional travel distance for flight operations entering from BL22-BL31 and EE04, EE05, EE08 and EE10. A set of 7 routes is identified for the selected entry waypoints (i.e., BL26, BL27, BL30, BL31, EE04, EE05, EE10) from the route inventory given a constraint on additional trip distance. Fig. 8(b) plots the routes that have less than 5% additional trip distance when compared to their respective minimum-distance route. The first two columns in Table 1 summarize the results based on a tradeoff analysis between reduced noise impact on people and a maximum increase of 5% in the total trip distance.



(a) (b)

Figure 8. Minimized population-of-fly routes in (a) and noise-aware routes with <5% additional trip distance constraint in (b)



(a) (b)

Figure 9. Contours of SELs (>=65 dBA) for the minimum-distance routes in (a) and for the reduced population-of-overfly routes in (b)

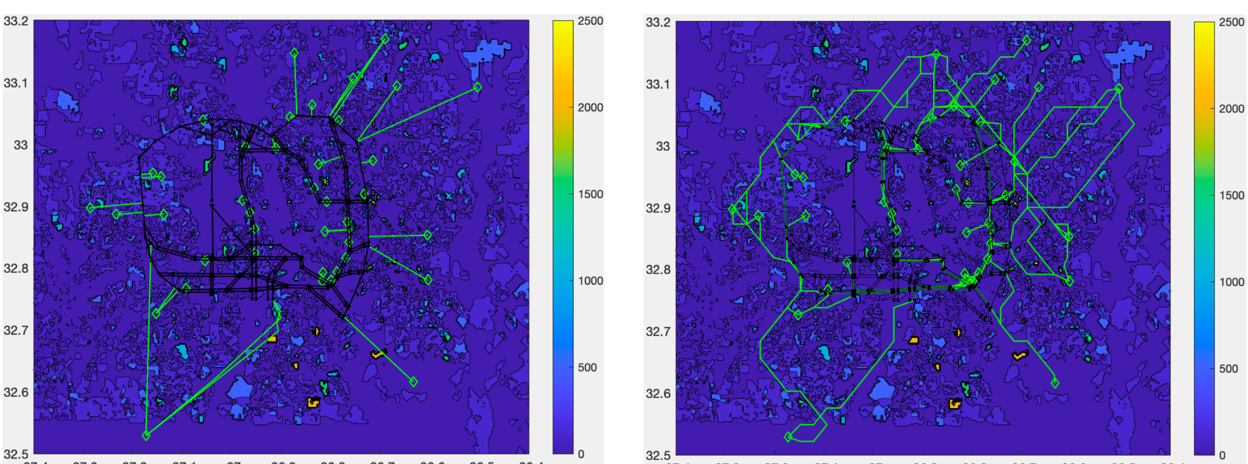
Figure 9(a) depicts the minimum-distance routes with contours of SELs greater than 65dBA for the 7 selected entry waypoints. The 65dBA, 75dBA, and 85dBA SEL contours are plotted in white, yellow and magenta, respectively. AIRNOISEUAM computed the SELs for RVLT's concept quadrotor UAM vehicle along the set of selected routes. Figure 9(b) depicts similar results for the noise-aware routes that can potentially reduce the cumulative population that UAM aircraft will fly over. The third column in Table 1 summarizes the results based on the number of people inside the SEL contour greater than or equal to 65 dBA. These results show a positive correlation between percent reduction of noise-impacted people inside the 65dBA SEL contour and those under the flight path estimated by the DP routing algorithm. Flights along the noise-aware routes that enter from BL30 and BL31 have the largest potential reduction in noise impact with only 0.4% additional travel distance.

Table 1. Tradeoff results with 5% constraint on additional distance per trip

Entry Waypoint	Additional Trip Distance (%)	Reduction in Population of Flyover (%)	Reduction in Population within 65 SEL Contours (%)
EE04	2.1	12	5
EE05	2.2	12	5
EE10	2.2	0.3	0.6
BL26	4.3	23	12
BL27	4.2	23	8
BL30	0.4	21	26
BL31	0.4	21	34

D. **Reduce Noise Impacts of Chosen UAM Demand Scenarios in DFW Metroplex**

This section designs a set of alternative routes for a low UAM demand level[4] and assesses the potential noise impacts for the baseline and alternate route networks. The noise impact of UAM aircraft is predicted based on the estimated number of people inside contours of SEL greater than 65 dBA. There are 50 vertiports and a baseline route for each of the 2,450 unique origin-destination pairs modeled for DFW metroplex given a low UAM demand level. The DP routing algorithm generates 100 alternative routes for each origin-destination pair. They are compared with the baseline route based on trip distance, approximated number of people under the flight path, and number of people exposed to various noise levels (i.e., inside various SEL contours). The noise-aware route option enables UAM operations to be distributed across all of the alternative routes given constraint of trip distance and noise impacts that depend on acoustic characteristics of the source of noise, number of operations, terrain elevation and spatial distribution of people. In this example, the route inventory consists of 245,000 alternative routes in addition to the baseline route, each with computed trip distance and number of people located under the flight path. The first step of this noise mitigation process identifies all alternative routes that satisfy a distance constraint and have fewer people under the flight path when compared to the baseline route. Then, AIRNOISEUAM computes SEL for the chosen UAM aircraft type (e.g., RVLT conceptual quadrotor aircraft) at the noise receptor locations in the area for a typical aircraft operation profile and terrain elevation.



(a) (b)

Figure 10. A set of baseline routes in (a) and the alternative noise-aware routes in (b)

Figure 10(a) plots the baseline routes for a set of 93 origin-destination vertiport pairs in green. Figure 10(b) plots each of the alternative counterparts selected from the route option set, using the objective of no additional travel distance and a maximum reduction of people directly under the flight path. The color-filled polygons in the background represent areas with various population sizes. The bar graph in Fig. 11(a) represents the trip distance of the baseline and alternative routes. Note that the baseline routes were not optimized with respect to trip distance. The distance savings of the alternative routes ranges from 0 km to 27 km for the set of origin-destination pairs, as shown in Fig. 11(b). The red-dotted line in Fig. 11(a) plots the population metric that is defined in this study for prediction of number of people potentially impacted by noise for each route. This study assumes that the population of each census block is evenly distributed in a set of reference points, and this metric is calculated based on total number of people at the reference points inside the SEL contours greater than 65 dBA. The percent reduction of this population metric is between 0.1% and 77%, with 29% average reduction. It is plotted by the red-dotted line in Fig. 11(b) for each origin-destination pair. Figure 12(a) depicts the 65dBA-, 75dBA-, and 85dBA-SEL contour, in white, yellow, and magenta, respectively, for RVLT's conceptual quadrotor UAM vehicle that operates on the baseline routes. Similarly, Figure 12(b) depicts the noise contours for quadrotor flights along the noise-aware routes.

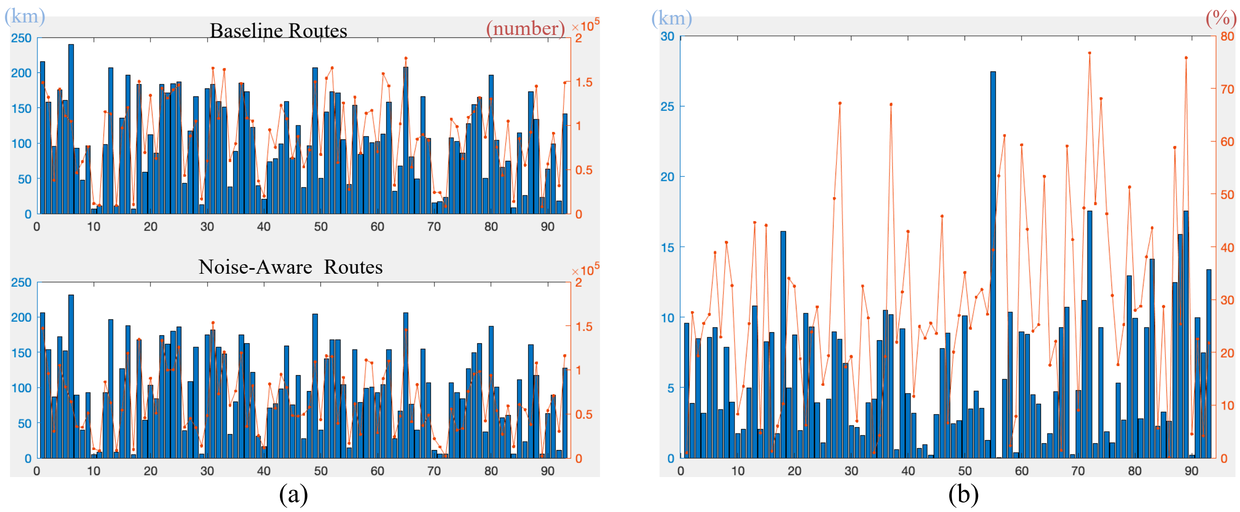


Figure 11. Travel distance and population metric for (a) the baseline and alternative routes and (b) the reduction in travel distance and potential percent reduction of people within the 65 dBA SEL contours

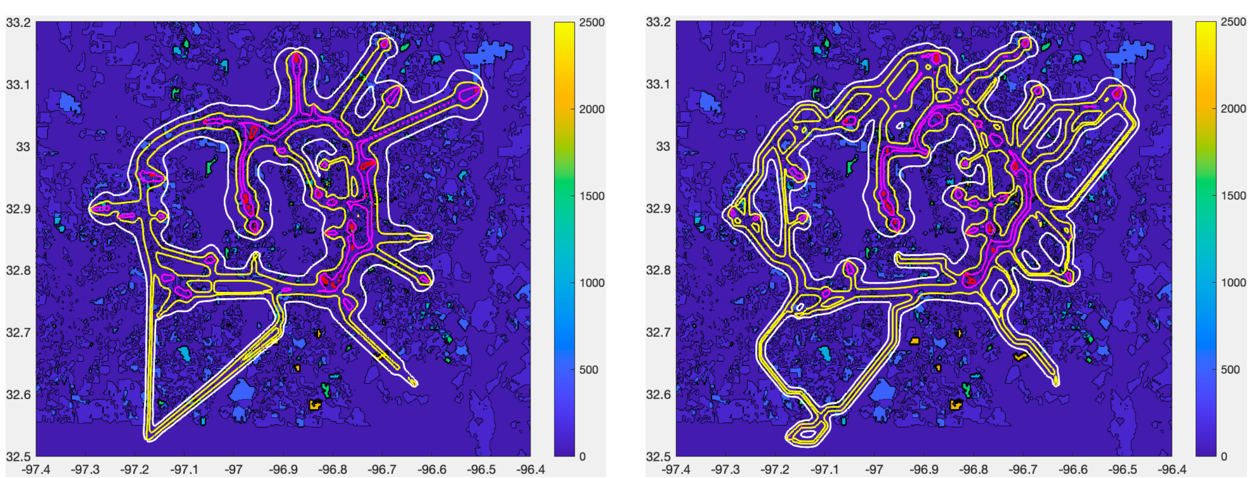


Figure 12. SEL Contours (>=65 dBA) for (a) the baseline routes and (b) the noise-aware routes

E. Noise Community Impact Analysis

Preliminary noise impacts to the local community in DFW metroplex is analyzed for the baseline and alternative route networks. AIRNOISEUAM calculates SEL for each route at a total of 60,491 noise receptors that are evenly distributed at a grid set with each receptor separated in 0.0033 degrees latitude and 0.0039 degrees longitude. The total trip distance along the baseline routes and the alternative routes is 10,054km and 9,474km, respectively, for the 93 origin-destination vertiport pairs. The SEL contours for the baseline and alternative networks is calculated by accumulating the SEL value of each single noise event for the two route networks, respectively. The size of areas, number of people, schools, places of worship, and hospitals impacted by 65dBA, 75dBA, 85dBA, and 95dBA SELs are shown in Table 2. The baseline route network has a smaller 65dBA or 75dBA area of SEL. The size of the noise contours depends on local terrain elevation that was not considered in the route generation and selection process. The alternative route network has a smaller population size impacted by 75dBA and above. By assuming that population is evenly distributed within each census block, the impacted populations are summed based on the percent of census block area inside the joint area between the census blocks and the noise contours. Note that the routing algorithm assumes the population located at the centroid of each census block and minimizes accumulation of population of all census blocks that are directly under the flight path.

Table 2. Noise Community impact for the baseline and alternative scenarios

	Baseline Routes				Alternative Routes			
Sound Exposure Level (dBA)	65	75	85	95	65	75	85	95
Area (km^2)	1725	732	136	5	1936	776	94	3
Impacted Population (thousands)	1964	901	195	7	1975	774	125	4
Schools (number)	157	30	0	0	157	51	0	0
Places of Worship (number)	100	0	0	0	99	0	0	1
Hospitals (number)	0	0	0	0	0	0	0	0

Noise compliance analysis can be done for any chosen demand scenario to identify potential areas exceeding a noise threshold and impacted noise-sensitive facilities. It is estimated that the area of 95dBA SEL contour has a noise level of 65dBA DNL given a total of 86 daytime operations for each of the 93 routes. Similarly, the area of 85dBA, 75dBA, and 65dBA SEL contours has a noise level of 65dBA DNL given 860, 8,600 and 86,000 daytime operations for each route, respectively. The alternative route networks can potentially reduce community noise impacts when total daytime operations are below 8,600 for each route.

V. Concluding Remarks

This study presented dynamic programming algorithms to generate noise-aware route options to analyze the trade-off between additional trip distance and reduction of noise-impacted population. The routing algorithm generated alternative route options and an optimal-cost-specific topographic map for enhancement of the baseline route design for reduction of potential noise impact. A map is designed based on the minimized population-of-flyover costs and the optimal routes from all grid points to provide reference route segments to DFW airport**.** Preliminary analysis of noise impacts and potential mitigation needs for UAM flights that originate outside the controlled airspace and terminate at DFW airport was performed through investigation of route options from each of the 35 entry waypoints of the UAM route network. The entry waypoints and the noise-aware routes that have the largest potential reduction in noise impact with less than 5% additional travel distance are identified. Noise impact analysis and noise-aware route option design are done for a low UAM demand scenario in DFW metroplex for 2,450 unique origin-destination vertiport pairs. Simulation results show that the percent of people potentially exposed to SEL of 65dBA or greater could be reduced by 29% on average, with distance savings up to 27km when UAM flights operate on the noise-aware routes for the selected 93 vertiport pairs. In addition, the alternative route networks could potentially reduce community noise impacts when total daytime operations are no more than 860 for each route based on analysis of population size and number of noise-sensitive facilities impacted by 65dBA DNLs.

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References

[1]Aviation Environmental Design Tool (AEDT), Version 3c, Technical Manual, Federal Aviation Administration, *DOT-VNTSC-FAA-20-05* (2020).

[2]Li, Jinhua, Zheng Y., Rafaelof, M., Ng, H., Rizzi, S., "The AIRNOISE-UAM Tool and Verification with FAA Aviation Environmental Design Tool," 50th International Congress and Exposition on Noise Control Engineering, Washington, DC, 1-5 August 2021.

[3]Verma, Savita A., Keeler, J., Edwards, T., Dulchinos, V., "Exploration of Near-term Potential Routes and Procedures for Urban Air Mobility," 2019 AIAA Aviation Forum, Dallas, TX, 17-21 June 2019.

[4]Rimjha, M.L., Hinze, N., Tarafdar, S., Hotle, S., Swingle, H., and Trani, A., "Demand Forecast Model Development and Scenarios Generation for Urban Air Mobility Concepts," *NASA Contractor Report (Internal) from Virginia Polytechnic Institute*, April, 2020.

[5]Silva, C., Johnson, W., Antcliff, K.R. & Patterson, M.A., "VTOL Urban Air Mobility Concept Vehicles for Technology Development," 2018 Aviation Technology, Integration, and Operations Conference, AIAA-2018-3847 (2018).

[6]Li, Jinhua, Ng, H., Zheng, Y., Gutierrez, S., "Noise Exposure Maps for Urban Air Mobility," 2021 AIAA Aviation Forum, Washington, DC, 7-11 June 2021.

[7]https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html.

[8]"Noise Control and Compatibility Planning for Airports," Federal Aviation Administration Advisory Circular (AC 150/5020-1), U.S. Department of Transportation, August 5, 1983.

[9]Vascik, Parker D., Hansman, J., "Allocation of Airspace Cutouts to Enable Procedurally Separated Small Aircraft Operations in Terminal Areas," 2020 AIAA Aviation Forum Virtual Event, June 15-19, 2020.

[10]Dijkstra, E. W., "A Note on Two Problems in Connexion with Graphs," Numerische Mathematik, Vol. 1, No. 1, December 1959, pp. 269–271.

[11]Hart, P. E., Nilsson, N. J., and Raphael, B., "A Formal Basis for the Heuristic Determination of Minimum Cost Paths," SIGART Newsletter, No. 37, 1972, pp. 28–29.

[12]Ng, H.K., Morando, A., and Grabbe, S., "Automated Flight Routing Using Stochastic Dynamic Programming," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, TX, 13-15 September 2010.