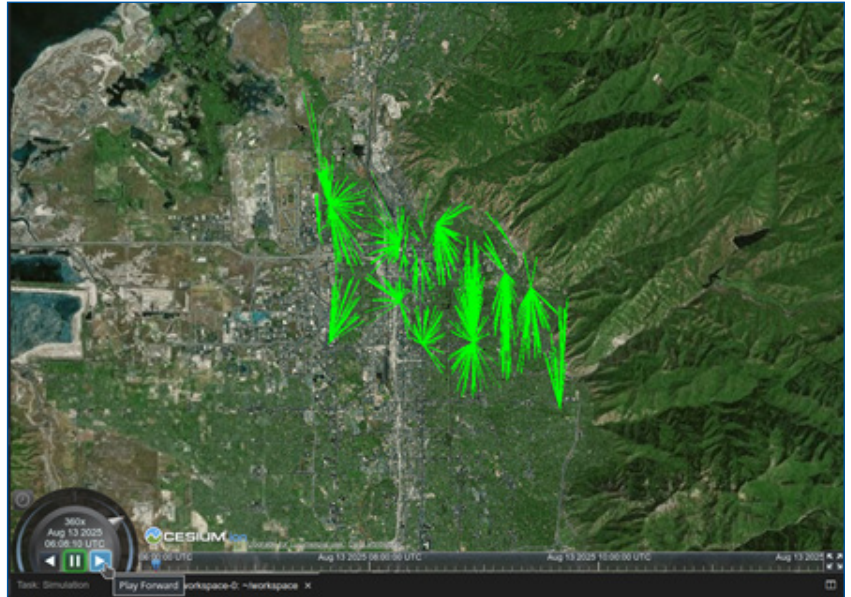# MOUNTAIN-PLAINS CONSORTIUM

MPC 24-512 | D. Sacharny and X. C. Liu

STRATEGIC DEPLOYMENT
OF DRONE CENTERS AND
FLEET SIZE PLANNING
FOR DRONE DELIVERY
IN UTAH

MOUNTAIN-PLAINS
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16. Abstract

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STRATEGIC DEPLOYMENT OF DRONE CENTERS AND FLEET SIZE PLANNING FOR DRONE DELIVERY IN UTAH

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ABSTRACT

The research project produces a statewide airspace network, delivery schedule, and truck/drone fleet mix. Such an airspace network is optimized to ensure that drones are strategically deconflicted as required by NASA and the total energy over that day is minimized. Such an airspace network is realized in a web-based platform named the Utah Advanced Air Mobility Simulator (UAAMS). The UAAMS enables researchers, planners, and practitioners to record and update assumptions about the distribution of vertiports, traffic, population, and other requirements that may affect the operation of the transportation network. These parameters are important not only for considering the feasibility of unmanned aircraft systems (UAS) package delivery within the state, but also for determining the impact and ultimately the efficient operation of drone delivery. The UAAMS allows UDOT to assess different assumptions of the model and run "what-if" scenarios by generating animation of the optimized airspace network. The platform provides the state with more clarity about the energy impacts of large-scale drone delivery as well as a viable airspace network. The tool can further inform the UDOT Division of Aeronautics to develop policies and negotiate with industry stakeholders.

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EXECUTIVE SUMMARY

The research project produces a microsimulation framework that outputs a statewide airspace network, delivery schedule, and truck/drone fleet mix for a given set of parameters. These simulations answer many questions surrounding advanced air mobility in Utah, but specifically on whether a combination of unmanned aircraft systems (UAS) and ground-based trucks is more efficient at delivering packages than trucks alone. This research looks at the energy consumed by the hybrid system (i.e., UAS and trucks) given the unique geography and demographics of Utah. The airspace network produced by the simulations are then considered as part of an optimization process to minimize the total energy consumed over a day, considering the locations of vertiports. Such an airspace network is realized in a web-based platform named the Utah Advanced Air Mobility Simulator (UAAMS). The UAAMS enables researchers, planners, and practitioners to record and update assumptions about the distribution of vertiports, traffic, population, and other requirements that may affect the operation of the transportation network. These parameters are important not only for considering the feasibility of UAS package delivery within the state, but also for determining the impact of these operations.

The UAAMS allows UDOT to assess different assumptions of the model and run "what-if" scenarios by generating animation of the optimized airspace network. The platform provides the state with more clarity about the energy impacts of large-scale drone delivery as well as a viable airspace network. The tool can further inform the UDOT Division of Aeronautics to develop policies and negotiate with industry stakeholders.

Through this project, the implementation and deployment of the UAAMS was successful and will be available for continuing research in the development of advanced air mobility in the state of Utah. This type of tool is critical for research in this area, as it incorporates the latest software and infrastructure development techniques available. Also shown was the viability of considering the large-scale impacts (e.g., environmental) of advanced air mobility on specific communities by using micro-simulation technology. In contrast to micro-simulations performed for human-controlled ground and air traffic, in this case a model for the autonomous agents has the potential to be exact since their algorithms must be documented. Future improvements will consider further optimizations to the simulator, allowing for a more thorough exploration of the possible configurations of vehicle and vertiport parameters.

1. INTRODUCTION

1.1 Problem Statement

In a 2017 report by the RAND corporation (Lohn, 2017), analytical methods for calculating the total energy consumed by a mix of delivery trucks and drones were developed and shown to be highly dependent on the layout of distribution centers as well as distance traveled by delivery vehicles. This suggests that the city layout, i.e., street connectivity and other network parameters, are important considerations for energy-conscious policies. While industry stakeholders must determine the market viability of drone delivery, they are not required to calculate the external and indirect costs that may be associated with this burgeoning industry.

The web-based platform developed for this report, called the Utah Advanced Air Mobility Simulator (UAAMS), enables researchers, planners, and practitioners to record and update assumptions about the distribution of vertiports, traffic, population, and other requirements that may affect the operation of the transportation network. These parameters are important not only for considering the feasibility of unmanned aircraft systems (UAS) package delivery within the state, but also for determining the impact and ultimately the efficient operation of these new transportation technologies. Furthermore, additional analysis and what-if scenarios may be developed using this simulator. Example Jupyter notebooks (Python) are provided to help guide development; however, users are not limited to any particular programming language.

To facilitate the iterative process needed for the development of advanced air mobility in the State of Utah, the UAAMS is a web-based software and can be accessed from any web browser. Additionally, the simulator is delivered with the open-source web-map server GeoServer (GeoServer, 2021), which contains the geospatial data used or generated by the simulations. This enables multiple agencies within the state, who often use geographic information systems (e.g., ArcGIS), to communicate planning efforts and incorporate data from, or provide data to, these simulations. Figure 1.1 shows the main features of the software developed for this project:

- Simulator Form: The simulator form enables the client to enter assumptions about the vehicles and the environment, and then execute the simulation
- 3D Map Interface: A viewer for map and simulation data
- File System Explorer: Input and output files for simulations (e.g., vertiport locations and result figures) may be stored in the filesystem. Additionally, all the source code for simulations is accessible through this file system explorer.
- Simulation Output Viewer: Simulations produce a number of figures that can be viewed here.
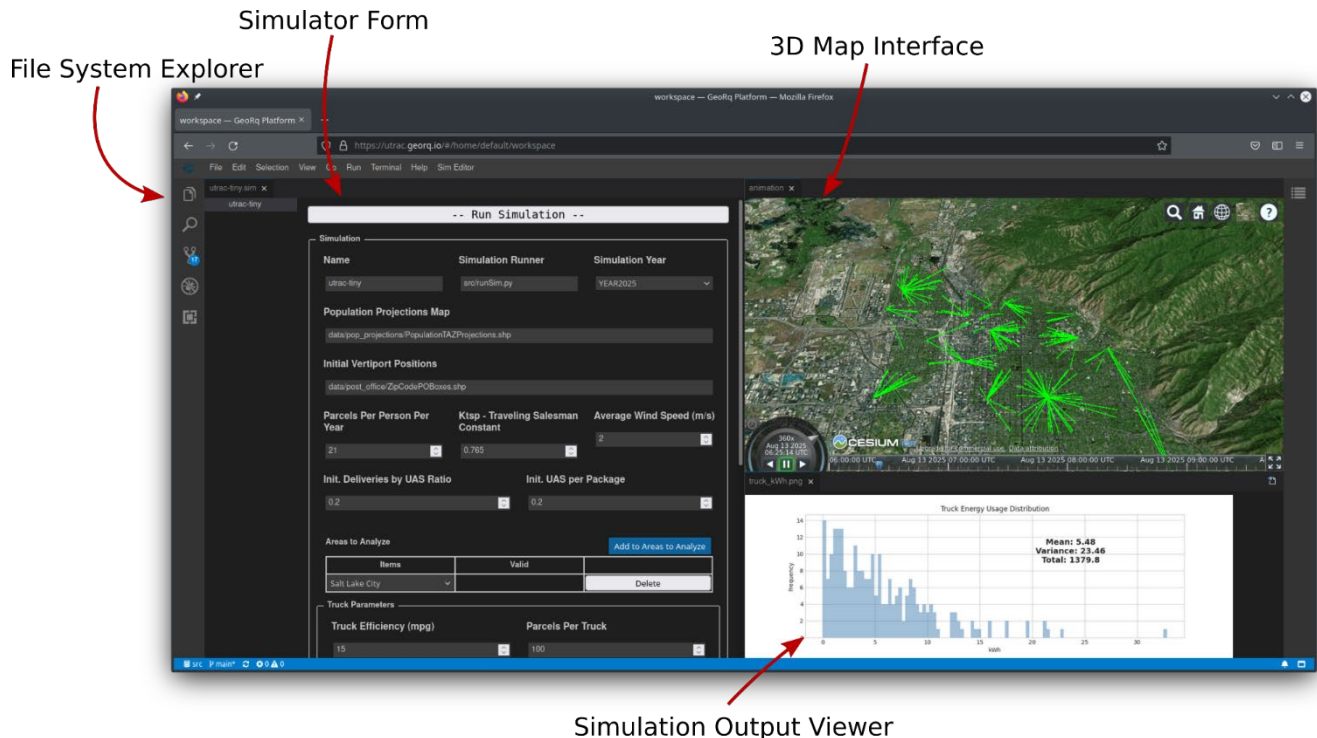
Figure 1.1 The Utah Advanced Air Mobility Simulator (UAAMS)

An initial simulation implementation was developed for this report to demonstrate the workflow for running simulations, as well as developing new ones, and is described in the sections that follow. The UAAMS is deployed to U.S. data centers on Google Cloud and is accessible by anyone with authorized credentials by visiting the URL https://utrac.georq.io.

1.2 Objectives

The motivation for this work is to provide regulators, policymakers, and industry stakeholders with a data-driven framework for assessing the energy costs and trade-offs of large-scale drone delivery in the state of Utah. The primary objective is to produce a web-based platform that takes inputs of a statewide road network, the total number of (drone-deliverable) packages to deliver on a given day and their destinations, and energy and cost assumptions per vehicle and produces a statewide airspace network, delivery schedule, and truck/drone fleet mix. A secondary objective is to understand the impact of such truck/drone fleet mix models to determine whether such a hybrid approach is more cost and energy efficient when compared with the current truck-only delivery model. This is built upon the optimization framework developed in this project to ensure that drones are strategically deconflicted as required by NASA and that the total energy over a day is minimized. Overall, this program will provide the state with more clarity about the energy impacts of large-scale drone delivery as well as a viable airspace network.

This research involves three major components: data collection, optimization model development, and web-based platform development. We first gathered data on the statewide roadway network, population data (year 2025), traffic analysis zone (TAZ) boundary, and post office locations. The dataset enabled the creation of delivery zones to simulate package delivery coverage area for each drone center. In addition, an air delivery network was created by lifting the virtual highway network into the sky. This includes generating airways, deconflicting zones for Utah considering the delivery scheduling, and launching/landing lanes. An optimization model was developed to determine the schedule and deployment of drones within the study area. The developed system model with the optimization component was then implemented onto a web-based platform where people can assess different assumptions of the model and run what-if scenarios by generating animation of the optimized airspace network.

1.3   Outline of Report

The rest of the report is structured as follows. Chapter 2 summarizes the research methods. Chapter 3 illustrates the web-based platform along with a case study for a medium-sized simulation with 33 TAZs. Chapter 4 presents the results and findings and outlines the lessons learned for follow-up research. The Appendix includes the user guide of the developed web-based platform.

2.   RESEARCH METHODS

2.1   Overview

Large-scale drone delivery is on the horizon nationwide, as it has the potential to decrease pollution and help alleviate road congestion. Until now, industry is mainly concerned with the market viability of drone deployment, and very little attention has been paid to external costs such as energy tradeoffs. The benefits of drone deployment, however, are largely dependent upon the layout of distribution centers and distance traveled. To this end, we employ a data-driven approach to strategically replace ground-based delivery networks with air-based drone deployment. In this project, we structured the air space by regulating and treating it as lanes and optimize drone dispatch. Figure 2.1 shows the methodological framework of our research.
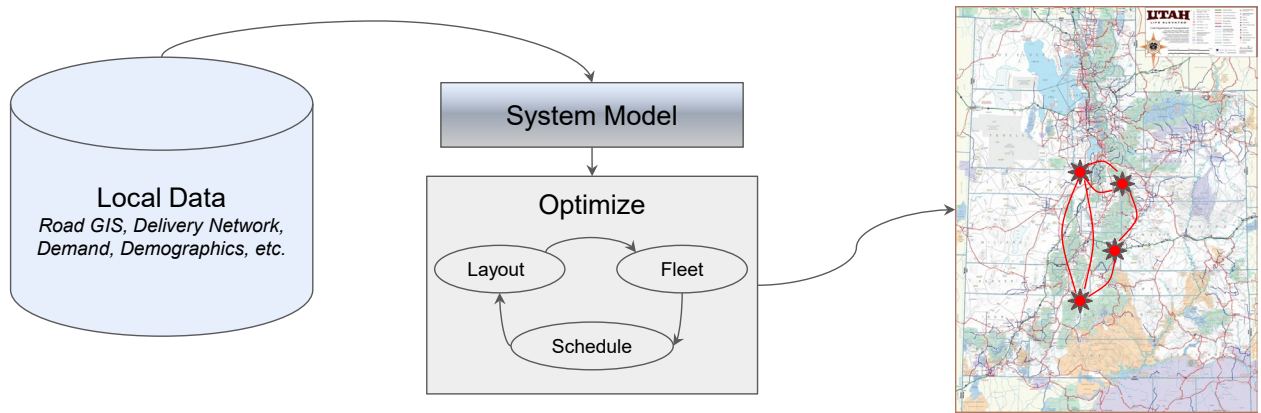

Figure 2.1 Methodology Framework of Proposed Drone Network Optimization

2.2   Data Sources

The main data sources utilized to be fed into the airspace network construction consist of four parts:

- Population projection: this is retrieved from the Utah Geospatial Resource Center (UGRC) (UGRC, 2021). and is collected at the TAZ level. Year 2025 data were retrieved as the demand input. The population projection was further converted into parcel demand estimation, where, on average, 21 parcels/capita/year were assumed initially (SPIEGEL, 2019).
- Post office locations: this is retrieved from UGRC (UGRC, 2021) to serve as potential truck delivery centers. Figure 2.2 shows the overlay of post office locations with the TAZ boundary.
- Utah road network: this is retrieved from UGRC (UGRC, 2021), and the layout is used to create the elevated virtual airways in the sky for the drone fleet.
- Utah building footprints and addresses: this is retrieved from UGRC (UGRC, 2021) and provides the locations of possible drone deliveries for demand modeling.
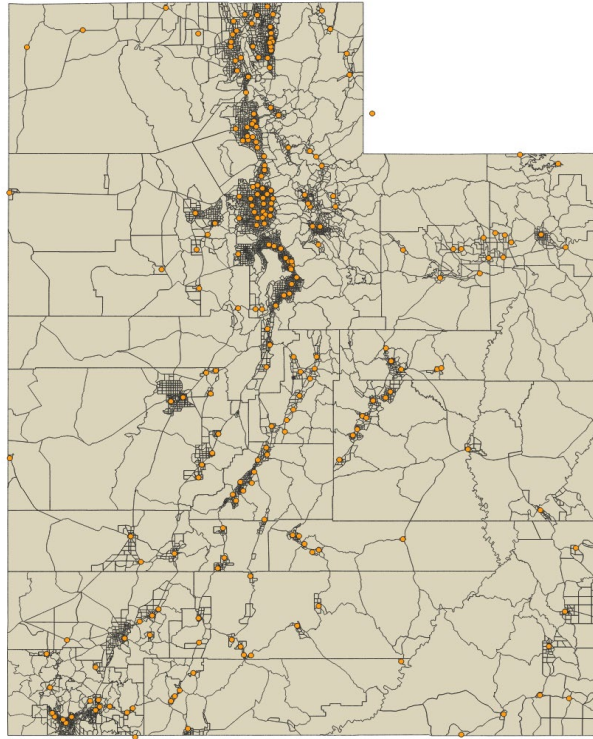
Figure 2.2 TAZs with Post Office Locations

2.3 Optimization Setup

The optimization procedure considers possible locations for vertiports to answer the question: Does there exist a different set of vertiport locations that minimizes the total energy requirements? The spatial distribution of vertiports affects those addresses served by them and therefore the distance traveled by UAS. Other parameters, such as vehicle characteristics, the proportion of packages that are delivered by UAS, and the routes of UAS and trucks, have important effects but were not considered in this procedure. To gain some idea about how the locations of drone ports can affect package deliveries, consider the relative locations of a drone center, truck center, and two TAZs in Figure 2.3. At the start of the optimization, the drone center and the truck center are co-located. Package deliveries are scheduled according to the procedure detailed in Section 3, which assigns aircraft to addresses that are within range and capabilities (according to the simulation parameters), and then fills the resulting demand with truck deliveries. For more efficient simulation, the truck distances and energy are calculated by solving a probabilistic traveling salesman problem (Lohn, 2017). In contrast to the regular shaped cells used for this calculation in Lohn's 2017 article, this simulation calculates the resulting convex hull that encompasses the truck-assigned demand.
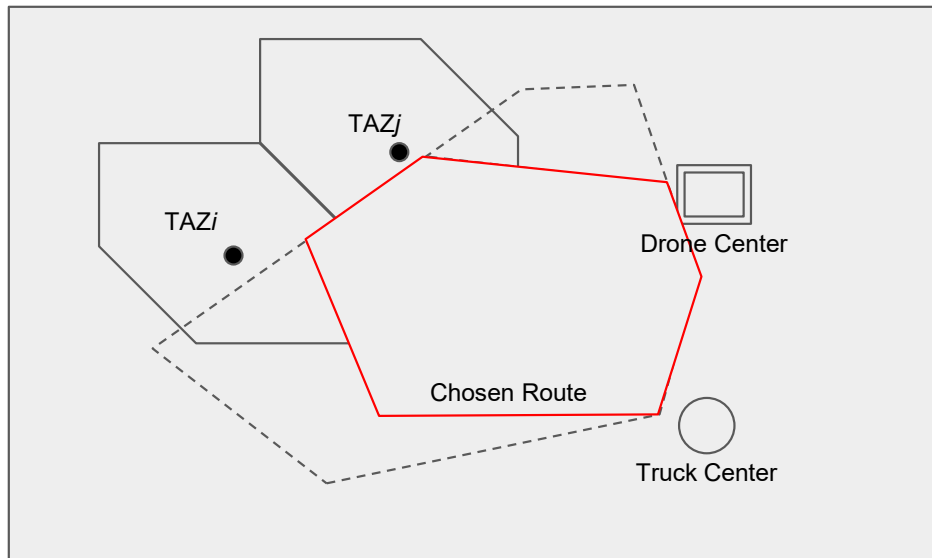
Figure 2.3 Illustration of the Impact of Drone Center's Location on Truck and Drone Services

At each iteration of the optimization, the drone centers are moved to a new location, the simulation is re-run, and the resulting total energy is calculated. The optimization is complete when further updates to the locations of the drone centers result in an increase in the total energy consumption. Several methods for optimizing vertiport locations were considered for this project, with the settled approach being the covariance-matrix adaptation evolution strategy (CMAES) (Hansen, 2019). The objective was to minimize the total energy required by both UAS and trucks to deliver a set of packages in an area. Only the locations of the vertiports were considered variables in the optimization, while the job mix, number of vertiports, and vehicle parameters were held constant. Therefore, the number of variables in the optimization equals the number of vertiports under consideration. Figure 2.4 shows a plot of a sample optimization run for a single TAZ.
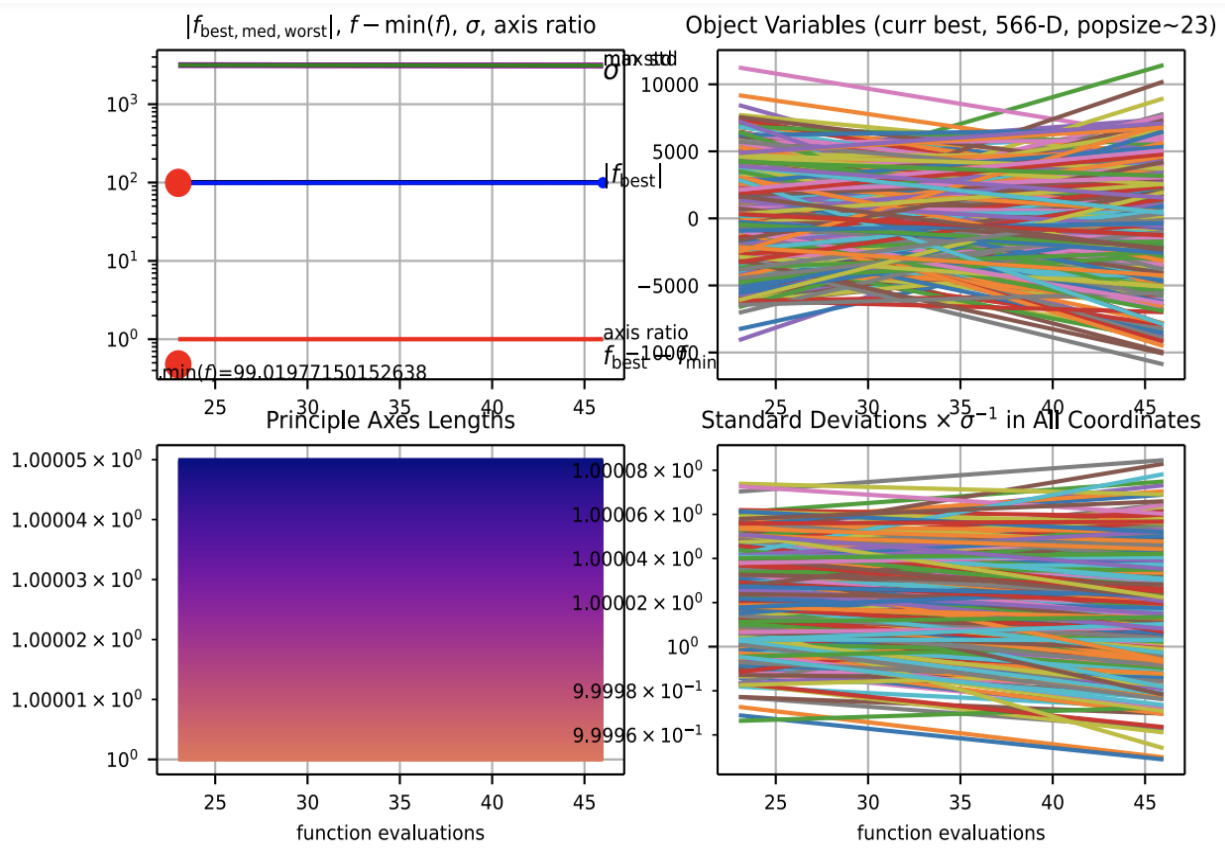
Figure 2.4 Optimization Iterations Showing Divergent Behavior

3. WEB-BASED PLATFORM IMPLEMENTATION

3.1 Overview

A simulation that extends what was described in the RAND report is provided along with the UAAMS. This simulation incorporates all the parameters listed in Table 3.1. In contrast to the RAND report, this simulator considers the real locations of addresses in Utah (UGRC, 2021), as well as the projected population densities in order to simulate projected demand that is more accurately distributed throughout the state. Figure 3.1 shows a cross-section of these datasets.
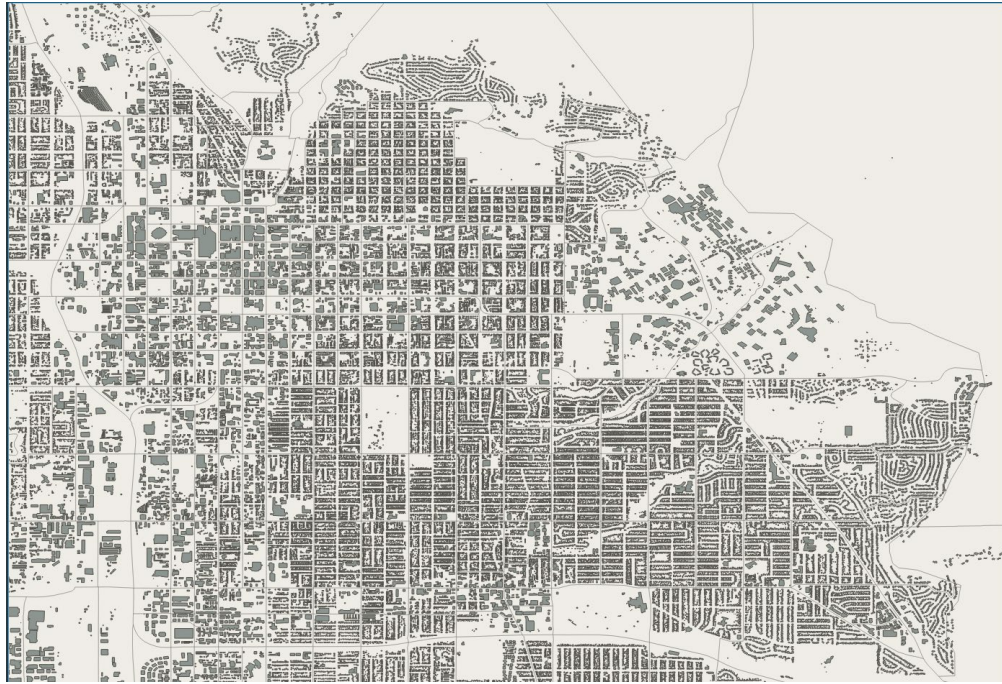
Figure 3.1 Utah Buildings Dataset Overlaid on Population Projections Dataset

The simulation implementation progresses along the following procedure:
1. Load vertiport locations
2. Load truck depot locations
3. Load population projections (at TAZ level)
4. Load building locations
5. Initialize UAS model
6. Filter TAZ based on requested city areas
7. Create demand (parcel requests for a day)
8. Source parcel requests to the nearest vertiport
9. Calculated parcel requests within UAS range and capability
10. Calculate truck/UAS job mix
11. Generate UAS trajectories
12. Estimate UAS round-trip times
13. Estimate UAS energy requirements
14. Estimate truck energy requirements
15. Generate animation
16. Generate results

3.2 Case Study

A medium-sized simulation was executed that included 33 TAZs as a case study to demonstrate the web-based platform.

3.2.1 Simulation Form

A simulation form is displayed whenever a file with the suffix.*sim* is clicked in the workspace explorer. As this form is edited by the user, the parameters are written to the *.sim* file (the raw json format can be viewed by opening the file in the code editor as shown in Figure 3.2). When the *Run Simulation* button is clicked at the top of the form, the Python program defined in the *Simulation Runner* field is executed and the *.sim* file is provided as an argument to the program.

A description of all the fields in the form is provided in Table 3.1.

Figure 3.2 Simulation Form

Table 3.1 Simulation Parameters

Form Field	Units	Description
Simulation Parameters		
Name	-	The name of the simulation. This is the label of the folder created in the workspace.
Simulation Runner	-	The name of the Python script to run the simulation. The path should be relative to the workspace root.
Simulation Year	-	The year to use for population projection. This value represents the column name in the travel analysis zone (TAZ) dataset.
Population Projections Map	-	A shapefile or geojson file containing population projections. The path should be relative to the workspace root
Initial Vertiport Positions	-	A shapefile or geojson file containing point locations for package sources, e.g., post offices. These locations are used to source truck deliveries and also as an initial starting point for vertiports.
Parcels Per Person Per Year	parcels / (person * year)	The average number of packages that a person orders per year
Ktsp	-	Traveling salesman constant - used to estimate truck route distances
Average Wind Speed	m/s	The average wind speed that a UAS is likely to encounter. Currently this subtracts from the UAS airspeed no matter the direction.
Init. Deliveries by UAS Ratio	-	An initial ratio of deliveries that are offloaded from trucks to UAS. During optimization this may change automatically.
Init. UAS Per Package	-	Ratio of UAS per package at a given vertiport. For example, a value of 0.1 would create 1 UAS for every 10 packages at a vertiport
Areas to Analyze	-	A list of areas to consider from the TAZ dataset. Taken from the *CityAreas* column in that shapefile.
Truck Parameters		
Truck Efficiency	mpg	The efficiency of trucks in miles-per-gallon
Parcels Per Truck	parcels / truck	The number of packages that a truck can carry

UAS Parameters		
UAS Payload Mass	kg	The mass of the payload that a UAS will carry
Lift-to-Drag Ratio	-	The lift to drag ratio of the UAS
UAS Vehicle Mass	kg	The mass of the UAS
Power Transfer Efficiency	-	The motor to propeller power transfer efficiency
Cruise Speed	kph	The cruise speed of UAS
Power Consumption of Electronics	kW	The power consumption by electronics onboard the UAS
Climb Rate	mps	The climb rate of UAS
Maximum Range	km	The maximum range of UAS
Package Load Time	minutes	The time it takes to load a package onto a UAS
Cruise Altitude	m	The cruise altitude of UAS

3.2.2 Simulation Procedure

The following section describes each step of the simulation in detail.

Load Input Location Data

This step includes loading the following location data:
- Vertiport locations
- Truck depot locations
- Population projections (at the TAZ level)
- Building locations

Depending on the size of the dataset, the location data can be loaded either from the filesystem or from a web map server (one is provided with UAAMS). For example, the population projections dataset was small enough to be loaded from a shapefile located on the filesystem into memory, while the building locations dataset is too large to handle in this way. The buildings dataset is loaded into the web map server offline, then during the simulation the server is queried within constrained areas.

Initialize UAS Model

The UAS model considered for this simulation is derived from a study conducted by D'Andrea (D'Andrea, 2014). The parameters considered are listed in Table 3.1.

Filter TAZ Zones Based on Requested City Areas

The simulation can consider a subset of areas in Utah, defined by the "City Areas" column in the Population Projections dataset (UGRC, 2021).

Create Demand (Parcel Requests for a Day)

For each TAZ under consideration, uniformly sample the building centroids within that TAZ from a binomial distribution with intensity given by the estimated number of parcels per person per day.

Source Parcel Requests to Nearest Vertiport

For each parcel request in the demand dataset (from the last step), calculate the nearest vertiport that can serve that request.

Calculate Truck/UAS Job Mix

Fixed by user input into simulation form.

Generate UAS Trajectories

For each parcel request that is served by a UAS, generate a trajectory based on the vehicle parameters provided in the simulation form.

Generate Animation

To help visualize the distribution and density of drone flights that meet the demand specified in the simulation, a 3D animation (see Figure 3.3 below) is generated that can be viewed within the workspace. The animation is specified by an open-source human/machine readable file called CZML (Analytical Graphics Inc., 2021). Figure 3.3 shows an example frame from this animation.
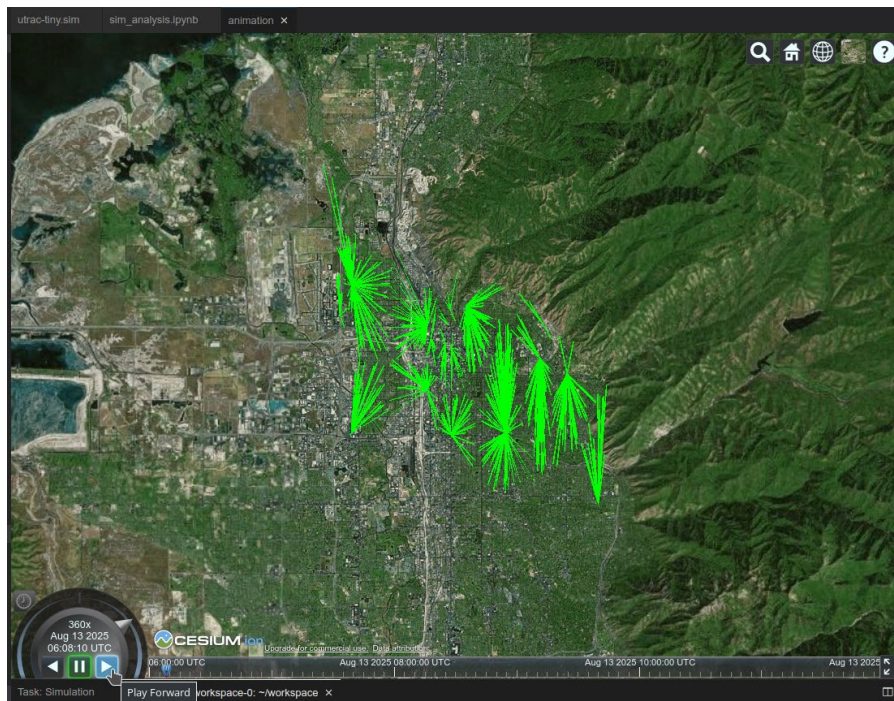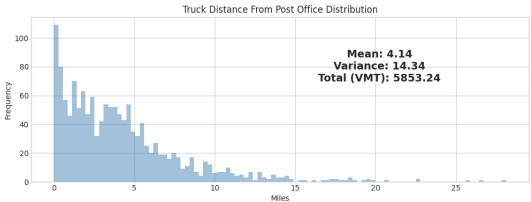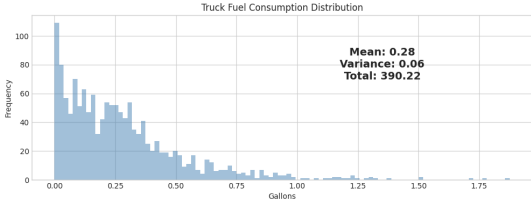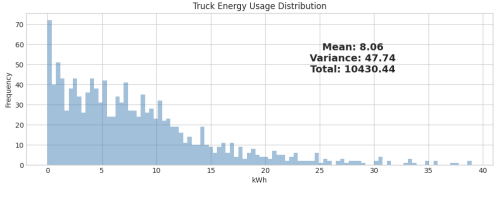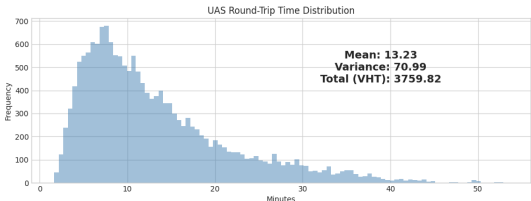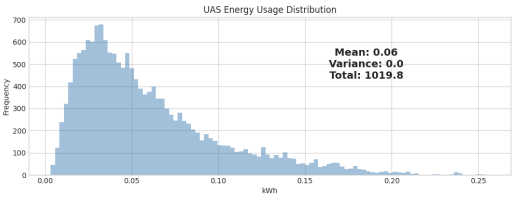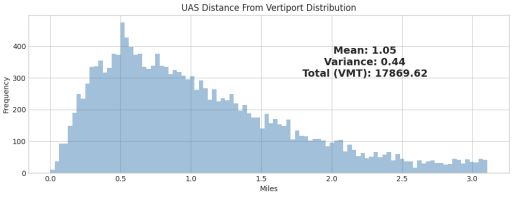

Figure 3.3 Simulation Results Animation

Generate Results

Results are generated and stored in figures as described in Table 3.2.

Table 3.2 Automatically Generated Figures from Simulation

Figure	Description	Example
truck_distances.png	The distribution of distances that trucks traveled during the simulation.	Truck Distance From Post Office Distribution — Mean: 4.14, Variance: 14.34, Total (VMT): 5853.24
truck_gallons.png	The distribution of gallons consumed by trucks during the simulation.	Truck Fuel Consumption Distribution — Mean: 0.28, Variance: 0.06, Total: 390.22
truck_kWh.png	The distribution of energy consumed by trucks during the simulation.	Truck Energy Usage Distribution — Mean: 8.06, Variance: 47.74, Total: 10430.44
uas_rt_time.png	The distribution of round-trip times for UAS during the simulation	UAS Round-Trip Time Distribution — Mean: 13.23, Variance: 70.99, Total (VHT): 3759.82
uas_kWh.png	The distribution of energy consumed by UAS during the simulation.	UAS Energy Usage Distribution — Mean: 0.06, Variance: 0.0, Total: 1019.8
uas_distances.png	The distribution of distances traveled by UAS during the simulation.	UAS Distance From Vertiport Distribution — Mean: 1.05, Variance: 0.44, Total (VMT): 17869.62

3.2.3 Medium-Size Simulation Input and Results

Figure 3.4 shows the input parameters to execute the medium-size simulation. This simulation assumes that the post office locations are co-located with UAS vertiports.

**Figure 3.4** Medium Simulation Input Parameters

Figures 3.5 through 3.9 show the statistics generated from the simulation. For example, during the simulation, demand for every address within the TAZ (Figure 3.4) was generated for a day. Some addresses requested no deliveries, while others requested multiple packages. This demand was split between ground-based trucks and UAS, trajectories were calculated, and the deliveries were scheduled and executed. Figure 3.5 shows a histogram of the distances that trucks traveled during the execution of this simulation. In total, about 619 miles were traveled by all the trucks combined. Similarly, Figure 3.7 shows that the average UAS traveled about a mile (round-trip) to make a delivery.
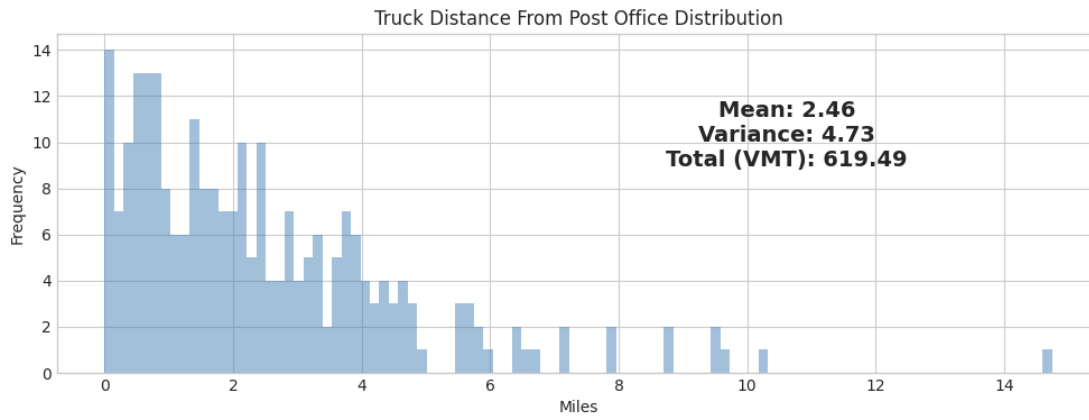
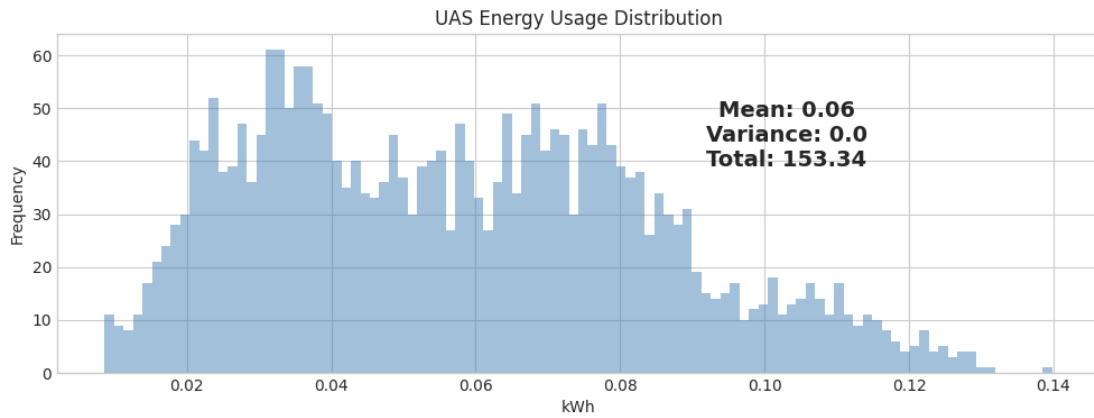**Figure 3.5** Truck Distances Traveled During Simulation
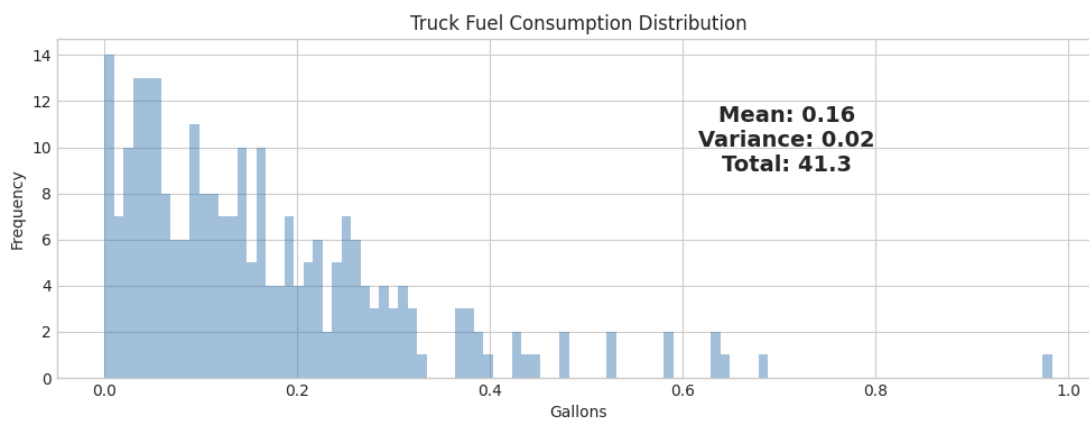
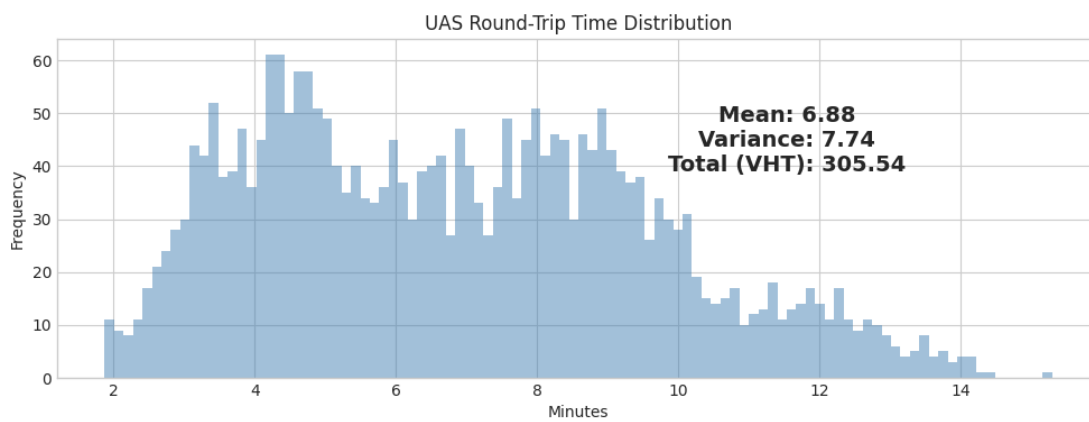**Figure 3.6** Truck Fuel Consumption Required During Simulation
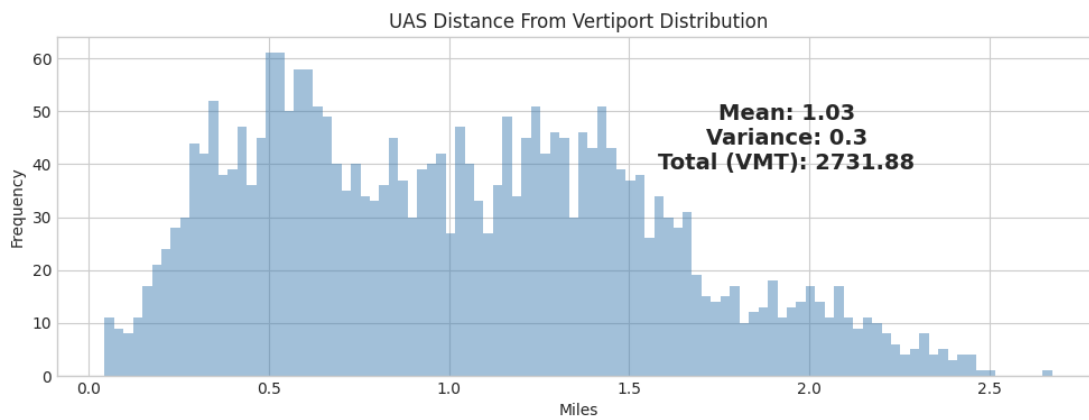
Figure 3.7 UAS Distances Traveled During Simulation

Figure 3.8 UAS Energy Required During Simulation

Figure 3.9 UAS Round-Trip Times During Simulation

Table 3.3 Medium-Sized Simulation Results

Simulation Metric	*Mean*	*Total*
Truck Distances: Distances that trucks traveled during the simulation	2.46 mi	619.49 mi
Truck Energy: Gallons of fuel or kWh required by trucks during the simulation.	0.16 Gal (5.48 kWh)	41.3 Gal (1379.8 kWh)
UAS Round-Trip Times: Round-trip times for UAS during the simulation	6.88 Min.	305.54 Hours
UAS Energy: Energy required by UAS during the simulation.	0.06 kWh	153.34 kWh
UAS Distances: Distances that UAS traveled during the simulation.	1.03 mi	2731.88 mi
Total Energy Required: Sum of UAS and truck energy required.	-	1533.14 kWh

4.   CONCLUSIONS

4.1   Summary

The implementation of a cloud-based collaborative simulator represents the bulk of this research project. A major unexpected hurdle was that the scale of the simulation required significant memory and computer resources to execute. In particular, the building dataset represented a challenge and required the use of a web map server rather than simply loading the entire shapefile into memory. During the demand creation step in the simulation implementation, small areas were queried to avoid overwhelming memory resources.

With regard to the test simulation, the total energy required by both UAS and trucks combined was slightly more than the required energy if trucks were to meet the same demand alone. This could be a result of the chosen vehicle parameters, as well as the location distribution of vertiports. Despite this result, it may still be desirable to take advantage of the short distance and round-trip times that UAS has to offer.

Another challenge was encountered with the optimization objective. It was found to be computationally difficult to consider all the vertiport locations as well as the various input parameters that could have been considered. The algorithm chosen to perform the optimization is called the covariance-matrix adaptation evolution strategy (Hansen, 2019) because it has a good reputation for handling highly non-linear problems with many variables. However, the algorithm proved to be rather slow, likely due to the random sampling and database querying that occurred during the demand creation step. Consequently, in the time allotted for optimization, the algorithm did not successfully converge to a solution.

4.2   Conclusion

Overall, the implementation and deployment of the UAAMS was successful and will be available for continuing research in the development of advanced air mobility in the state of Utah. This type of tool is critical for research in this area as it incorporates the latest software and infrastructure development techniques available. Also shown was the viability of considering the large-scale impacts (e.g., environmental) of advanced air mobility on specific communities by using micro-simulation technology. In contrast to micro-simulations performed for human-controlled ground and air traffic, in this case a model for the autonomous agents has the potential to be exact since their algorithms must be documented. Less certain are the emergent effects that may result from the parallel execution of these algorithms and the environmental impacts of their collective behavior.

4.3   Future Research and Improvements

This research has resulted in feedback from stakeholders that can be used to improve the simulation tool as well as the subsequent analysis. For example, simplifications to the workspace are necessary for non-developer—or non-engineer—stakeholders (e.g., planners). Enabling frictionless communication and collaboration between technical and non-technical stakeholders is a major goal of the UAAMS. Future improvements will also consider optimizations to the objective function in the optimization procedure, which would allow a more thorough exploration of the possible configurations of vehicle and vertiport parameters.

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APPENDIX

The UAAMS User Guide

Introduction

In a 2017 report by the RAND corporation, analytical methods for calculating the total energy consumed by a mix of delivery trucks and drones were developed and shown to be highly dependent on the layout of distribution centers as well as distance traveled by delivery vehicles. This suggests that the city layout, i.e., street connectivity and other network parameters, are important considerations for energy-conscious policies. While industry stakeholders must determine the market viability of drone delivery, they are not required to calculate the external and indirect costs that may be associated with this burgeoning industry.

This simulator enables researchers and practitioners at the UDOT and other participating agencies to continually update assumptions about the distribution of vertiports, traffic, population, and other dynamic inputs. These parameters are important not only for considering the feasibility of unmanned aircraft systems (UAS) package delivery within the state, but also for determining the impact and ultimately the efficient operation of this new transportation technology. Furthermore, additional analysis and what-if scenarios may be developed using this simulator. Example Jupyter notebooks (Python) are provided to help guide development, however users are not limited to any particular programming language.

This simulator is delivered on a custom version of the GeoRq Platform, a cloud-based geospatial integrated development environment (IDE). As part of this project, the platform was modified to enable a workflow for considering the various assumptions related to drone delivery in the state, including population projections and the distribution of drone centers (vertiports). All the code written to produce the initial analysis is provided along with the platform to enable further modification and updates as necessary. Additionally, the platform was deployed to U.S. data centers on Google Cloud, enabling researchers and stakeholders to access the platform from anywhere by visiting the URL https://utrac.georq.io. The site requires authentication credentials, which can be requested via the support email listed below.

Support inquiries should be directed via email to david.sacharny@georq.com. Additional updates may be deployed to the UDOT's custom workspace during the period of support to supply user improvements. Feedback from users is welcomed via the same support email.

Quickstart: Run a New Simulation

1.   Login to the Simulator Workspace
        a.   Visit https://utrac.georq.io
        b.   Sign-in with your email and password

2.   Enable Auto Save
        Enable Auto Save for the workspace if it is not already enabled, as shown in the figure below, by ensuring the check is present in the File menu.
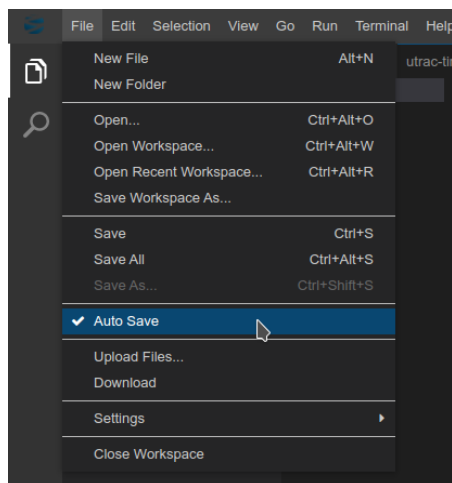

Figure. Auto Save Enabled (indicated by the check mark)

3.   Start New Simulation
        Select "New Sim File" from the "Sim Editor" menu, as shown in the figure below.
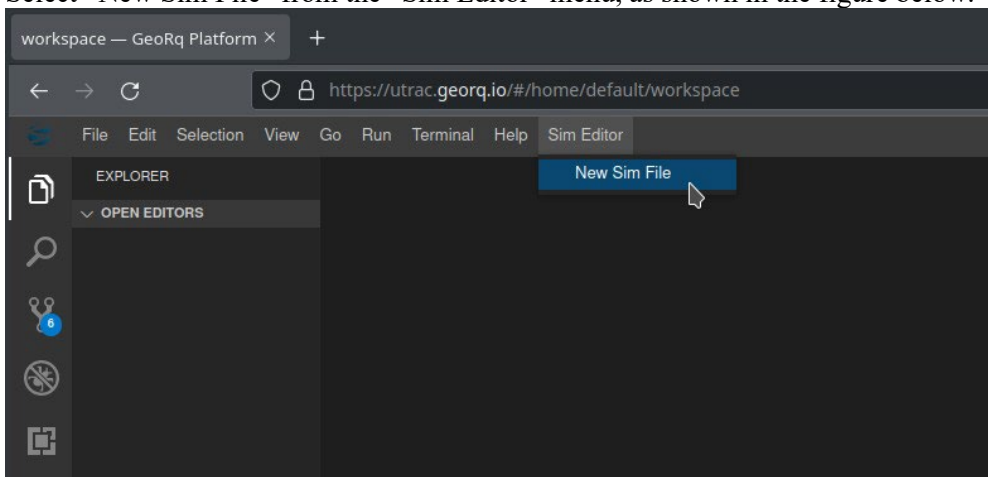
Figure. Select "New Sim File"

4.   Create Simulation File
        Accept the default simulation name, or provide your own (it is important to preserve the ".sim" suffix), and select OK as shown in the figure below.
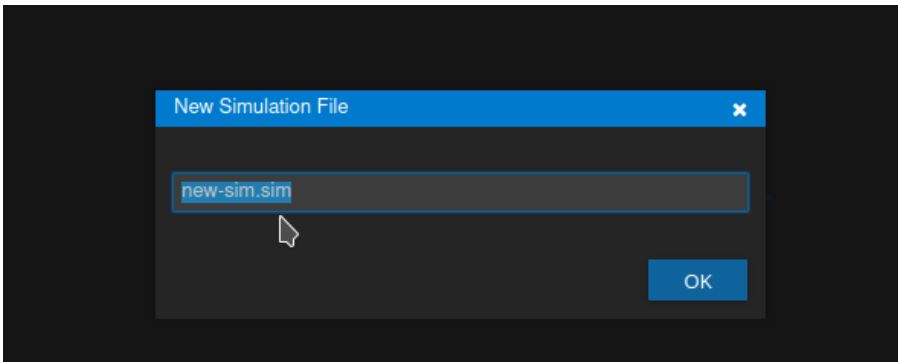
Figure. Input Simulation File Name

5. Update Simulation Form
    A simulation form will appear as shown in the figure below. Update the "Name" field, and any other fields as desired.
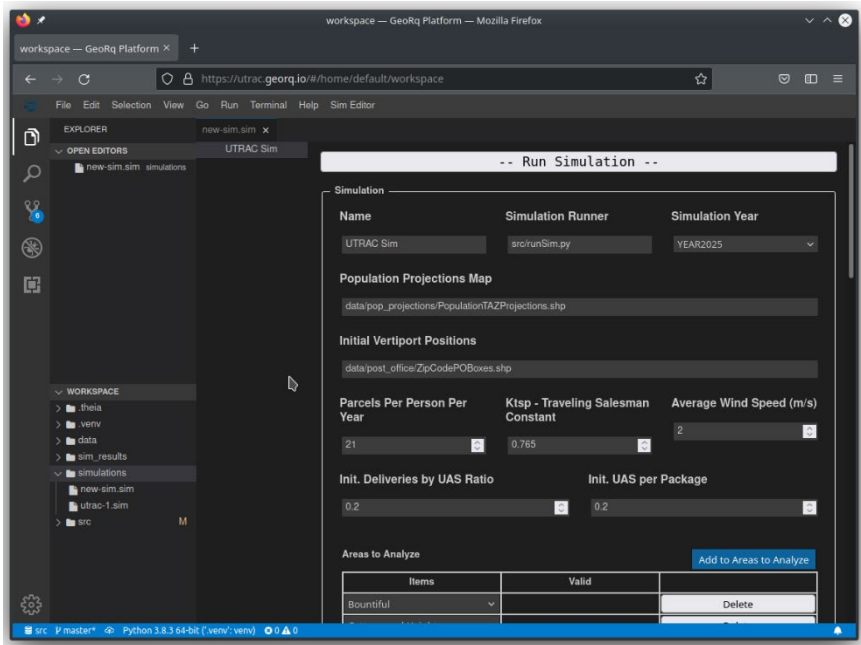
Figure. Change Name Field on Simulation Form

6. Run Simulation
    Select the "Run Simulation" button at the top of the form. A task window will appear to display the simulation progress.
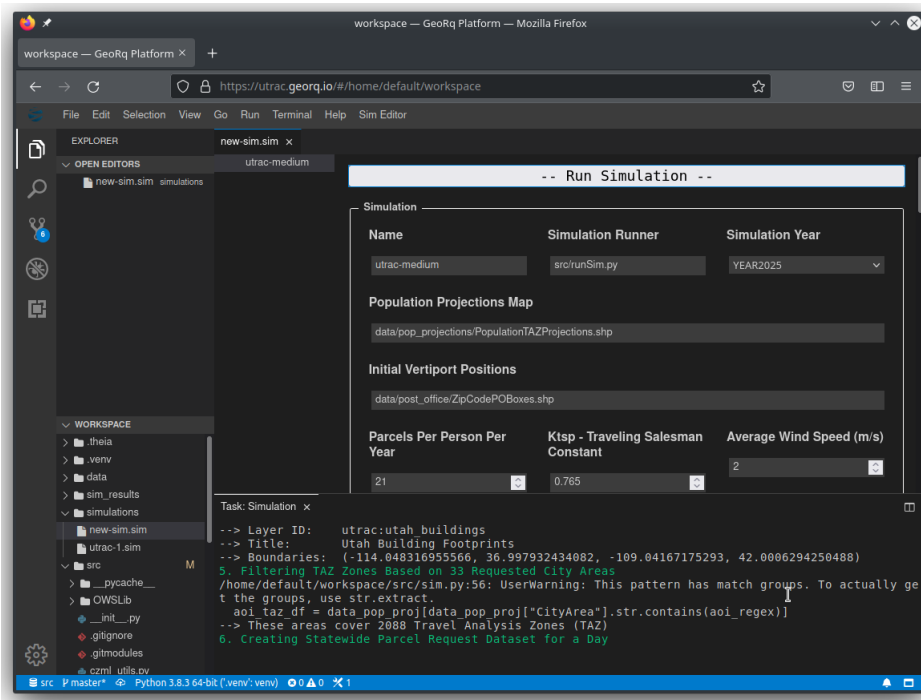
Figure. Watch Simulation Progress

7.   View Simulation Output

If the simulation was successful, then the simulation progress window will show the words "Simulation Complete." A folder in the workspace will be populated with several simulation files. See below for instructions on how to explore the workspace files.

View the Simulation Animation

The drone delivery trajectories are animated in order to view the distribution of aircraft over the area of interest. To view the animation, follow these steps:

1.   Open the workspace explorer, if it is not already visible, by clicking the Explorer icon on the left panel as shown in the figure below:
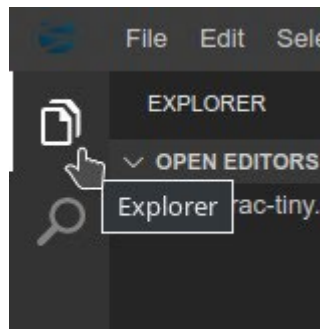
Figure. Open the Explorer Window by Clicking the Explorer Icon

2.   Navigate to the sim_results folder, and then to the folder with the name of your simulation. Select the animation.czml file, as shown in the figure below:
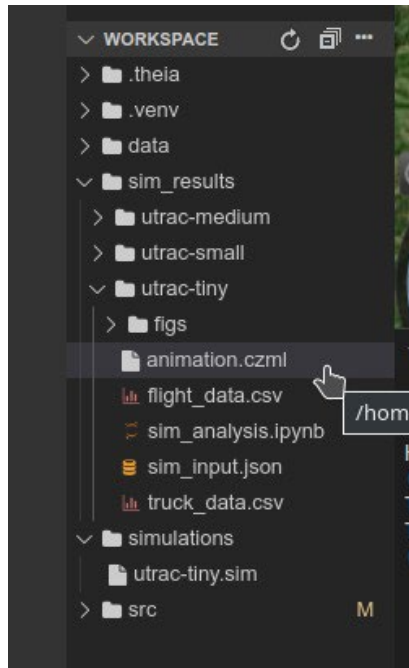
Figure. Select the animation.czml file

3.   Select the animation.czml file to open a map containing animation controls and the simulation of drone deliveries. Use the animation controls at the bottom of the map to control the playback of the animation. Loading this file may take a few minutes if the simulation was large.
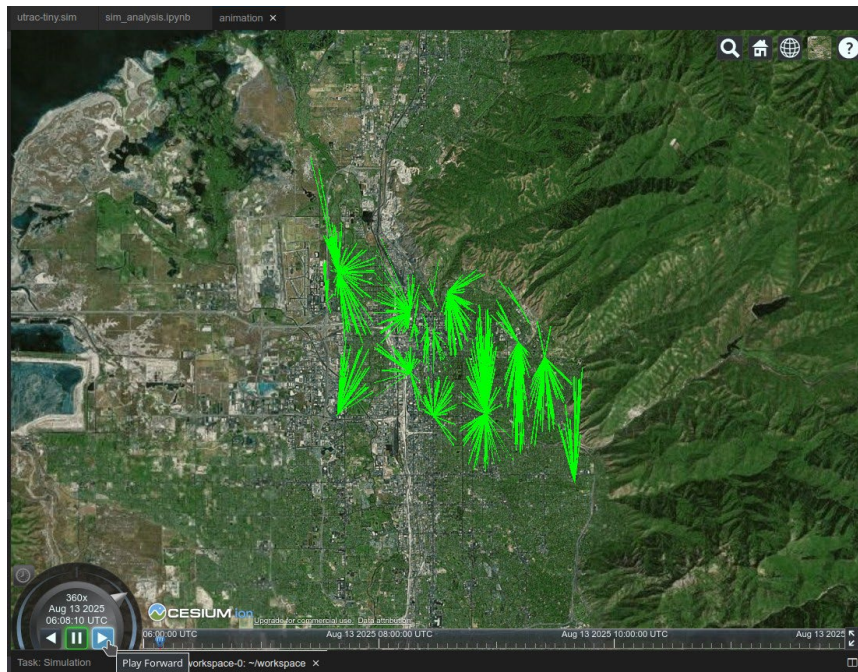

Figure. Animation Playback Controls

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Perform Analysis on Simulation Output

Further analysis on the simulation output can be performed via the provided Python Jupyter notebook template, as shown below:
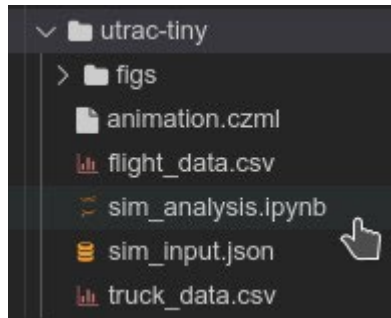
Figure. Click on the sim_analysis.ipynb file to perform further analysis

Download the Simulation Output and Figures

This simulation output can be downloaded by right clicking any of the files or folders and selecting Download, as shown below.
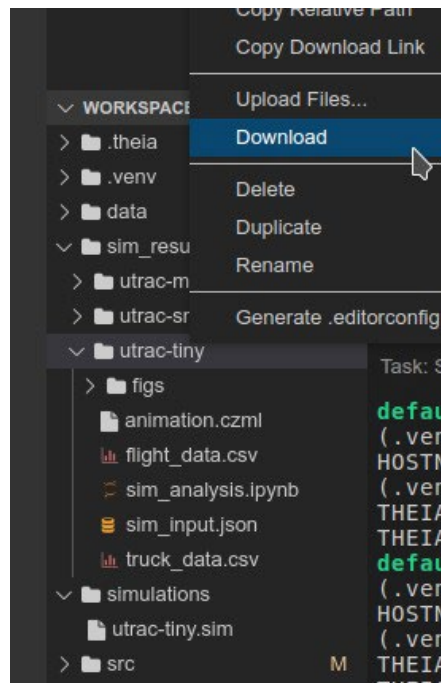
Figure. Download Simulation Files

The *figs* folder contains plots of distances and energy for the simulation. They were generated via the sim_analysis.ipynb notebook in the simulation results folder. Clicking on a figure will open it in the workspace for quick viewing.

Quickstart: View Existing Simulation

1.	Login to the Simulator Workspace
	a.	Visit https://utrac.georq.io
	b.	Sign-in with your email and password

2.	Open Explorer Window
	Open the workspace explorer, if it is not already visible, by clicking the Explorer icon on the left panel as shown in the figure below:
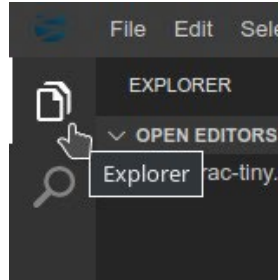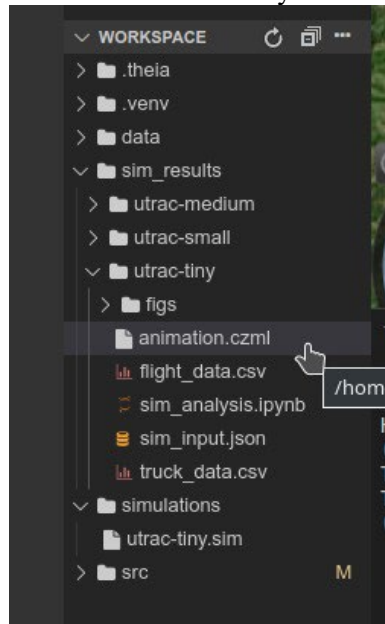

Figure. Open the Explorer Window by Clicking the Explorer Icon

3.	Navigate to Simulation Results Folder
	Navigate to the *sim_results* folder; subfolders of this directory contain existing simulation results.

Figure. Select the animation.czml file

4.	Select Simulation Output to View
	Select the *animation.czml* file to open a map containing animation controls and the simulation of drone deliveries. Use the animation controls at the bottom of the map to control the playback of the animation. Loading this file may take a few minutes if the simulation was large.
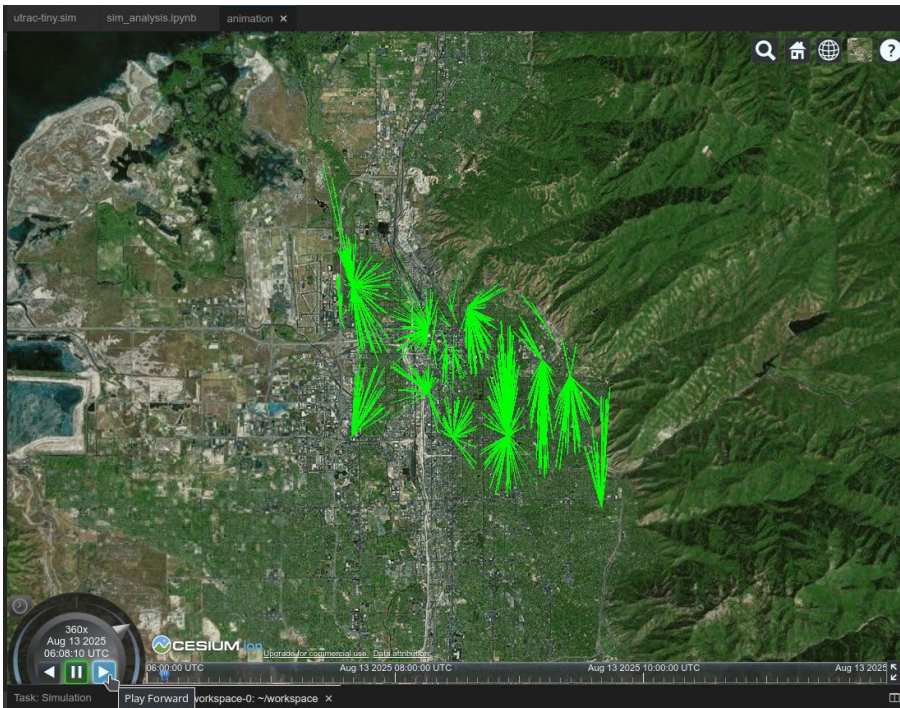
Figure. Animation Playback Controls

5.   Perform Additional Analysis on Simulation Output
        Further analysis on the simulation output can be performed via the provided Python Jupyter notebook
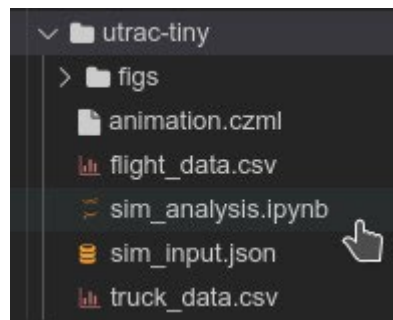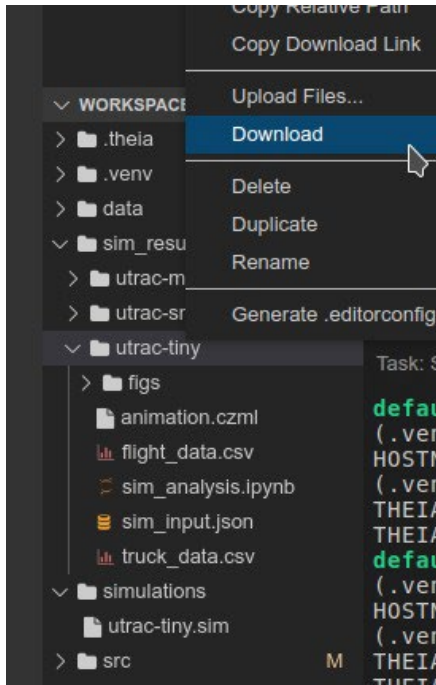template, as shown below:

Figure. Click on the *sim_analysis.ipynb* file to perform further analysis

6.   Download the Simulation Output and Figures
        This simulation output can be downloaded by right clicking any of the files or folders and selecting *Download*,
as shown below.

Figure. Download Simulation Files

The *figs* folder contains plots of distances and energy for the simulation. They were generated via the sim_analysis.ipynb notebook in the simulation results folder.

7.   View Figures in Workspace

It is also possible to view the simulation output plots in the workspace by clicking on them in the explorer window.

Simulation Parameters

The simulation form is displayed whenever a file with the suffix *.sim* is clicked in the workspace explorer. As this form is edited by the user, the parameters are written to the *.sim* file (the raw json format can be viewed by opening the file in the code editor as shown in the figure below). When the *Run Simulation* button is clicked at the top of the form, the Python program defined in the *Simulation Runner* field is executed and the *.sim* file is provided as an argument to the program.

A description of all the fields in the form is provided in the table below.

Figure. Simulation Form

Figure. The Simulation Form Can be Viewed from Inside the Code Editor

Form Field	Units	Description
**Simulation Parameters**		
Name	-	The name of the simulation. This is the label of thefolder created in the workspace.
Simulation Runner	-	The name of the Python script to run the simulation.The path should be relative to the workspace root.
Simulation Year	-	The year to use for population projection. This value represents the column name in the travel analysis zone (TAZ) dataset.
Population Projections Map	-	A shapefile or geojson file containing population projections. The path should be relative to the workspace root.
Initial Vertiport Positions	-	A shapefile or geojson file containing point locations for package sources, e.g., post offices. These locations are used to source truck deliveries and also as an initial starting point for vertiports.
Parcels Per Person Per Year	parcels / (person * year)	The average number of packages that a person orders per year
Ktsp	-	Traveling salesman constant - used to estimate truck route distances
Average Wind Speed	m/s	The average wind speed that a UAS is likely to encounter. Currently this subtracts from the UAS airspeed no matter the direction.
Init. Deliveries by UAS Ratio	-	An initial ratio of deliveries that are offloaded from trucks to UAS. During optimization this may change automatically.
Init. UAS Per Package	-	Ratio of UAS per package at a given vertiport. For example, a value of 0.1 would create 1 UAS for every 10 packages at a vertiport
Areas to Analyze	-	A list of areas to consider from the TAZ dataset. Taken from the *CityAreas* column in that shapefile.
**Truck Parameters**		
Truck Efficiency	mpg	The efficiency of trucks in miles-per-gallon
Parcels Per Truck	parcels / truck	The number of packages that a truck can carry

UAS Parameters		
UAS Payload Mass	kg	The mass of the payload that a UAS will carry
Lift-to-Drag Ratio	-	The lift to drag ratio of the UAS
UAS Vehicle Mass	kg	The mass of the UAS
Power Transfer Efficiency	-	The motor to propeller power transfer efficiency
Cruise Speed	kph	The cruise speed of UAS
Power Consumption of Electronics	kW	The power consumption by electronics onboard the UAS
Climb Rate	mps	The climb rate of UAS
Maximum Range	km	The maximum range of UAS
Package Load Time	minutes	The time it takes to load a package onto a UAS
Cruise Altitude	m	The cruise altitude of UAS

Supplemental Analysis and Development

The customized workspace enables a development flow that follows the procedure presented below:

1. Create a simulation file using the provided form (see Quickstart: Run a New Simulation). If the current form does not meet your needs, contact support - it is possible to generate other custom forms.
2. Write a Python script to handle the .json that is generated by the form (see runSim.py for an example)
3. Select Run Simulation from the form to execute the Python script with the form as an argument.
4. Perform post simulation analysis.

Example code for generating animations is provided with this grant, specifically in the *czml_utils.py* file. CZML is a format for data that is readable by the Cesium javascript library (see https://github.com/AnalyticalGraphicsInc/czml-writer/wiki/CZML-Guide) and is what enables 3D animations on the map that is included with the GeoRq workspace. Clicking on a file with the *.czml* suffix in the workspace explorer window automatically opens the map in a window and loads the *czml* into it. If it is a large animation, it could take some time to load (future work includes optimizing how these data are loaded).

GIS map data can be loaded into the workspace for further analysis via two methods. The easiest is to drag and drop a zipped shapefile or geojson into the explorer window. Once the file is in the workspace, it can be unzipped through the command line using the procedure in Unzipping a Shapefile. For larger data files, for example the building dataset, they should be loaded into the included postgres database and GeoServer. Please contact support if you would like to use this feature (we are working on optimizing this feature).
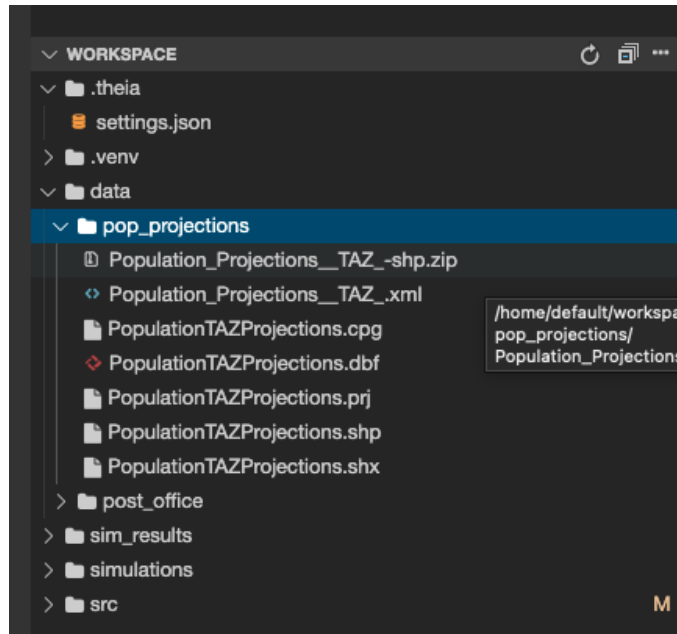
Figure. Population Projections GIS File Uploaded to Workspace

Unzipping a Shapefile
1.   Open a new terminal from the Terminal menu, as shown in the figure below.
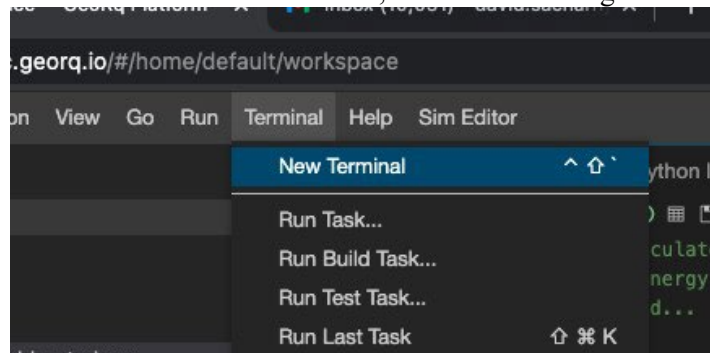

Figure. Starting a New Terminal

2.   A new terminal will open in a window. The workspace runs on a Linux virtual machine and as a user you have full access to Linux facilities. Navigate to the folder containing the zip file. For example, if the zip file is located in the data/pop_projections folder then execute *cd data/population_projections*, as shown in the figure below.
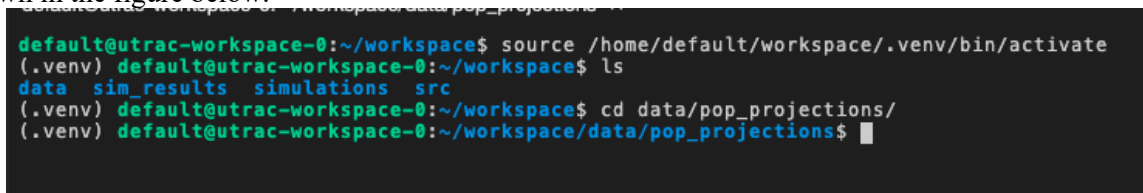
Figure. Navigate to Folder Containing Zip File

3.   Execute unzip <filename> as shown in the figure below.

Figure. Unzip File

Post-Simulation Analysis

The easiest way to perform post-simulation analysis, including generating plots, is to work in a Jupyter notebook. Several notebooks are provided as examples, and each simulation run includes a notebook, as shown in the figure below. Click on any file with the *.ipynb* suffix to open a notebook.
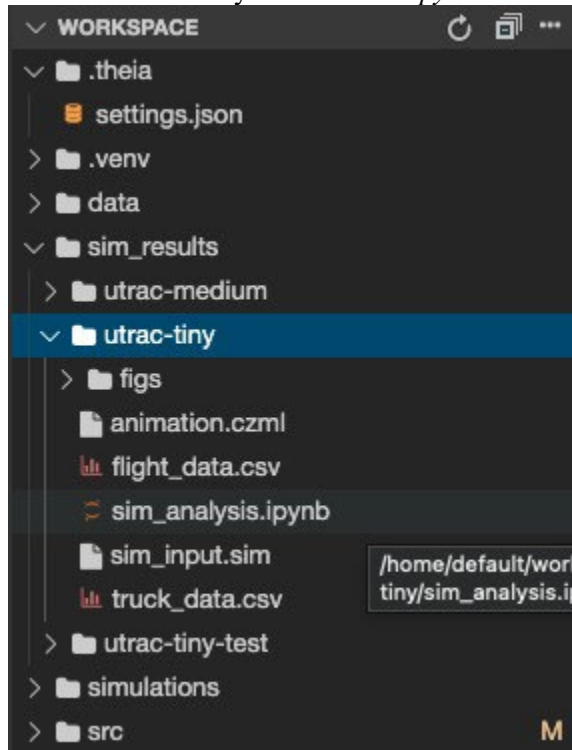

Figure. Jupyter Notebook Files

Some figures are currently automatically generated, as described in the table and figures below. They can be viewed by clicking on them in the workspace explorer.
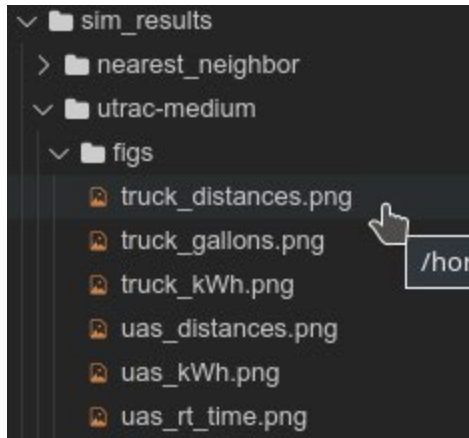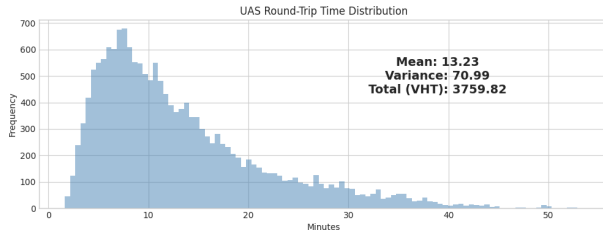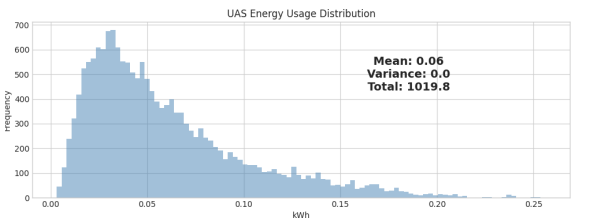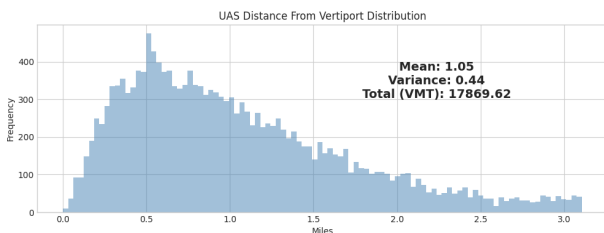
Figure. Clicking on a Figure File will Open it in the Workspace

Table. Automatically Generated Figures from Simulation

Figure	Description	Example
truck_distances.png	The distribution of distances that trucks traveled during the simulation.	
truck_gallons.png	The distribution of gallons consumed by trucks during the simulation.	
truck_kWh.png	The distribution of energy consumed by trucks during the simulation.	

uas_rt_time.png	The distribution of round-trip times for UAS during the simulation	
uas_kWh.png	The distribution of energy consumed by UAS during the simulation.	
uas_distances.png	The distribution of distances traveled by UAS during the simulation.	