No-contact drone delivery of medicines and pharmacy essentials to elderly people in low-income areas.

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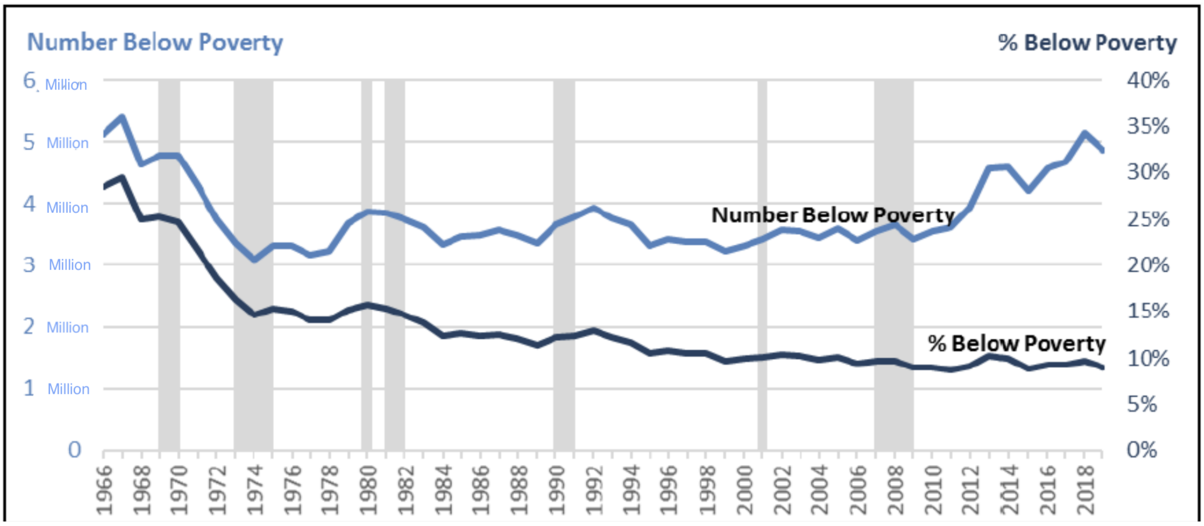
Introduction:

The number of elderly people (65 years and older) in the US who live below poverty level has been growing since 1970 (please see the graph below).



Graph 1 – Number and % of elderly population below the poverty level in US

Many of these people have additional health and mobility issues, psychological problems, many of them live a lonely lifestyle and so on. By implementing this project Walmart wants to protect this threatened group by providing them access to medicines and pharmacy essentials at low costs without needing to physically visit a store. The actuality of this project grows in the sight of a global pandemic reasoned by COVID-19 Virus.

In frames of this project, we want to design a contactless drone delivery system and implement it in a suitable area. It should be a low-income area with a sufficient number of Elderly population and have favorable conditions for drone delivery. We want this project to be economically efficient thus the proposed solution will be designed accounting the specific area we chose and evaluated in frames of costs. Also, we want to satisfy the requirements of the project provided by Walmart:

- Need to be able to serve an average of 100 customers per day (Min: 75)
- Cost no more than $ 10 per delivery on average (Min: 5, Max: 15)
- Take no more than 75min per delivery (Min: 30min, Max: 120min)
- Delivery weights are, on average, 5 lbs (Min 3 lbs, Max 10lbs)
- Delivery volumes are, on average, 500 cubic inches. Drones cannot deliver packages that weigh more than 10lbs, box sizes: 500 cubic inches (consider ± 10% of each box size)
- 3 Walmart staff are dedicated to drone delivery per store location
- The range of delivery should be an average of 5 miles (Min 1 mile, Max 8 miles)

AIM :

- Design Contactless Drone Delivery System
- Identify Target Areas of Need (Low-income areas with enough Elderly population)
- Keep Costs Low

The stages of the project can be described as follows:

- **List Suitable Areas**
  - Low-income areas
  - Large elderly population
  - Proximity to Walmart
- **Select Areas For Implementation**
- **Develop a Solution**
  - Different models of drones, different technologies, different suitabilities…
- **Perform Cost Assessment and Evaluation**

Approach:

In the frames of this project, we did not really use any sophisticated data science or machine learning techniques. Instead, we relied on simple research and exploratory data analysis methods that do not need to be described. Based on our data we tried to identify low-income areas (low-income census tracts) in the US. Then by doing additional research we tried to find the state that will be the best for drone delivery. By merging our datasets with Walmart locations data and census tracts centroids geo-data for the selected state we were able to identify low-income areas that lie in the delivery radius (8 miles) around each Walmart in the selected state. Then based on our demand requirements given by Walmart (100 packages per day) we forecasted demand for potential areas of implementation and picked the area that is the closest to the average demand requirement.

Based on the forecasted demand, we decided to select two drones for the delivery program. We selected a drone model capable of delivering three packages in a single flight. Based on the Assumptions provided by Walmart, the drone model was chosen because of its capability of delivering three packages in a single flight. The costs of various factors which contribute to the delivery program were researched. The goal was to keep the costs as low as possible while satisfying the delivery requirements.

Data:

The main sources of data are:

1. US Census 2020 data: https://www.census.gov/programs-surveys/decennial-census/decade/2020/2020-census-results.html
2. Walmart geo-data: https://walmart-open-data-walmarttech.opendata.arcgis.com/datasets/walmart-store-status-public-data/explore?location=6.758644%2C-38.041912%2C2.20&showTable=true
3. Census 2020 geo-data: https://tigerweb.geo.census.gov/tigerweb/

The US Census 2020 represents the results of the US 2020 data about different characteristics of the US population that can be represented in frames of different geo-structures. It provides comprehensive information about the US population including information about education, unemployment, health, gender and other important social-economic characteristics.

Walmart geo-data includes information about Walmart store locations around the US including the type of location, address, gps coordinates and others.

Census 2020 geodata represents the geo information about the Census 2020 areas. At this source you can find the maps of Census 2020 for different levels of scope as well as coordinates and other relevant geo data of map units.

Experiments:

LISTING SUITABLE AREAS

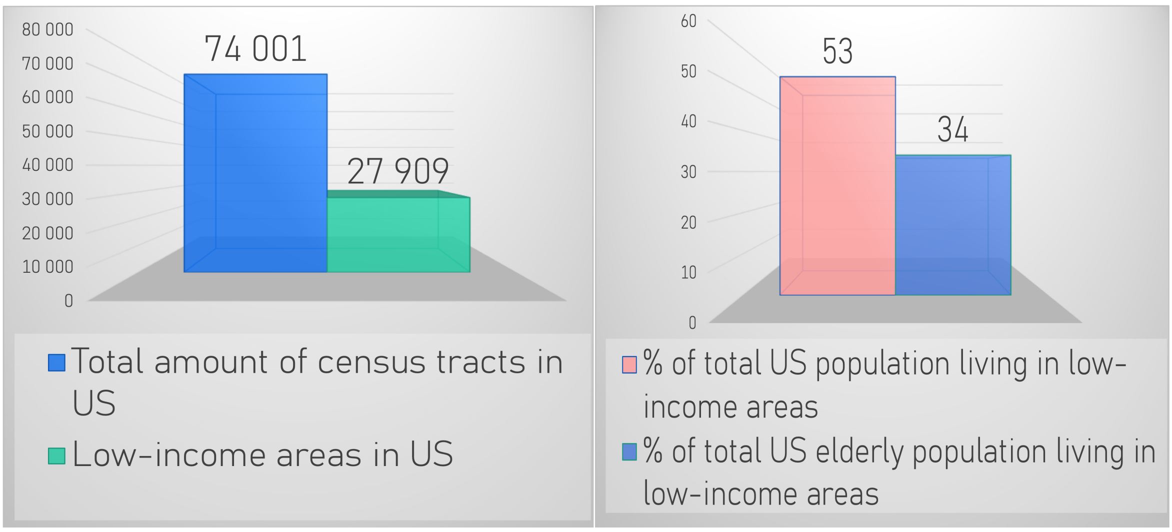
We chose the census tracts as the level of observation since it was the smallest unit for which comprehensive information about population was available. If we decide to drop the observation level further we will not be able to get the necessary information about the area (such as income, elderly population and others).

A census tract is a small, relatively permanent statistical subdivision of a county delineated by a local committee of census data users for the purpose of presenting census data. Census tract boundaries normally follow visible features but may follow governmental unit boundaries and other non-visible features, and they always nest within counties. Census tracts are designed to be relatively homogenous units with respect to population characteristics, economic status, and living conditions at the time the users established them. They usually contain 1,500 to 8,000 people and are made up of on average about four block groups. There are 74,001 tracts nationwide according to the census 2020 data.

Based on the official definition census tract considered to be low-income area if in the most recently completed decennial census published by the United States Bureau of the Census is reported to have a poverty rate of at least 20 percent or in which the median family income does not exceed 80 percent of the greater of the statewide or metropolitan median family income.

To detect low-income areas, we merged the US census tracts table containing such variables as total population, elderly population, median family income and others with a table of state median family income.

There are total 74 001 census tracts in US. After data cleaning, excluding census tracts with 0 population and 0 elderly population and checking the condition to be qualified as low-income area (the median family income does not exceed 80 percent of the state) we are left with 27 909 low-income areas where 53% of total US population and 34% of total US elderly population live.



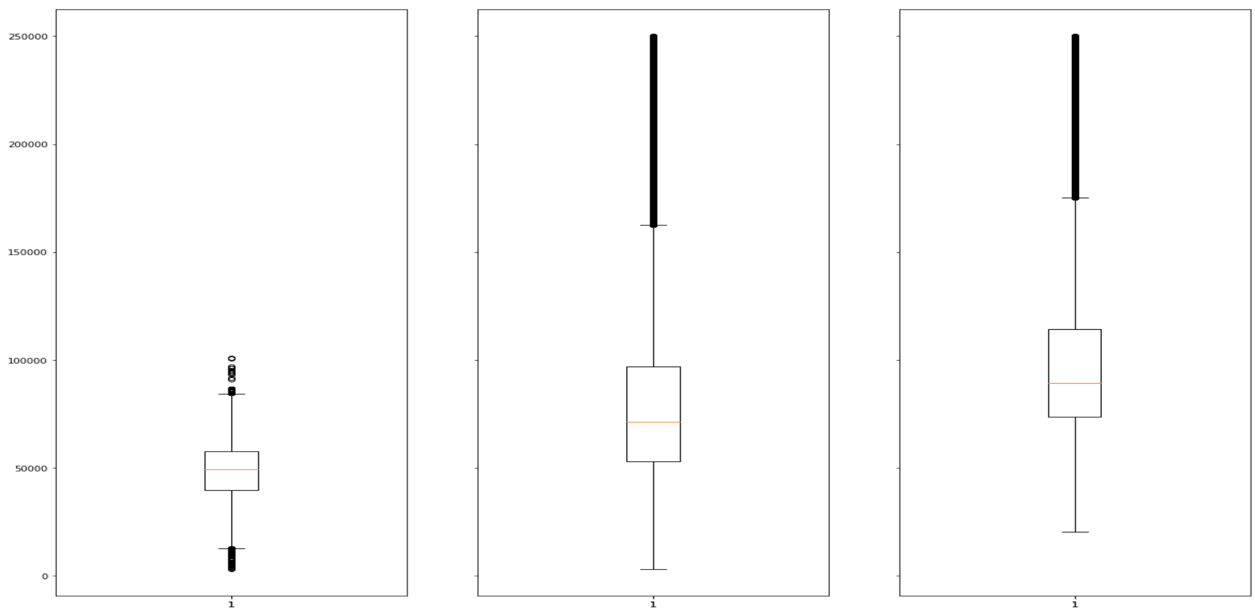
Graph 2 - low-income areas and population in low-income areas

California, New York and Texas are leaders among the US states by the number of low-income areas:

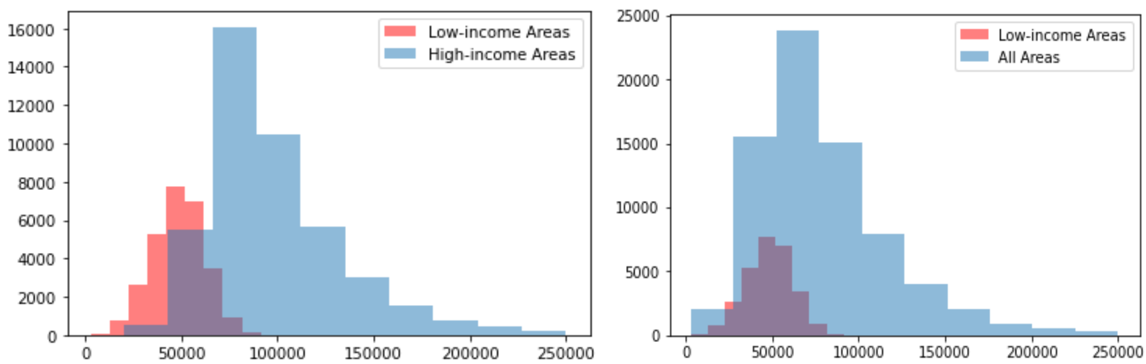
State	# of low-income areas
All	27909
California	3188
Texas	2291
New York	1872
Florida	1575
Illinois	1320
Pennsylvania	1127
Ohio	1119
Michigan	1071
Georgia	883
North Carolina	836

Table 1 - top 10 states with low-income areas

If we compare the boxplots for the median family income distribution for low-income areas vs all areas vs all the other areas that are not low-income, we will see that income in low-income areas is significantly lower compared to any other groups. The histograms just confirm the information presented at the boxplots.



Graph 3 – boxplot of income distributions of census tracts



Graph 4 – histograms of income distributions of census tracts

After we identified low-income areas, we need to narrow our search and find the area for the project implementation. As the first step we merged data for the table we created for the low-income areas with the table containing census tracts centroids geo location data (gps-coordinates). The data was webscrapped using the pandas **package *(pd.read_html(Url)).***

Code:

```
url_base='https://tigerweb.geo.census.gov/tigerwebmain/Files/tab20/tigerweb_tab20_tract_2020_'
states = ["AL", "AK", "AZ", "AR", "CA", "CO", "CT", "DC", "DE", "FL", "GA",
          "HI", "ID", "IL", "IN", "IA", "KS", "KY", "LA", "ME", "MD",
          "MA", "MI", "MN", "MS", "MO", "MT", "NE", "NV", "NH", "NJ",
          "NM", "NY", "NC", "ND", "OH", "OK", "OR", "PA", "RI", "SC",
          "SD", "TN", "TX", "UT", "VT", "VA", "WA", "WV", "WI", "WY", "PR"]
html_string=".html"
URL_list=[]
for i in range(0,len(states)):
```

```
    url=url_base+states[i]+html_string
    URL_list.append(url)
TABLES=[]
for i in range (0, len(states)):
    table=pd.read_html(URL_list[i])[0]
    TABLES.append(table)
Census_tract_geo=pd.concat(TABLES)
```

As a second step, we found the state for the project implementation. In the result of our research, we found that most of the drones are not able to operate in strong wind and when it’s raining or snowing. The drone we particularly suggest to use for this project (Wingcopter 198) has the following weather resistance characteristics:

- Wind resistance:15 m/s average wind 20 m/s gusts
- Operating temperature: 0-45 C
- No operation in heavy rain or snow.

The area we choose should have a low precipitation level and be non-windy. Also, it should satisfy the operating temperature condition for the selected drone. Thus, we chose Nevada as the area of the implementation (The driest US State (10 inches of yearly precipitations), average yearly wind speed (17 mph)).
Using the geopy package we found the distances between every Walmart and every low-income area centroids in Nevada and found all that lie in a 7 miles radius around Walmart (the max radius is 8 miles, but we subtract 1 mile to count for error because we are dealing with centroids). Then we organized the data frame that contains all necessary information required for further analysis: Walmart address, census tract id, name, centroid coordinates, distances from Walmart to census tract and some others.

Code:

```
#Creating a list of walmarts and all necessary features and distances
# to all low-income census tracts in NV
List=[]
for i in range(0,30):
    for j in range (0,220):
        i=i
        j=j
        walmart_objectid=data_Walmart_NV_GEO.iloc[i].objectid
        walmart_gps=data_Walmart_NV_GEO.iloc[i].gps
        walmart_ad1=data_Walmart_NV_GEO.iloc[i].ad1
        walmart_ad2=data_Walmart_NV_GEO.iloc[i].ad2
        walmart_ad3=data_Walmart_NV_GEO.iloc[i].ad3
        walmart_zip=data_Walmart_NV_GEO.iloc[i].zip_code
        ct_geoid=data_ct_GEO_NV.iloc[j].GEOID
        ct_name=data_ct_GEO_NV.iloc[j].Geographic_Area_Name
        ct_county=data_ct_GEO_NV.iloc[j].County
        ct_state=data_ct_GEO_NV.iloc[j].State
        ct_lat=data_ct_GEO_NV.iloc[j].CENTLAT
        ct_long=data_ct_GEO_NV.iloc[j].CENTLON
        ct_elderly_pop=data_ct_GEO_NV.iloc[j].Population_over_65

distanceWtoCT=geopy.distance.distance((data_ct_GEO_NV.iloc[j].CENTLAT,data_ct_GEO
```

```
_NV.iloc[j].CENTLON),(float(data_Walmart_NV_GEO.iloc[i].gps[1]),float(data_Walmart_NV_GEO.iloc[i].gps[0]))).miles

row=[walmart_objectid,walmart_gps,walmart_ad1,walmart_ad2,walmart_ad3,walmart_zip,ct_geoid,ct_name,ct_county,ct_state,ct_lat,ct_long,ct_elderly_pop,distanceWtoCT]

    List.append(row)

data_distnces_NV=pd.DataFrame(List)
```

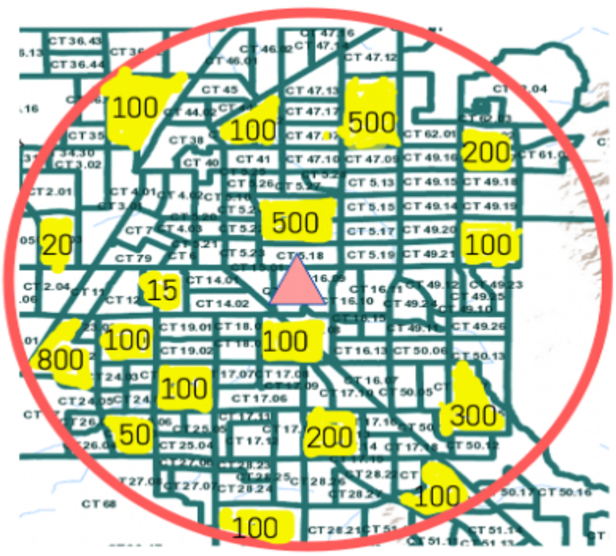
Then based on the demand requirements we tried to estimate the demand for all Walmart's in Nevada. Based on the research we assumed that the average US elderly person makes 2 orders per month. Walmart pharmacy market share is equal to approximately 10% (the share of Walmart pharmacists in the total number of pharmacists in major market players).
We suggest the following formula for the monthly demand in the delivery area (8 miles radius around Walmart):

Monthly demand = Elderly population in low-income areas*Average elderly person monthly orders

Keeping in mind that we should serve 100 customers per day on average assuming we deliver 6 days a week we need to deliver:

100 packages*6 days per week*51 week/12 months=2550 packages per month

We present the idea of the demand estimation in the picture below. Pink triangle is selected Walmart, red circle – delivery area, green lines – census tract boundaries, yellow areas – low-income census tracts, numbers – monthly demand calculated using suggested formula. To satisfy the requirement to do 100 deliveries per day we need the sum in the red circle to be 2550 or more.



Graph 4 – demand estimation scheme

As a result of our analysis we found that only 11 Walmarts in Nevada accumulate the necessary amount of the elderly people to satisfy average demand requirements and the one (with id 18934) is really close to the average requirement.

Walmart id	**Number of Census tracts in delivery distance**	**Estimated monthly demand for the area**
19585	121	11660
19863	116	11073
19450	96	8831
15797	93	9107
18612	90	8471
15823	73	7688
18883	43	4857
20474	37	3793
19451	35	3615
16238	34	3977
18934	19	2583

Table 2 – Walmarts in Nevada satisfying average demand requirement

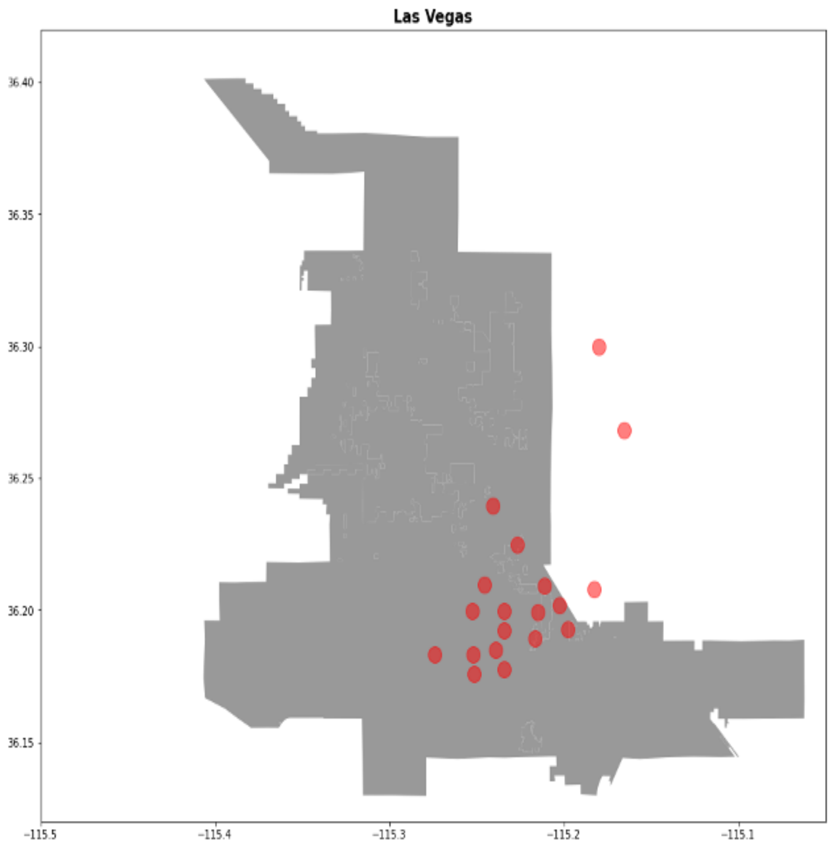
After further analysis we found that Walmart with id 18934 is in Las Vegas. The city has extremely favorable weather conditions for the drone delivery:
- Average wind speed: 9.1 mph
- Average yearly precipitation: <4.2 inches
- The temperature typically varies from 38°F to 105°F

Thus, we chose this Walmart to implement the project. Using the geopandas package we plot the map of the project area representing the low-income areas centroids by red points.

Code:

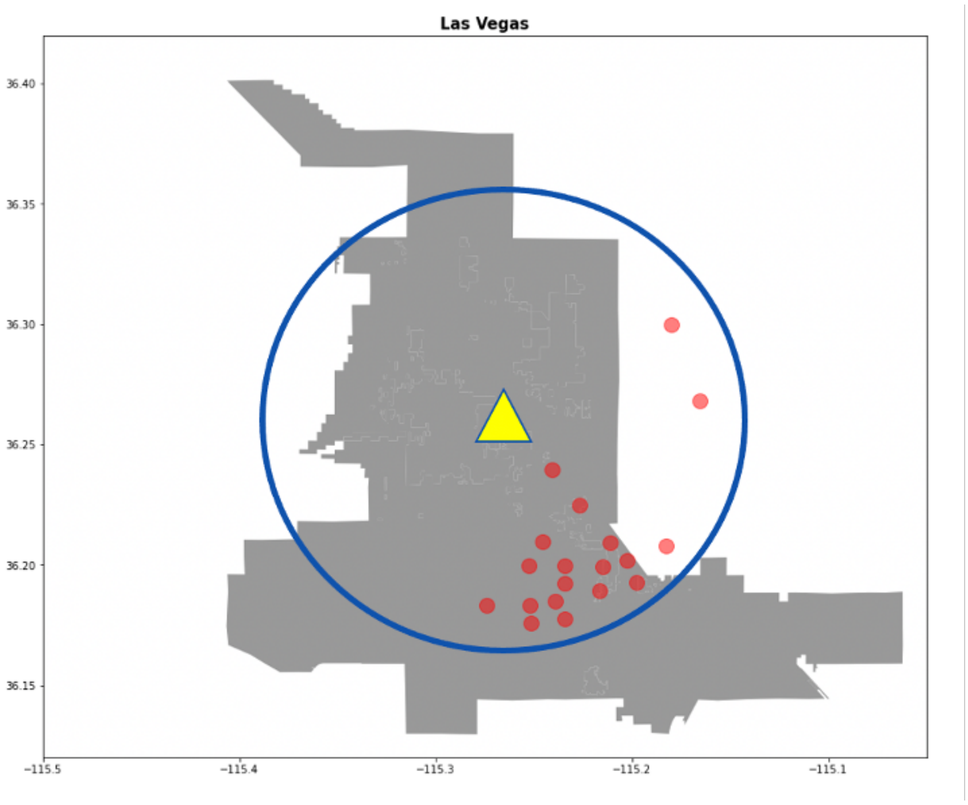
```
crs={'init':'epsg:4326'}
# create figure and axes, assign to subplot
fig, ax = plt.subplots(figsize=(15,15))
# add .shp mapfile to axes
street_map2.plot(ax=ax,alpha=0.8, color='grey')
# add geodataframe to axes
```

```
# assign ‘price’ variable to represent coordinates on graph
# add legend
# make datapoints transparent using alpha
# assign size of points using markersize
geo_df.plot(column='DemandM_2',ax=ax,alpha=0.5, legend=True,markersize=200, color='r')
# add title to graph
plt.title('Las Vegas', fontsize=15,fontweight='bold')
# set latitiude and longitude boundaries for map display
plt.xlim(-115.5,-115.05)
plt.ylim( 36.12,36.42)
# show map
plt.show()
```



Graph 5 – Las Vegas map with low-income census tracts centroids

Using PowerPoint we upgraded this map. Yellow triangle is selected Walmart (8060 W.TROPICAL PKWY, LAS VEGAS, CLARK, 89149), blue circle is delivery area, red dots – low-income census tracts centroids, x-axis – longitude, y-axis – latitude.



Graph 6 – Las Vegas map (area of the implementation)

For this project we were looking for a drone that can carry and deliver several packages separately because it's more efficient than delivering one package at a time. The best existing drone for this purpose according to our search is Wingcopter 198. Its features are presented in the Table below.

Maximum payload	6 kg
Maximum amount of packages	3
Maximum payload with triple drop	5 kg
Maximum range with triple drop	45 miles
Average speed (2-3 kg payload)	40 mph
Operating temperature	0 - 45° Celsius
Wind resistance	15 m/s average 20 m/s gusts

Table 3 – selected characteristics of Wingcopter 198

The next stage of our project is to apply algorithms for the optimization of delivery. Important assumptions that we made:

- Complete graph (19 addresses + Walmart)

- Drone needs to go from Walmart and return to Walmart
- The total weights of the packages will not ever exceed the total capacity of the drone
- The volume of the packages will not ever exceed the total capacity of the drone
- Drone can visit no more than 3 addresses during the flight (same addresses accepted)
- Maximum flight range 45 miles, assumed average speed 40 miles per hour.

COST ESTIMATION

The estimated cost of the *Wingcopter 198* drone we chose for this project is *$20,000/unit*. The cost of maintenance for each drone is:
Drone cost - $20,000 (+ $5,000 maintenance per year)

Since we use extra batteries to keep the drones continuously running we include the Battery costs:
Batteries= $2000

The total cost of 2 drones and 2 extra batteries:
*Total cost for 2 drones = ($20,000 + $5000+$2000) * 2 = $54,000*

According to the challenge, the target number of deliveries per day is = *100 deliveries*.
Target number of packages(1 yr) = 100 packages x 6 days x 51 weeks x 1year=30,600 deliveries.

Human Labor Costs:
Since our drones have the technology to navigate to the input GPS coordinates, they can be operated by one drone operator and can be loaded by two clerks.
The salaries for the operator and the clerks are *$25/hr* and *$20/hr* respectively, according to the current industry trends.
*Operator cost(1 person) = $25 * 10 hrs * 6 days* 51 weeks * 1 year = $76,500/yr*
*Clerk cost(2 persons) = $20 * 10 hrs * 6 days * 51 weeks * 1 years * 2 clerks= $122,400/yr*
Human labor cost = Operator Salary + Clerks Salary = $76,500 + $122,400= $198,900/yr

The Cost of Yearly Operations:
Human labor cost + Drones Cost = $198,900/yr + $54,000/yr
Cost per package = $252,900/30,600 packages = ***$8.26/ package.***

DELIVERY PROGRAM IMPLEMENTATION:

Various algorithms and ideas were considered while designing the delivery program, but the main goal was to keep it as simple as possible taking time into consideration. We chose to implement different algorithms for both the drones. This was crucial to make sure that no deliveries are ignored. The Shortest job first algorithm was used to schedule deliveries to the first drone. The SJF algorithm is known to produce the best results when it comes to job scheduling.

The deliveries for the second drone were scheduled using the Highest Response Ratio Next strategy. Although the SJF produces best results, it always seems to favor the shortest jobs while ignoring the jobs which take a longer time to be completed. If both the drones used SJF, there was a risk of the larger jobs being ignored. This may lead to infinite starvation and the jobs would end up unattended.

Inputs for the algorithm

LOCATION = GPS coordinates of customer location.

DELIVERY_TIME = Distance of location/ speed of drone.

ORDER_LIST = List of orders sorted in the ascending order of their delivery times.

2 Drones = Drone_1, Drone_2

SHORTEST JOB FIRST:

1. Apply Shortest Job First algorithm for the First half of the list.
2. 50% of the drones always select the 3 nearest Jobs first.
3. Apply TSP by taking the 3 nearest locations as input nodes. .

HIGHEST RESPONSE RATIO NEXT:

The Second half of the list is serviced by the other 50% of drones which follow the Highest Response Ratio Next strategy.

The deliveries with highest Response ratios are prioritised and accordingly top 3 deliveries are selected.

TSP is applied by taking the top 3 locations as input nodes.

Discussions:

The results obtained in frames of this project are solid considering the time constraints we were given. The project can be improved. First, we can consider other techniques and different scenarios to estimate demand, count orders that will come from non-low-income areas and not elderly people, and account for the competitive advantage of new technology. Additionally, we should try different algorithms and compare their performance considering different possible inputs based on the different solutions suggested for different areas of implementation.

Conclusion:

Drone delivery itself is a novelty. Many customers who reside within range of drone delivery are likely to be excited by the very idea of receiving their packages delivered by drone. Shorter delivery response times will always be a major. The time for drone delivery will almost certainly average less than vehicular delivery time. Currently, customers are faced with a decision between driving to a store to buy the medicines and waiting several days for delivery to their door. With drone delivery, the customer receives the product without the drive and just a minimal wait. With this delivery program, Walmart stands to gain a strong competitive advantage over both online and physical pharmacies. The quick delivery and initial novelty of drone delivery should increase its market share. As per our cost analysis and estimations we can conclude that it has a cost advantage over ground delivery.

Based on the research and data analysis done in frames of our project we suggest implementing no-contact drone delivery in Las Vegas, Nevada. around the Walmart at 8060 W TROPICAL PKWY, LAS VEGAS, CLARK, 89149. The suggested model of drone is Wingcopter 198. The main advantage of the model is the ability to carry and deliver 3 small packages simultaneously (per 1 flight). According to our findings 3 Walmart staff should be dedicated to the project: 1 drone operator and 2 stock clerks. Selected area of implementation covers 12,915 elderly people, 1292 of them will be served by Walmart (based on the market share)

Technical summary:

- ✓ PC: MacBook Pro 2017, 2,9 GHz Intel Core i7, 16 GB 2133 MHz LPDDR3, Radeon Pro 560 4 GB.
- ✓ Software used: Python 3.7, PowerPoint, Excel.
- ✓ Python packages used: Pandas, Numpy, Seaborn, Itertools, Geopandas, Matplotlib, Json, Geopy.