Decision Analytics for Business and Policy
Project Final Report

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Optimizing the Point of Dispense Assignment During the COVID-19 Epidemic

I. Literature Review

There are various models proposed for POD management.

Ramirez-Nafarrate et al (2015) proposed a model that selects PODs from a candidate set and suggests how to staff each POD so that average travel and waiting times are minimized. Different from other studies that used a sequential solution approach that first optimizes location and then capacity (2-stage stochastic optimization), the proposed model applied simultaneous optimization of location and capacity of each POD, which is more flexible for coping with infeasible scenarios. A genetic algorithm (GA) was applied to solve the problem based on travel and queuing approximations (QAs) with the flexibility to relax soft constraints when the dispensing goals cannot be met.

Carr & Roberts (2010) created a simulation of the disease spread process employing a SEIR compartmental model. The model includes employment patterns and separates the population into age groups and spatial location to more accurately describe disease spread behavior. Clinics were opened in locations that maximize the infected population coverage subject to budget and resource-related constraints, using a MIP location-allocation model.

Serra & Marianov (1999) implemented a P-median model and introduced the concept of regret and minmax objectives when locating a fire station for emergency services in Barcelona. The authors addressed uncertainties in demand, travel time or distance by using scenarios to incorporate the variation of uncertainties and seek to give a compromise solution by minimizing the maximum regret over the scenarios (Robust optimization).

II. Problem Statement

During the Covid-19 epidemic, it is essential for governments to distribute essential supplies (e.g. test kits, General purpose medicines, PPE) to the public. This project takes Allegheny County as background, aiming to develop a model and find the best way to select a list of Points of Dispense (PODs) from the candidate sites to open.

We propose a linear optimization model under uncertainty to solve this problem.

Our overall goal is to minimize the fixed and variable cost of operating a POD site. In addition, we seek to minimize the total travel distance of the population (P-median models), and to minimize the maximum travel distance for anyone (P-center models) from their place of residence to the assigned PODs.

III. Data Summary

A brief description of the data files imported into the model and variables used can be found in the data summary in the annex.

IV. Problem Formulation

A. Model Assumptions

- New Covid cases vary across residential districts (refer to COVID cases by SD sheet). This will inform the probability of contracting COVID in our baseline scenario. We forecast two additional alternative scenarios:
    - Worst case: Double current Covid case rates across each residential area
    - Best Case: Gradual decline in Covid cases across each residential

- Each candidate site has a fixed capacity (maximum number of households that it can serve).
- Each household will need to be assigned to one POD while each POD can match with several households up to its max capacity.
- Each household will collect medical supplies for all household members. All the residents from the same residential district are assigned to the same POD.
- In each district, households are clustered in the center of each school district for the purpose of distance calculation (distance matrix sheet).
- Distance between the center of each district to each POD site is measured using Google Maps based on shortest driving distance.
- The budget constraint limits the number of POD sites that can be opened out of the 47 potential candidate sites.
- The capital budget for 2021 for Allegheny county is $127.5 million and the overall budget is $2,598.9 million. Considering the importance of containing covid, it is assumed that 0.5% of the overall budget funds i.e. $13 million is allotted for setting up PODs.

Costing Assumptions

The costing for Point of Dispensing has 2 components, fixed and variable cost. Fixed cost is for renting the location for POD, setting up the POD with equipment and infrastructure and manpower cost. The variable cost is determined by the per unit cost of medicine and equipment supplies (i.e.masks, test toolkit, thermometer, etc) that varies based on the number of residents to be serviced by POD. Refer to the data dictionary for details.

B. Model Formulation

Indices

- i = 1,2,3,...,42 I: Residential Areas
- j = 1,2,3,...,47 J: POD Candidate Sites
- s = 1,2,3 S: Scenarios (1: Baseline, 2: Best-Case; 3: Worst case)

Parameters

- D_{ij} = distance between residential area i and POD site j
- C_j = capacity of POD site j (unit : number of households per site)
- H_i = Number of households in each residential area i
- FC_j = Fixed cost for opening POD site j
- VC = Unit variable cost for medical supplies and PPE
- B = Budget ($13 million)
- p_{is} = probability parameter for percentage of people infected by the COVID-19 scenario in residential area i for scenario s where s = 1 (baseline), 2 (best case), 3 (worst case)
- alpha = weights = [0, 0.001, 0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.99, 0.999, 1]

Decision Variables

- x_j : whether POD site j is opened (1: open; 0: close)
- y_{ij}: whether residential area i is assigned to POD site j (1: assigned; 0: not assigned) *(first-stage decision variable)*
- N_{js} = # of people served by the POD site j under scenario s *(second-stage decision variable)*

Objective 1: Minimizing the total weighted travel distance of the households + fixed/operational costs (Stochastic Multi-objective Optimization)

Assigning households to the PODs based on the nearest location and that minimize fixed and operational costs.

Min $alpha \cdot \sum_{i=1}^{42} \sum_{j=1}^{47} Hi \cdot yij \cdot Dij +$

$(1 - alpha) \cdot [\sum_{j=1}^{47} xj \cdot FCj + \sum_{i=1}^{42} \sum_{s=1}^{3} pis \sum_{i=1}^{42} \sum_{j=1}^{47} [VCj \cdot xj \cdot yij \cdot Njs]]$

Constraints

- Capacity constraint of each POD site

  $\sum_i y_{ij} H_i <= C_j x_j$ for all j = 1, 2, 3…, for all s = 1, 2, 3
- Each HH is assigned to exactly one POD site

  $\sum_j y_{ij} = 1$ for all i = 1, 2, 3…, for all s = 1, 2, 3
- Budget constrained the number of POD sites that can be opened.

  $\sum_{j=1}^{47} xj \cdot FCj + \sum_{i=1}^{42} \sum_{s=1}^{3} pis \sum_{i=1}^{42} \sum_{j=1}^{47} [VCj \cdot xj \cdot yij \cdot Njs]$ <= B for all s = 1, 2, 3

  y_{ij}, x_j are binary, Njs is an integer >= 0

Objective 2: Minimizing the maximum travel distance for anyone (Robust Optimization Objective)

Min Max_distance

Where $yij \cdot Dij \leq$ Max_distance $\forall i, j$ # constraint for the minimax setting

Constraints

- Capacity constraint of each POD site

  $\sum_i y_{ij} H_i <= C_j x_j$ for all j = 1, 2, 3…, for all s = 1, 2, 3
- Each HH is assigned to exactly one POD site

  $\sum_j y_{ij} = 1$ for all i = 1, 2, 3…, for all s = 1, 2, 3
- Budget constrained the number of POD sites that can be opened.

  $\sum_{j=1}^{47} xj \cdot FCj + \sum_{i=1}^{42} \sum_{s=1}^{3} pis \sum_{i=1}^{42} \sum_{j=1}^{47} [VCj \cdot xj \cdot yij \cdot Njs]$ <= B for all s = 1, 2, 3

  y_{ij}, x_j are binary, Njs is an integer >= 0

Objective 3: Minimizing the total weighted travel distance of the households

Min $\sum_{i=1}^{42} \sum_{j=1}^{47} Hi \cdot yij \cdot Dij$

Constraints

- Capacity constraint of each POD site

  $\sum_i y_{ij} H_i <= C_j x_j$ for all j = 1, 2, 3…, for all s = 1, 2, 3
- Each HH is assigned to exactly one POD site

  $\sum_j y_{ij} = 1$ for all i = 1, 2, 3…, for all s = 1, 2, 3
- Budget constrained the number of POD sites that can be opened.

  $\sum_{j=1}^{47} xj \cdot FCj + \sum_{i=1}^{42} \sum_{s=1}^{3} pis \sum_{i=1}^{42} \sum_{j=1}^{47} [VCj \cdot xj \cdot yij \cdot Njs]$ <= B for all s = 1, 2, 3

  y_{ij}, x_j are binary, Njs is an integer >= 0

C. Implementation

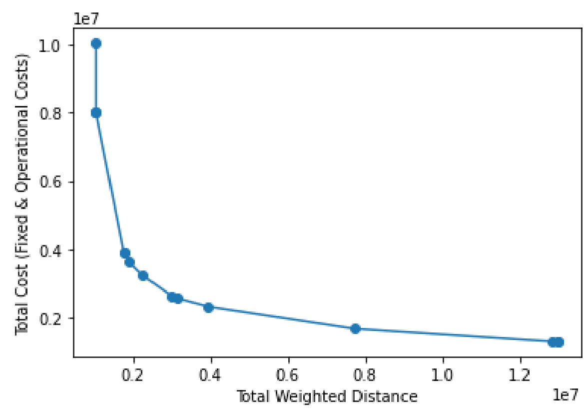
The python code used in this study can be found in dabp_updated.ipynb file.

D. Results

The results of the POD site assignment for all the objectives are as follows.

Objective	Total weighted distance (miles)	Total cost ($)	Max distance (miles)	# of selected POD
Objective 1: Stochastic Multi-stage (Min total weighted distance & total cost)				
Weight assigned (alpha) = 0.0	9,375,365.3	1,055,512	35.0	2
Weight assigned (alpha) = 0.1	7,996,458.6	1,055,512	29.0	2
Weight assigned (alpha) = 0.2	3,910,011.7	1,765,740	19.0	4
Weight assigned (alpha) = 0.3	3,910,011.7	1,765,740	19.0	4
Weight assigned (alpha) = 0.4	3,648,377.5	1,880,796	17.0	4
Weight assigned (alpha) = 0.5	3,234,849.6	2,250,868	16.0	5
Weight assigned (alpha) = 0.6	2,634,314.9	3,003,760	13.0	7
Weight assigned (alpha) = 0.7	2,562,623.3	3,163,856	13.0	7
Weight assigned (alpha) = 0.8	2,321,662.8	3,949,268	10.0	8
Weight assigned (alpha) = 0.9	1,674,158.0	7,737,832	9.0	15
Weight assigned (alpha) = 1.0	1,298,698.4	12,966,344	9.0	23
Objective 2: Robust (Min Max distance)	1,480,661.8	12,753,516	5.1	21
Objective 3: Robust (Min Total weighted distance)	1,298,698	12,966,344	9.0	23

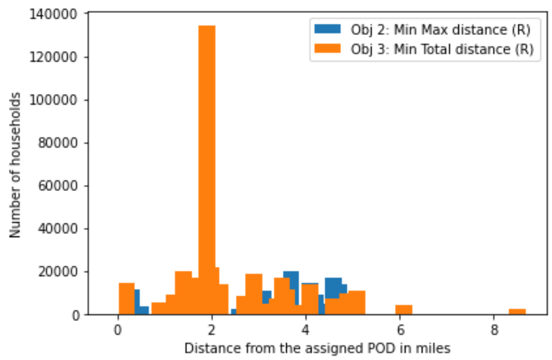
The POD assignment under the multi-objective stochastic optimization (objective 1) is optimized for different weights as shown in the graph on the right and table above. For different values of alpha, we can see that there is a trade off between total cost and the total weighted distance. We also calculated max individual travel distance and number of PODs selected under each weight circumstance.
As we can observe from the table, for Objective 1, as we assign more weights on minimizing total weighted distance, the optimal total weighted distance and optimal max distance decrease; while the optimal total cost and number of selected PODs increase.



E. Analysis

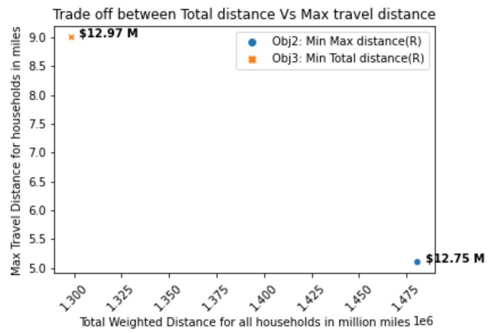
Selecting the best optimization model for POD assignment is dependent on three main factors 1. Total weighted distance for all the households, 2. Total cost for setting up and running the POD and 3. Maximum travel distance for the households.

For objective 1, we have the option of varying the weightage(alpha) for minimizing either the total weighted distance or total cost. For an alpha value of 0.5 (weighting the total weighted distance and the total cost equally), we can see that the total weighted distance is 3,234,849.6 miles and total cost is $ 2,250,868. We can see that based on the different alpha values, different numbers of PODs are assigned as shown in the above table. For lower values of alpha even though costs are kept low, the travel distance is high and very few PODs are opened, which may not be ideal.



Objective 2 is to minimize the maximum travel distance for all households. This is an objective which ensures equity for all the residents.It can be seen that the maximum distance travelled by any household is the lowest among the three objectives, but the total weighted distance travelled is highest and the cost is also very close to the budget constraint of $ 13 million.

Objective 3 is to minimize the total weighted travel distance for all the households in Allegheny county. As seen from the results, this objective provides the lowest total weighted travel distance and it can be seen from the bar plot that most households travel ~ 2 miles while some households end up travelling longer, 9 miles being the highest. The number of PODs which are opened are nearly similar between all the 3 objectives. Objective 3 is highly efficient, but does not fair well on equity as some households end up travelling longer distances.



F. Recommendations

Based on the results from our model and the analysis given above, it is clear that the decision for policy makers can be based on the trade off between maximum travel distance for all households, total weighted distance for all households and the total cost.

The multi-objective approach (the first objective) allows us to see the Pareto optimal frontier which represents how the increase in total weighted distance lowers the total cost (building less POD sites reduces total cost but leads to higher total weighted distance). This information can help policymakers decide the location (assignment) of the POD depending on what they want to achieve most (minimizing total weighted distance or total cost).

The second and the third objectives are the cases when counties want to utilize its budget constraint of $13 million. So, they can either choose to minimize the maximum travel distance so that the worst-off person travels the least distance (equity aspect) or to minimize the total weighted travel distance to make the overall people satisfied in terms of the travel distance (efficiency aspect).

References

Carr, Sean & Roberts, Stephen. 2011. Planning for infectious disease outbreaks: A geographic disease spread, clinic location, and resource allocation simulation. Proceedings - Winter Simulation Conference. 2171 - 2184. 10.1109/WSC.2010.5678858.

Ramirez-Nafarrate, Adrian, Joshua D. Lyon, John W. Fowler, and Ozgur M. Araz. 2015. "Point-Of-Dispensing Location And Capacity Optimization Via A Decision Support System". *Production And Operations Management* 24 (8): 1311-1328. doi:10.1111/poms.12323.

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