Lead Poisoning Crisis in Allegheny County

94867- Decision Analytics for Business & Policy

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Team Member	Tasks
Hajra Shahab	1. Match research numbers with required data in the formulations 2. Data cleaning on the water and medicine supply side 3. Report writing
Laknath Gunathilake	1. Match research numbers with required data in the formulations 2. Data cleaning on the POD and census tract side 3. Report writing
Javier Rico Aristizabal	1. Match research numbers with required data in the formulations 2. Cleaning of the formulations and the scenarios 3. Collecting travel distance data from Google maps for the seven different scenarios 4. Report writing
Erin Lin	1. Match research numbers with required data in the formulations 2. Cleaning of the formulations and the scenarios 3. Collecting travel distance data from Google maps for the seven different scenarios 4. Report writing

I. Background

The Flint Water crisis in 2014 became one of the most widely reported public health crises in America that led to the declaration of a federal state of emergency and an ensuing criminal trial that led to the resignation of the Governor in Michigan. At the height of the crisis, homes in Flint reported lead levels of around 27 ppb.[1]

Just after two years when the Flint crisis was fading away from the public's consciousness, a water crisis was emerging in Pittsburgh. The issue started with Pittsburgh Water & Sewer Authority (PWSA) hiring a private utility management company called Veolia to manage its day-to-day operations. After a slew of cost-cutting measures, including halving the lab staff for water quality testing and transferring the former water quality director of 36 years, Veolia changed the corrosion control chemicals without testing or getting approval.[2] Consequently, by early 2016, water lead levels were reported at 22 ppb, only a few units short of the water lead levels reported in Flint at the height of the crisis.

While the water lead levels have reduced since 2016 due to replacement of over 3200 lead lines, the city still has "thousands of pipes to replace." The complete replacement of the existing pipe infrastructure is slated for completion by 2026. [3]

This project simulates a public health crisis that could happen in Allegheny County and at a scale more severe compared to the lead crisis of 2016. The simulation could help city and county policy-makers understand potential contingency measures. While a possible emergency may not be of the same level of severity, our simulation could help City and County officials think about factors, such as which point of dispense (POD) facilities to consider for relief efforts, where to secure clean water in case of having to shut down the water supply, and how to secure medication used for treating lead elimination.

Our setup considers a lead poisoning outbreak due to rapid pipe corrosion in Allegheny county's water lines, affecting both children and adults. The outbreak has a high impact on children under 9 years old, and as such we consider them as a high-risk population[1]. The county government anticipates the following scenario:

Global outbreak Scenario- In this scenario, lead poisoning cases were popping up across the County, and the commissioner has decided to halt the entire water supply and direct residents to POD shelters

Assumption
Citizens have to be provided with DMSA, a medication that increases urine lead elimination[4] which is manufactured in Germany and in short supply as well as clean water to be procured from neighboring countries. These two elements include the manufacturing/supply side of our model.

On the demand side we are required to provide residents with DMSA and water. We make the following assumption when formulating our model

1. Lead-free water will be transported from the Beaver County River
2. The water storage capacity will differ for each POD between 10,000 and 60,000 gallons
3. Each POD has its own built-in water storage tanks
4. There will be no set-up costs borne by the county, since they have sought assistance from the Strategic National Stockpile to set up medical stations at the identified POD's.[5]

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[1] "August Mack Environmental." n.d. Accessed November 27, 2021. https://augustmack.com/2020/02/19/watershed-the-flint-water-crisis-and-epa-lead-exposure-thresholds/.

[2] "This Major City's Drinking Water Was Fine. Then Came the Private Water Company. – Mother Jones." n.d. Accessed November 27, 2021. https://www.motherjones.com/environment/2016/10/private-water-pittsburgh-veolia/.

[3] "After a Years-Long Crisis, the Lead Levels in Pittsburgh's Water Finally Meet Federal Compliance - PublicSource." n.d. Accessed November 27, 2021. https://www.publicsource.org/after-a-years-long-crisis-the-lead-levels-in-pittsburghs-water-finally-meet-federal-compliance/.

[4] A, Bradberry S; Vale. "Dimercaptosuccinic Acid (Succimer; DMSA) in Inorganic Lead Poisoning." Clinical toxicology (Philadelphia, Pa.). U.S. National Library of Medicine. Accessed November 7, 2021. https://pubmed.ncbi.nlm.nih.gov/19663612/.
[5] https://www.phe.gov/about/sns/fms/Pages/default.aspx

5. Operating costs for each POD will vary between $20,676 and $4,135.

II. Problem Statement

The Decision Making

The county governments need to decide which of the PODs to open from the candidate sides and the POD to which each census tract is assigned to. The country governments also need to decide the quantity of each supply item to be allocated at each POD and the number of delivery trucks to be used. The county government has two major objectives: (1) minimize the travel time from residents to PODs and from water supply facilities to PODs, and (2) minimize the total operating cost. For the first objective, the county government sets up two different formulations: (1-1) minimize the total travel time of the population, and (1-2) minimize the maximum travel distance to reach a POD. Both objectives are subject to the following constraints.

Each resident needs to access a shelter at least once during the ten days to obtain medicine, and at least once a day to obtain water. A POD site cannot provide more water or medicine beyond what is available.

III. Mathematical Formulation

Indices

$i = 1,..., 401$ demand locations by census tract in Allegheny County

$j = 1,..., 94$ possible POD sites in Allegheny County (Schools and EMS's)

$k = 1, 2$ supply items (1: DMSA and 2: clean water)

Decision Variables

$x_j =$ 1if POD *j* is built, 0 if not

$y_{ij} =$ 1if census tract *i* is assigned to POD *j*, 0 if not

q_{kj}: quantity of supply item *k* allocated to each POD *j*

ntr : number of trucks to be used

Z: maximum travel time from any census tract to the POD

Parameters

Internal to PODs	B: total budget allowed c_j: operating costs for POD *j* a_k: quantity of supply item k required by a person f_j: water storage capacity for POD *j*
Demand Dynamics (Census tract → POD)	pop_i: population in census tract *i* d_i: number of children under 9 years old in census tract *i* tt_{ij}: travel time from census tract *i* to POD *j*
Supply Dynamics (Water facilities and airport → POD)	ts_j: travel time from water supply facility to POD *j* ta_j:travel time from the airport to every POD *j* tr: water capacity per truck in gallons ctr : cost associated to using every truck per hour

Objective

1. **Formulation 1**

   Min $(c_{tr} * n_{tr} * \sum_j ts_j + \sum_j c_j * x_j) + (\sum_j ta_j * x_j + \sum_i \sum_j pop_i * y_{ij} * tt_{ij})$

The objective for formulation 1 is to minimize (1) **costs**, including delivery truck costs and operations costs for PODs, and (2) **travel time**, including travel time from the airport to PODs and *total travel time of the population from every census tract to PODs.*

2. **Formulation 2**

   Min $(c_{tr} * n_{tr} * \sum_j ts_j + \sum_j c_j * x_j) + (\sum_j ta_j * x_j + Z)$

The objective for formulation 2 is to minimize (1) **costs**, including delivery truck costs and operations costs for PODs, and (2) **travel time**, including travel time from the airport to PODs and *maximum travel distance for anyone from every census tract to PODs.*

Constraints

1. $\sum_j c_j * x_j + c_{tr} * n_{tr} * \sum_j ts_j \leq B$
2. $\sum_j y_{ij} = 1$, ∀ i
3. $y_{ij} \leq x_j$, ∀ i, ∀ j
4. $q_{j,1} \geq \sum_i a_0 * y_{ij} * d_i$, for k = 1 (medication), ∀ j
5. $q_{j,2} \geq \sum_i a_1 * y_{ij} * pop_i$, for k = 2 (water), ∀ j
6. $q_{j,1} \leq f_j$, ∀ j
7. $tr * n_{tr} = \sum_j q_{j,1}$
8. All variables non-negative, x_j, y_{ij} binary
9. $y_{ij} * tt_{ij} \leq Z$, ∀ i, ∀ j   *Applied only to formulation 2

Constraint (1) ensures the sum of operating costs and truck costs is covered by the total budget allowed. Constraint (2) ensures that every census tract is assigned to one POD. Constraint (3) allows census tract can only be assigned to opened POD. Constraints (4) and (5) ensure that medication and water demand at each POD are completely satisfied from the suppliers. Constraint (6) ensures that the total water allocated to the POD is less than or equal to the water storage capacity at that POD. Constraint (7) calculates the total water shipped from water facilities, which should be equal to total water allocated to all PODs. Constraint (9) only applies to formulation 2, serving as a goal minimax constraint.

IV. Data Summary

We collected and used the following data files:

- PODs_Coordinates.csv

- This .csv includes the operating costs. From our research we found that a small size POD is staffed by 25 members, and that a large size POD has around 100 staff members. We also found that staff members on average work 12 hours shifts. Using hourly wage data from the Bureau of Labor Statistics we calculated the operating cost for a small and large POD and assumed that each POD in our model would have an operating cost between these two ranges.

- water storage capacity in gallons [6]
  - considering an average storage of 20,000 gallons per school and an added capacity to some schools up to 60,000 gallons, and travel time to the airport obtained with the google sheets and google maps resource[7] for every possible POD out of 94 locations.
- census_POD_travelMatrix_min.xlsx
  - Matrix that includes the travel time in minutes to each of the possible POD locations (94) from every census tract (401) calculated with the OSRM package in R Studio[8].
- POD_watersupply_time.xlsx
  - Excel file that has the travel times from the water supply location to each of the 94 POD locations calculated with the google sheets and google maps resource[6] .
- population_by_census_tract.xlsx
  - Excel file that has the total population and the population under nine for every each of the 401 census tracts in Allegheny County obtained with the Census tract reporter[9].

V. Implementation

The optimal solution in our final min-max model requires the use of nine PODs out of the 94 available locations. The required investment according to the cost considered in the model are expected to be seven million dollars. The maximum travel distance under this scenario will be 24 minutes. The selected POD locations are mostly schools that can be associated with the higher water storage capacity that schools have on average, compared to EMS locations. The selected locations are the following. (1) Baldwin High School, (2) Cornell Jr/Sr High School, (3) North Allegheny High School, (4) Obama 6-12 High School, (5) Allderdice High School, (6) Riverview Senior High School, (7) Wilkinsburg High School, (8) Woodland Hills High School, and (9) Kirwin VFD Rnnerdale VFC.

VI. Analysis

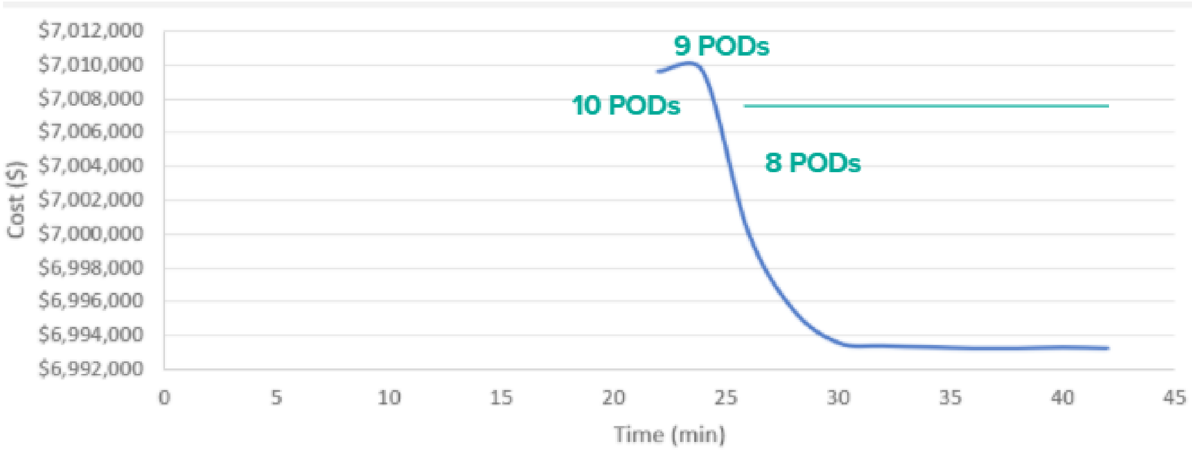
The optimal selection of PODs was made based on our objective function, which includes costs and travel distances. In addition, our objective function was restricted in order to reduce our maximum travel distance.

Under our first analysis, we ran the model without including the min-max goal. This model suggested using 73 out of the 94 available POD locations. The average travel distance was considerably low, around 8 minutes, but there was also a skew on the travel times from some census tracts to their assigned PODs. The budget was also high, 20.5 million dollars, compared to our final budget.

[6] https://iwaponline.com/washdev/article/9/1/119/65468/Water-consumption-in-public-schools-a-case-study
[7] Google Maps Formulas for Google Sheets. https://www.labnol.org/google-maps-sheets-200817
[8] osrm: Interface Between R and the OpenStreetMap-Based Routing Service OSRM. https://cran.r-project.org/web/packages/osrm/index.html
[9] Census tract Reporter. https://censusreporter.org/data/table/?table=B01001&geo_ids=04000US42,01000US,140%7C05000US42003#valueType%7Cestimate

Finally, the model includes the min-max restriction for the travel times. We performed sensitivity analyses restricting the budget. These ones didn't reflect a major change in the outcome, usually being around 7 million dollars. Meanwhile, the maximum travel time could be also restricted, and it presented interesting results.

Our sensitivity analysis was made based on the maximum travel time restriction. The lowest travel time we could apply was 22 minutes, the model ended up as infeasible being lower than that. From that number, we started increasing the maximum travel time and identified how this affected the number of PODs to be selected. We also identified the budget that was required under each of these scenarios. The following graph summarizes the number of PODs required for the restricted maximum travel distance, joined with the budget required for each case.



The budget doesn't change drastically when restricting to 22 minutes the maximum travel distance, compared to higher travel times. The optimal solution is the one given in the implementation section, using 9 PODs for a maximum travel distance of 22 minutes. Finally, the number of trucks required to supply the required water is 85.

VII. Recommendations

○ Comparative Analysis

We used the Flint Water Crisis as a use case to understand lead poisoning issue in the US in greater detail. Our policy recommendations are informed through this comparative analysis and the current landscape of infrastructure development in Allegheny County. The Flint water crisis affected the African American community and poor citizens who went ignored by officials. While Flint crisis stemmed from the transfer of water authority from one organization to another, lead poisoning in Allegheny County stems from the public vs. private distribution of pipes. County officials have changed old pipes but the water pipes that fall under private ownership are still mostly contaminated. Efforts have been made to overcome this issue but the threat around lead poisoning still remains.

○ Policy Recommendations

- Diversify water storage sources from rainwater and other sources to decrease dependence on other counties in health crisis situations such as the one discussed in this scenario.
- Establish a working group to devise a plan to allocate resources from "The Bipartisan Infrastructure Deal" and extend benefits to private households to upgrade their water pipes to fully eliminate the risks associated with lead poisoning in the county.
- Policymakers should devise a plan to develop a robust procurement plan of Chelation Therapy medication in the US markets which is currently only being manufactured by a German pharmaceutical company.
- Distribute water testing kits to residences regardless of whether it is requested or not to cut

down extensive processes and expand the scale of testing.

Appendix [Data Dictionary] : Data Collection and Sources

<table>
<tr><th>Category</th><th>Data Needed</th><th>Sources</th></tr>
<tr><td rowspan="3">Budget</td><td>Opening cost for PODs</td><td>1. The first link states that a small POD requires around 15 to 20 health care staff members to work 12-hour shifts. The second link is from the Bureau of Labor Statistics that provides the hourly wage for a Medical Assistant in the US. so we can calculate the # of Med Asst per shelter * hours per day * 7 days
2. Assumptions
a. labor is the only operational cost
b. All POD shelters will have the same # of staff</td></tr>
<tr><td>Operating cost for PODs</td><td>1. Data to calculate the operational cost
https://www.orau.gov/sns/training/podOverview/content/common/Resources/POD_Overview_CourseTranscript.pdf
https://www.bls.gov/ooh/healthcare/medical-assistants.htm</td></tr>
<tr><td colspan="2">(Alternative) Sensitivity analysis on the number of PODs that you can open</td></tr>
<tr><td rowspan="4">Travel Distance Estimation</td><td>Lat/Long for candidates sites for PODs</td><td>Provided on Canvas.
Calculation of times and instances with Google maps:
https://www.labnol.org/google-maps-sheets-200817</td></tr>
<tr><td>Lat/Long for the center point of each zip code</td><td>Allegheny county GIS census tract information:
https://openac-alcogis.opendata.arcgis.com/datasets/allegheny-county-census-tracts-2016/explore?location=40.452699%2C-79.925715%2C14.16&showTable=true</td></tr>
<tr><td>Number of households in each neighborhood</td><td>Population data by census tract:
https://censusreporter.org/data/table/?table=B01001&geo_ids=04000US42,01000US,140|05000US42003#valueType|estimate</td></tr>
<tr><td>Calculating time driving between two locations</td><td>https://cran.r-project.org/web/packages/osrm/index.html

https://www.labnol.org/google-maps-sheets-200817</td></tr>
<tr><td rowspan="2">Supply/Service Capacity</td><td>Water Supply Locations</td><td>Water Allocation in Pennsylvania:
Reservoirs near Beaver river geolocation</td></tr>
<tr><td>Water Supply needs</td><td>1 gallon per water per person per day (CDC). Emergency water supply:
https://www.cdc.gov/healthywater/emergency/creating-storing-emergency-water-supply.html#:~:text=Store%20at%20least%201%20gallon,and%20persons%20who%20are%20sick.</td></tr>
<tr><td></td><td>Water capacity of a truck</td><td>4,000 gallons of water capacity per truck
https://www.currysupply.com/water-trucks-101-everything-need-know-components/#:~:text=How%20much%20do%20water%20trucks%20hold%3F&text=hold%2C%20most%20water%20trucks%20are,models%20available%20on%20the%20market.</td></tr>
<tr><td></td><td>Rental of Water trucks</td><td>A water truck of 5,000 gallons per day is $5,200 per mont, $174 per day.
The efficiency of a truck is about 10 Miles per gallon. With the gas cost of $3 per gallon, and an average speed of 35 miles per hour (Including standby time), a truck spends $10.5 per hour on fuel. The total 24 hours of the truck working is $252 per day.</td></tr>
</table>

		Our daily cost per truck is $426 https://www.wilmarinc.com/blog/how-to-measure-the-efficiency-of-a-fleet-of-trucks#:~:text=Usually%2C%20all%20class%208%20trucks,between%208.5%20to%2011.5%20MPG