Locating new affordable housing projects to optimize accessibility to jobs and social equity: a case study in Philadelphia

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Abstract

This paper develops an optimal location model for locating new affordable housing units to maximize the accessibility of low-income jobs by public transportation and disperse perceived burden of residents near new affordable housing to enhance social equity. Housing that can provide more accessible public transit allows disadvantaged groups to reduce their reliance on automobiles, leading to savings on transportation-related expenditures. To maximize accessibility, this project uses a method of maximal coverage location problem (MCLP) based on network distance. The second objective disperses affordable housing projects across space using a p-dispersion model based on spatial interaction impacts. The objectives of maximizing accessibility and dispersing affordable housing are traded off and are subject to total budget of both acquisition and construction. The model is tested using data for Philadelphia including actual data for city-owned vacant parcels, network travel distance, and the location of low-wage jobs. This model can develop a tool for the city to help decision making process on leveraging resources to develop new affordable housing projects.

1 Introduction

The City of Philadelphia is in great need of new affordable housing projects to accommodate the low- and moderate-income citizens. Some estimates suggest that at least 60,000 affordable housing units are needed. Mayor Parker said in an interview, "There are people, working people, employed people, in the city of Philadelphia who cannot afford to own their own home".[1] Providing decent housing affordable to persons and families of modest means has long been a goal of US housing policy (Schwartz, 2021). Successful affordable housing can also benefit the community in many ways, including creating more opportunities for economic growth, reducing homelessness, and lowering the cost to taxpayers compared to alternatives like homeless shelters. Proximity to jobs, shopping, transportation infrastructure, childcare, good public schools, parks, cultural activities, health facilities, counseling, and other supportive services benefit the occupants of affordable housing (Schwartz, 2021). Thus, it becomes more essential to find the location of new projects that can better serve the population in terms of accessibility and social equity.

[1] https://www.fox29.com/news/philadelphia-housing-crisis-mayor-parker-city-leaders-break-ground-on-affordable-housing-initiative

However, the benefits from affordable housing projects are often trade-off against perceived fairness or equity to the host communities. Because affordable housing is sometimes considered as an undesirable facility by local residents and received political opposition based on the perception of negative impacts (Nguyen, 2005; Tighe, 2010).

Thus, we propose our objective to optimize the location of affordable housing projects in Philadelphia in terms of accessibility and equity.

2 Method

2.1 Literature review

Although it is acknowledged that location and accessibility are important ingredients in successful affordable housing, little research has been undertaken to determine optimal locations (Zhong et al., 2019). There are very few optimization models specifically developed for locating affordable housing (Zhong et al., 2019). Michael P. Johnson and his co-authors have published most of the optimal affordable housing location papers since 2000. Most related to this project, they used a multi-objective model for allocating vacant land to residential and non-residential purposes in one of the studies (Johnson et al., 2014). Zhang et al. wrote two papers utilizing a GIS-based spatial decision support system to analyze public affordable housing. (Zhang et al., 2009, 2013).

The importance of public transportation to residents of affordable housing is widely recognized and has been incorporated into GIS models. Travel survey results consistently find that low-income people are more likely to use public transit (Clifton and Lucas, 2004). Meanwhile, job accessibility is considered relevant to commute distance in general (Immergluck, 1998). Therefore, low-income households can benefit greatly from higher accessibility to job by public transportation in particular. There are many ways to evaluate the accessibility to public transportation, including gravity model and buffer coverage. Meanwhile, few existing research accounts for political opposition to public housing due to the perception of negative impacts (Tighe, 2010). For example, current residents may be opposed to affordable housing because of potential value decrease of their own houses.

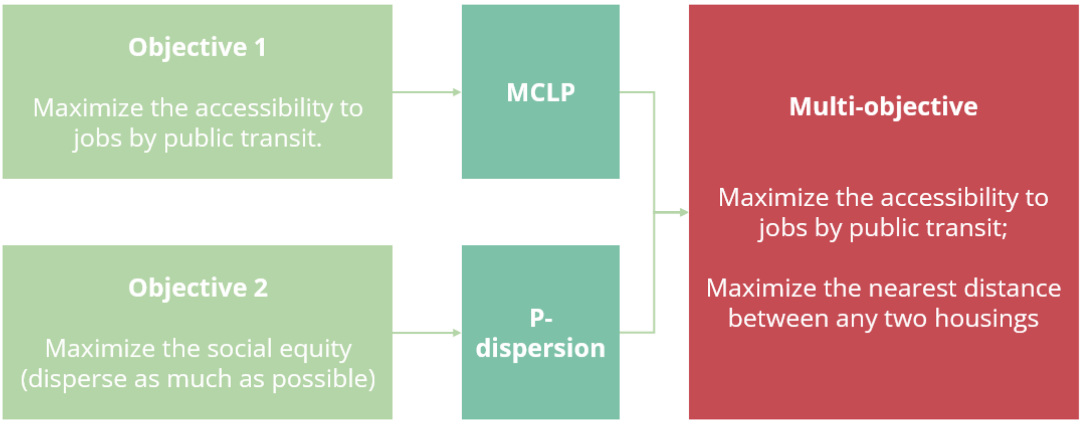


Fig 1. The combination of objectives

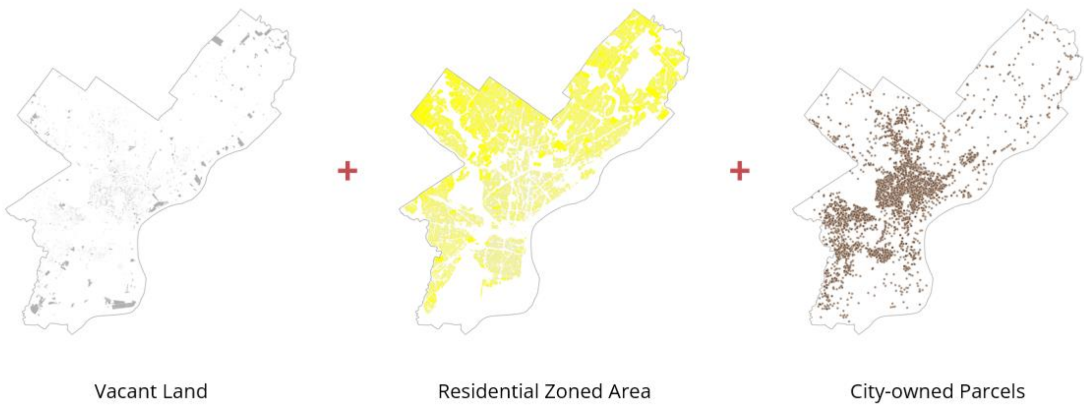
2.2 Data

Several data sets are needed for this study, as shown in the table below.

Name	Description	Source
Potential parcels for new affordable housing projects		
Land use	To find vacant parcels	https://opendataphilly.org/datasets/land-use/
Zoning	To find residential zoned area	https://opendataphilly.org/datasets/zoning-base-districts/
Zoning codes	Help with zoning understanding	https://www.phila.gov/documents/zoning-code-information-manual-quick-guide/
Accessibility to facilities by public transit		
Road network	To create buffer area of each bus stop (¼ mile network distance) and rail stations (½ mile network distance)	https://opendataphilly.org/datasets/street-centerlines/
Bus stops	To evaluate the accessibility to public transit of each parcel	https://data-septa.opendata.arcgis.com/datasets/ec2a9afbca6c43a69d7fc7abeec2ffbf_0/explore?location=40.067928%2C-75.294448%2C10.09
Jobs	To evaluate the accessibility to jobs paid lower than $1250 per month	https://lehd.ces.census.gov/data/lodes/LODES8/pa/wac/
Property Assessment	To evaluate social equity and community impact	https://opendataphilly.org/datasets/philadelphia-properties-and-assessment-history/
Constraints on construction cost		
Building construction cost	To help determine the constraints	US Census Bureau
Construction		Philadelphia City Planning

budget		Commission

Three types of data are needed to run the model in CPLEX for this project in total, namely the parcel information about its number of units, cost, and accessibility to jobs by public transit. First, we overlap the layers of land use, zoning, and property assessment data, and define the potential parcels to be city-owned, currently vacant, and zoned as residential use. After that, we read through the zoning guide for Philadelphia, and removed some parcels that do not meet the minimum area of its zoning code. The minimum lot area for Code RM1 is 1,440 square feet, we removed the parcels smaller than that. All potential parcels are shown in Fig 2.



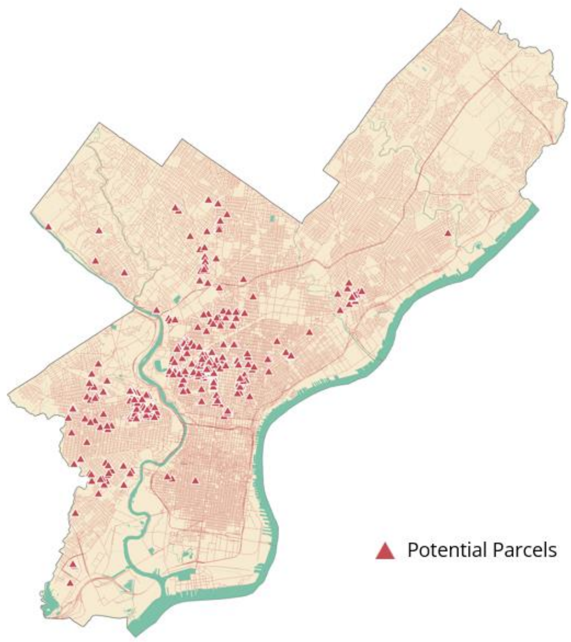


Fig 2. Definition and results of potential parcels

Then we calculated the units for each parcel. We assume the minimum net site area of a unit is 500 sq.ft for parcels zoned as single-family homes, either attached or detached. They are calculated as the maximum occupied area divided by unit area. For multi-family homes and apartments, we assume the unit area is 800 sq.ft, its number of units is calculated as total building area divided by unit area. We also account for FAR bonus of affordable housing projects. The results are shown in Fig 3., a parcel has 40 units at most.

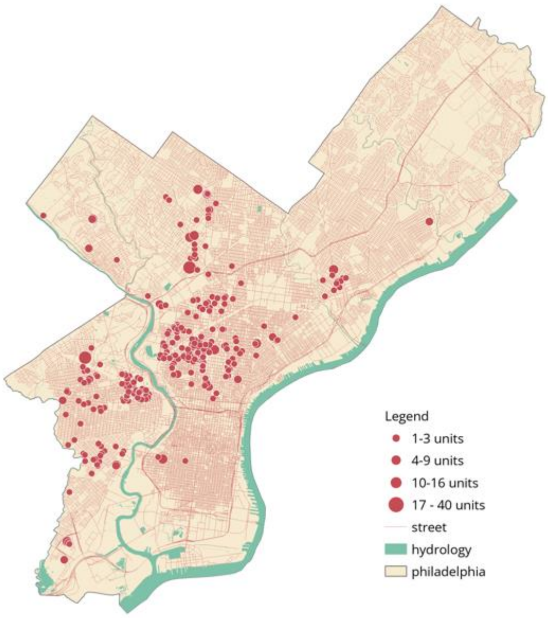


Fig 3. Number of units for each potential parcel

Second, for job accessibility of each parcel, we assume it is the function of the number of accessible jobs by public transit. To calculate it, we need bus stops, road network and potential parcels data. We conduct network analysis in ArcGIS Pro. All parcels are within a 0.25-mile radius buffer area from a bus stop, so they can all take advantage of public transit. According to The National Transit Database (NTD), Philadelphia bus speed is 10 mph. We assume a person thinks it acceptable to spend one hour commuting every day. So, it will be 30 min for one way trip, which is 5 miles network distance by bus. Then we find all accessible bus stops within that distance from a parcel and create buffer area of the bus stops with a 0.25-mile radius, and then calculate the jobs with this area. The result is shown in Fig 4.

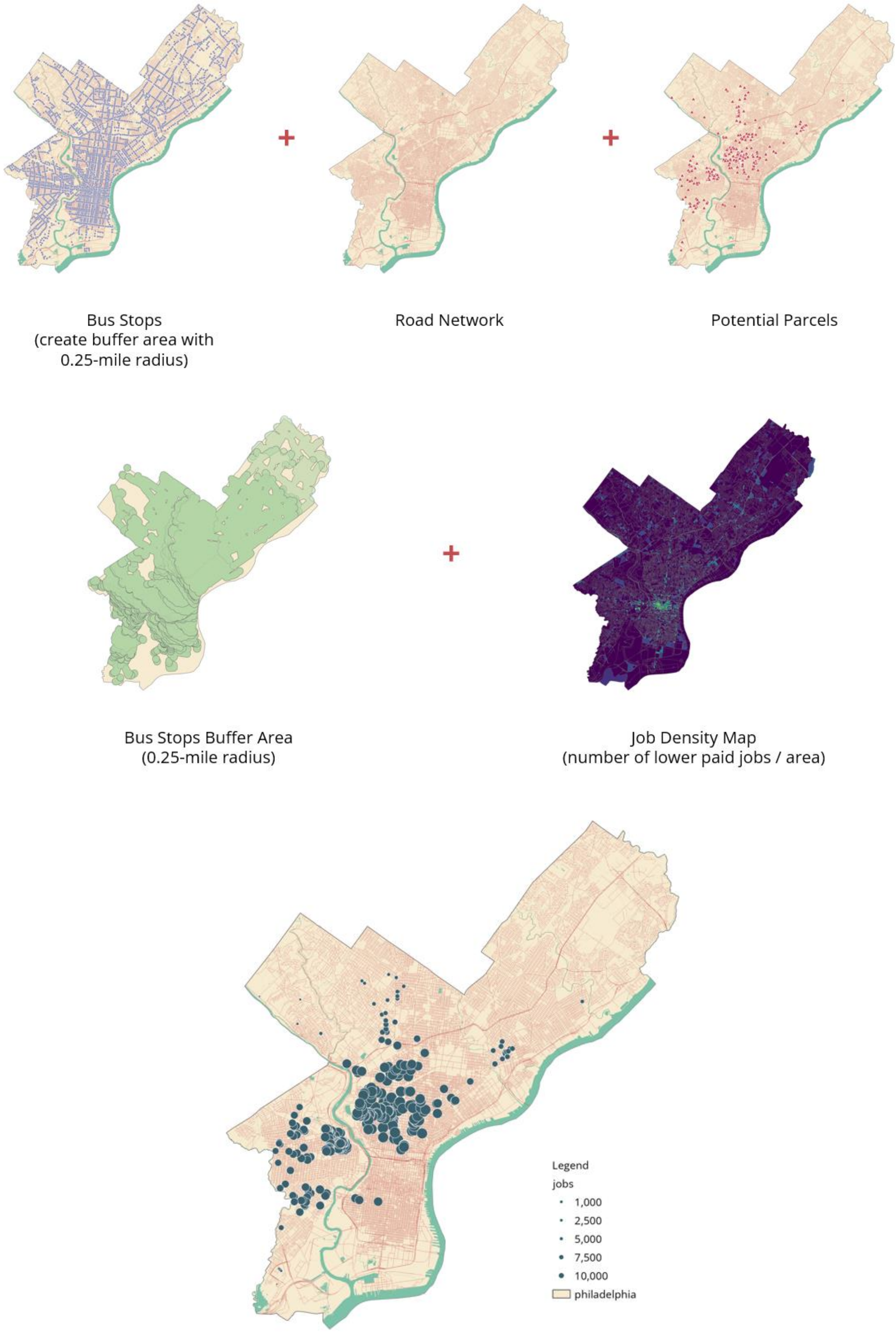


Fig 4. Definition and result of job accessibility by public transit

Total cost is the sum of land cost and construction cost. Land cost is from property assessment data, and construction cost is calculated according to house size, as shown in Fig 5.

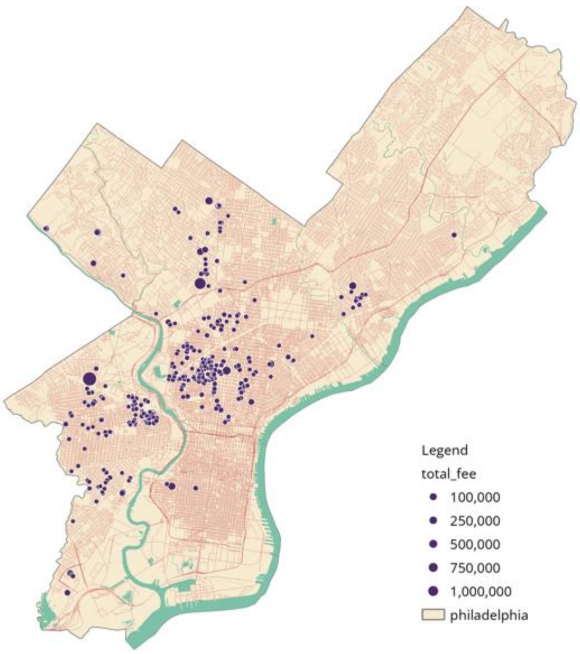


Fig 5. Total cost of each parcel

2.3 Model

As mentioned above, two objectives are combined to be a multi-objective model. Thus, we build and adjust our model by combining maximal coverage location problem (MCLP) and p-dispersion, as follows:

$$Maximize \sum_i A_i n s_i x_i$$

$$Minimize\ I$$

Thus, the formulas of the multi-objective model can be written as follows:

$$Maximize\ \alpha \left[\sum_i A_i n s_i x_i \right] - (1-\alpha) I \quad (1)$$

Subject to:

$$I \geq \frac{s_i + s_j}{d_{ij}} \left[1 - (1 - x_i)M - \left(1 - x_j\right)M\right] \; \forall i, j | i < j \quad (2)$$

$$\sum_i (c_i + l_i) x_i \leq B_{max} \quad (3)$$

$$X_j = \{0, 1\} \; \forall i \quad (4)$$

$$I \geq 0 \quad (5)$$

Where:

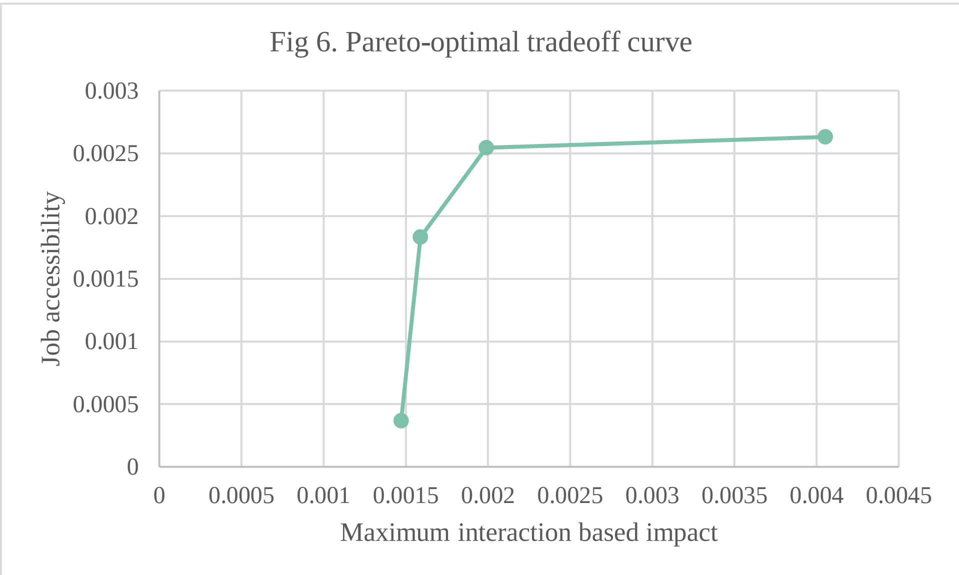
$$x_i = \begin{cases} 1, & \text{if facility is located at potential site } i \\ 0, & \text{otherwise} \end{cases}$$

I	the maximum interaction-based impact between two chosen locations
α	multi-objective weight
A_i	number of jobs accessible by public transit of a worker living at parcel i
n	number of workers each housing unit can accommodate
s_i, s_j	number of housing units in parcel i, j
c_i	construction cost of housing facility in parcel i
l_i	land cost of parcel i
B_{max}	maximum program budget
M	a very large number

The objective accounts for the overall weighted job accessibility of each parcel according to the maximum housed residents. The second formula is designed as maximum interaction-based impact to disperse two selected parcels as much as possible in terms of their distance and volume. It is different to the traditional p-dispersion model, because Zhong found it would shorten the solve time by adjusting the formulas this way (Zhong et al., 2019). The third one controls the maximum number of selected parcels by restricting the budget.

3 Result

We run the model under two different budgets, \$6.7m and \$7.5m. Though \$6.7m seems to be the real budget[2], we analyzed under the assumption of a total construction budget of \$7.5 million because the trade-off curve is clearer. There are four Pareto optimal solutions, as shown in Fig 6.



From left to right, they are called the first to fourth solutions respectively. Detailed information about each solution can be found in the table below. The first solution has the lowest maximum interaction based impact and lowest job accessibility, meaning that it did

[2] https://www.phila.gov/2023-03-02-mayor-proposes-fiscal-year-2024-budget-and-five-year-plan/

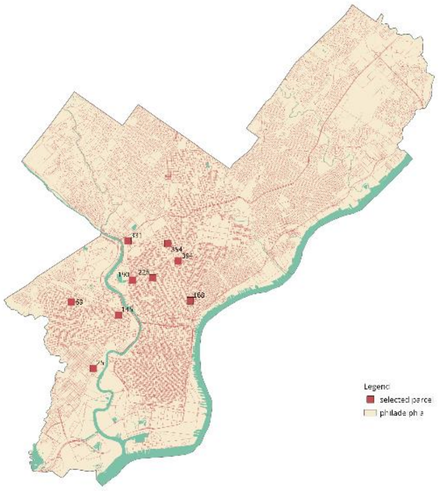
best in terms of social equity, but worst in terms of job accessibility. On the contrary, the last solution has the highest maximum interaction based impact and highest job accessibility.

Solution	Number of selected parcels	Number of new affordable units	Total cost	α
1	9	55	$7,483,800	1E-9
2	9	56	$7,495,400	5E-9
3	9	57	$7,476,400	7E-9
4	7	57	$7,489,200	9E-9

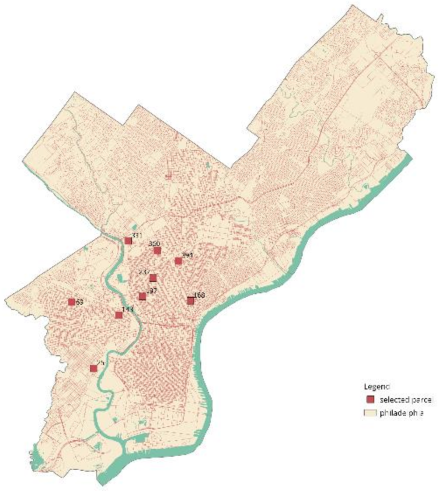
Furthermore, we explored the distance between two selected parcels which is the "worst case". The maximum interaction based impact will go down when it is shorter. The results can be found in the table below, and in Fig 7.

Solution	Parcel A size (units)	Parcel B size (units)	Distance (ft.)	I
1	3	3	6114	0.001472069
2	3	3	5663	0.001589347
3	3	3	4522	0.001990152
4	9	3	6659	0.004054594

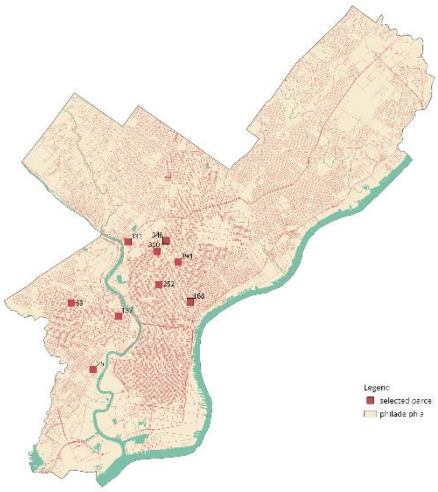
The objective of solving the multi-objective optimization problem is to support decision makers in finding the most preferred Pareto optimal solution according to their subjective preferences. Regarding the Pareto-optimal tradeoff curve as shown in Fig 6., the third solution would be the best choice. Because job accessibility increases vastly compared to the first two solutions, but only sacrifices a small amount of equity. Meanwhile, it does not give up too much equity to increase job accessibility as well compared to the last solution. Moreover, it has the lowest total cost compared to all other solutions.



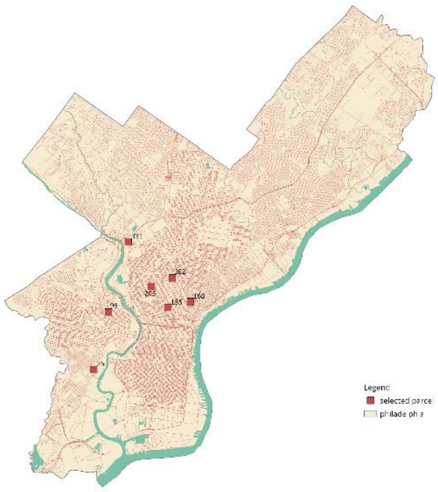
Solution 1



Solution 2



Solution 3



Solution 4

Fig 7. Selected parcels of each solution

Finally, we explored the solutions under different budgets, and chose the optimal solution for each budget. Theoretically, with the growth of budget, the curve will move up because more units can be built so that more jobs can be accessed. The curve will also move to the right because more units will force the worst-case pair closer together.

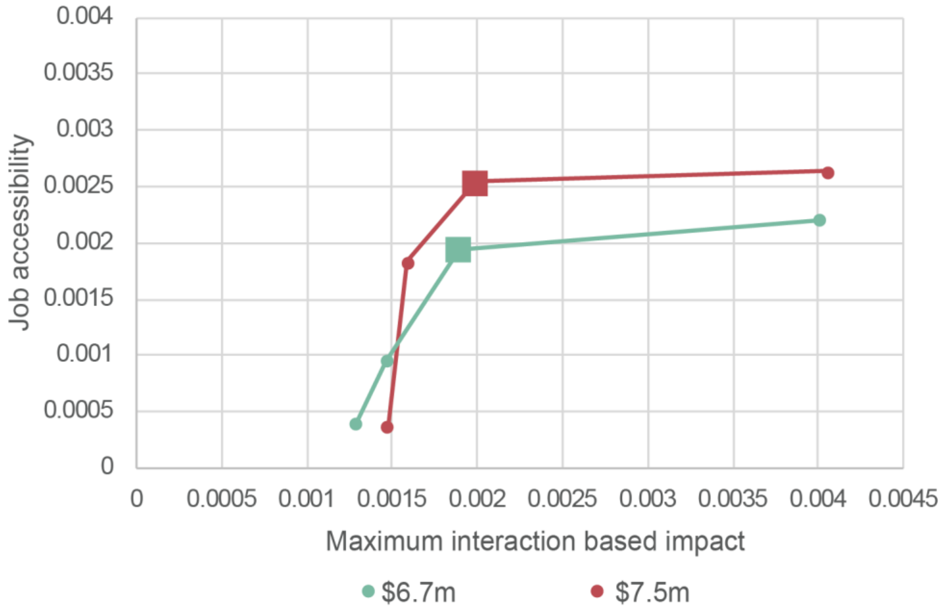


Fig 8. Sensitivity analysis

4 Conclusion

The model we built can maximize job accessibility by public transit while can also increase the social equity by dispersing selected parcels. The data needed for this problem accounts for number of units, cost, and zoning of city-owned vacant parcels, acquisition and construction costs and total budget, travel distance between parcels and jobs, number of accessible jobs, and networks analysis.

We applied the methodology to a case study of the City of Philadelphia, PA. All Pareto-optimal solutions were shown on the tradeoff curve, and selected Pareto-optimal solutions were analyzed and visualized. For future work, more elements can be accounted for to evaluate the overall accessibility by public transit for different groups of people in different needs when choosing their new affordable homes. This may involve accessibility to schools, parks, health services, restaurants, and trying to be away from high crime rate area.

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