Selecting Optimal Sites for New Hydrogen Vehicle Charging Station in Seoul

Team Demian

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1. Introduction

1.1. Background

As of March 2021, South Korea accounted for 33% of the total number of hydrogen cars, ranking first in the world. For the same period, the country recorded second lowest in the hydrogen infrastructure criteria, with its number of cars per hydrogen station being only 180 units. According to the Korea Automobiles Manufactures' Association (KAMA), the deficiency in the infrastructure criteria may hinder the future prospects of the Korean hydrogen car industry.[1]

The Korean government is fully aware of this deficiency, and therefore has developed plans to construct an addition of 310 stations by 2022, 30 of which will be located in Seoul.[2] However, the construction of these stations is followed by various constraints. The building site required for construction is restricted by construction laws and regulations, e.g. the hydrogen station should be located 200m away from school.

What makes it even more difficult for the South Korean government is that the existence of a construction site fulfilling the pre-specified conditions does not necessary mean that the same land is available for use. There are high possibilities that the chosen site is already occupied for other means, further increasing the difficulty of the search. [3] This prevalent issue of land supply shortage has therefore raised the discussion of integrating hydrogen stations with currently existing LPG stations.[4]

1.2. Our goal

Our project then aims to optimize the locations of new hydrogen stations which minimize the mean distance from a random point in Seoul to its closest station, while complying to regulations. However, as previously mentioned, the selection of construction sites further incorporates other restrictions, mostly coming from issues in land supply. Therefore in order to make this problem more feasible, we have decided to simplify it by only considering currently existing LPG stations as options for construction sites.

To achieve this goal, we have formulated a combinatorial optimization problem which optimizes the combination of existing LPG station locations. The optimal solution would then be able to provide the combination of stations that maximizes land coverage, given existing real-life constraints. The optimization process was done through the random sampling algorithm, where possible combinations are randomly picked and used to calculate the optimal value (or a solution that is close enough to optimum).

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1 신건웅, <국내 수소차 보급 세계 1위지만...충전소는 턱없이 부족>, <<뉴스1>>, 2021.04.28., <https://www.news1.kr/articles/?4289048>, 2021.05.16.

2 이종수, <2021년, 수소충전소 구축 가속화 분수령>, <<월간수소경제>>, 2020.12.30., <https://www.h2news.kr/mobile/article.html?no=8689₩>, 2021.05.16.

3 신석주, <수소충전소 구축 '흐림'... 속도 전환 필요하다>, <<에너지신문>>, 2020.05.20., <https://www.energy-news.co.kr/news/articleView.html?idxno=70512>, 2021.05.16.

4 신석주, <수도권 내 LPG충전소에서 '수소' 충전한다>, <<에너지신문>>, 2021.03.23., <https://www.energy-news.co.kr/news/articleView.html?idxno=75794>, 2021.05.16.

2. Experiments

2.1. Objective Function

The objective function formulated indicates the mean distance from pre-defined random spots to their closest hydrogen station. Both random spots and hydrogen stations are restricted to locations in Seoul.

$$\mathrm{MeanDistance}(\mathrm{N}, \mathrm{B}_1, \dots, B_{N_L}) = \frac{1}{N_s}\sum_{s \in S} positivemin(h(s, H_1), \dots, h(s, H_{N_H}), B_1 \cdot h(s, L_1), \dots, B_{N_L} \cdot h(s, L_{N_L}))$$

In this formula we have two decision variables.

- N: Number of hydrogen station to construct. (default =30)
- B_i: A binary variable that indicates whether we should construct a station at the location of a certain existing LPG station (L_i) or not.

For the parameters and functions inside our formula we have the following elements:

- H_i: Location (in x, y coordinates) of existing hydrogen stations. $H_i = (x_i,\ y_i), 1 \le\ i \le N_H$
- $H = \{H_1, \dots, H_{N_H}\}$
- N_H: Number of existing hydrogen stations (=4)
- L_i: Location (in x, y coordinates) of existing LPG stations. $L_i = (x_i,\ y_i), 1 \le\ i \le N_L$
- $L = \{L_1, \dots, L_{N_L}\}$
- N_L: Number of existing LPG stations (=78)
- S: set of location of random spots (in x, y coordinates) distributed proportionally to the number of registered cars of each district. The spots are selected in advanced of solving the problem.
- N_s: number of random spots in S (=5000)
- $h(\cdot)$: haversine distance between two points on Earth[5]
- $positivemin(\cdot)$: find positive values from list of values, and then find the smallest one.

2.2. Constraints

Before looking at the optimization process it is important to understand the constraints of our problem. The main constraints to be discussed can be divided into the budget constraint and the various regulatory constraints. However, information on the government budget allocated to constructing new hydrogen stations was not available, and therefore we have decided to construct exactly 30 stations (if possible), the same number set as the government goal of 2022.

As for the regulatory constraints, we cherrypicked only three relevant regulations because considering all of them would be too challenging.

- **[1] Regulations on Standards for Housing Construction**: Hydrogen stations should be located at least 50m away from apartment houses, medical facility, and facilities for elderly or children.
- **[2] The Cultural Properties Protection Law:** Hydrogen stations should be located at least 500m away from Cultural Assets.
- **[3] Act on the Protection of the Educational Environment:** Hydrogen stations should not be located in

[5] The **haversine formula** determines the great-circle distance between two points on a sphere given their longitudes and latitudes.

purification zones.

- Absolute purification zone: 50 meters from the school entrance (straight line)
- Relative purification zone: 200 meters from the school boundary (straight line)

Note: For simplicity, we only considered the relative purification zone; hydrogen stations must be at least 200 meters away from any existing school

For brevity of explanation, we will refer those three constraints as [1] House, [2] Culture, and [3] School.

The final constraints to be considered are the binary and nonnegativity constraints, where B_i should be binary and N should be a nonnegative integer.

The data needed to formulate the listed constraints were obtained from various open-data resources. The data sources are noted on Appendix 1).

2.3. Problem Solving Process

The first step to approaching this problem was to eliminate LPG stations that violated at least one of the given constraints. This then provided us with the remaining LPG stations, which we will note as $\mathrm{n_{valid}}$, which perfectly fulfilled our pre-specified conditions. The next focus was then on the government target number of 30 stations. If the number of $\mathrm{n_{valid}}$ is smaller than 30, the optimized combination of LPG stations would be the remaining LPG stations. If the number is greater than 30, another optimization problem selecting the 30 best LPG stations $\binom{\mathrm{n_{valid}}}{30}$ combinations should be formulated. However, the latter optimization problem is non-linear and belongs to the combinatorial optimization problem, and therefore is NP-hard and cannot be solved with polynomial time. Thus, we have decided to adopt the random brute-force algorithm.

A brute-force approach is any algorithm that tries possible solutions one after the other until it finds one that is acceptable or until a pre-set maximum number of attempts. Our brute-force optimization algorithm would thus simply evaluate value after value for a given time and return the value with the optimal result as its solution at the end. Finally, a random brute-force search is one that selects the values to evaluate randomly, mainly due to lack of computational resources.[6]

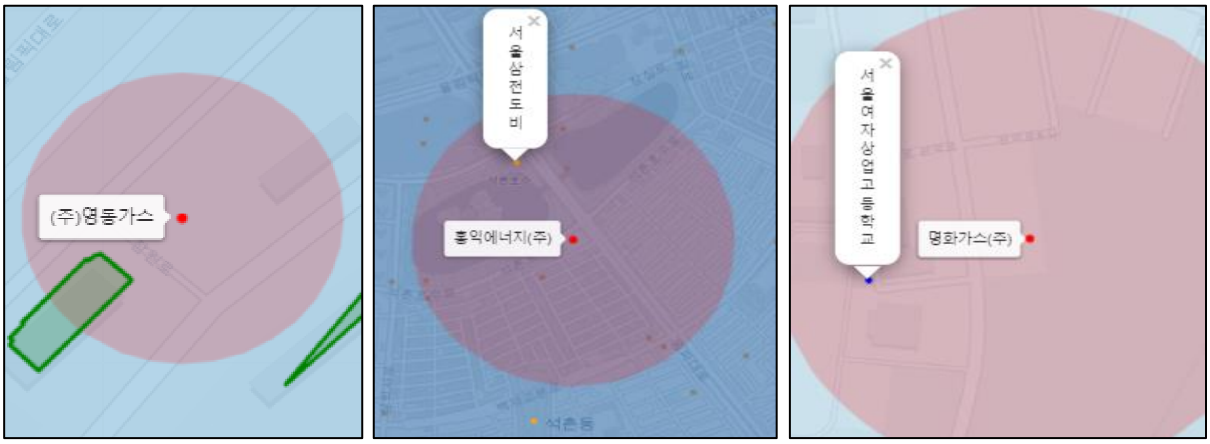
2.4. Analysis with De-regulation

We also conducted some additional analysis, ignoring some or all of the constraints, and compared the results with the fully constrained one. Results are described at Appendix 5 due to lack of space.

[6] Random Brute-force Search, <https://ece.uwaterloo.ca/~dwharder/NumericalAnalysis/11Optimization/randombrute/>

3. Results

3.1. Base-case Results



[1] House (50m) [2] Culture (500m) [3] School (200m)

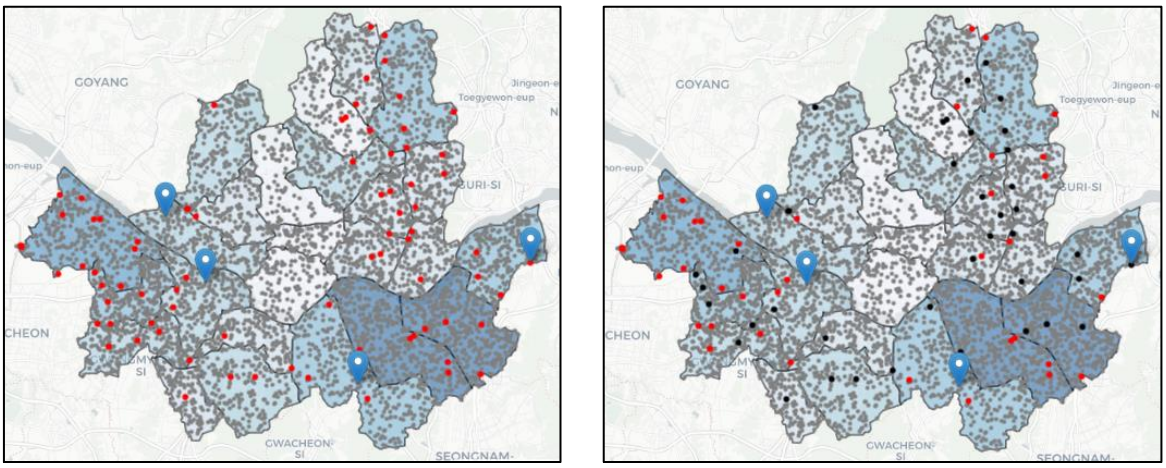
Figure 1. These are examples of eliminated LPG stations for each constraint. In [1], the LPG station (㈜영동가스) is eliminated because there exists a apartment house (or medical facility or facilities for elderly or children) within 50m radius from it. [2] and [3] are also conducted in the same manner.

The number of LPG stations eliminated by each constraint and number of remaining stations are as follows:

Constraints	# Eliminated LPG stations	# Remaining LPG stations
[1] (House)	31	47
[2] (Cultural Properties)	6	72
[3] (School)	11	67
[1] and [2]	34	44
[1] and [3]	38	40
[2] and [3]	16	62
[1] and [2] and [3]	**40**	**38**

Table 1. The more stations remaining, the more options available, and thus smaller the objective function value

As expected, the [1] House constraint causes highest elimination, as there are uncountably many apartments, medical facilities and elderly or children facilities in Seoul. On the other hand, the [2] Cultural Properties constraint has a relatively small effect, as cultural assets in South Korea are relatively sparse, with most of them crowded around the Jongno District. (Appendix 2)



(a) (b)

Figure 2. (a) All LPG stations in Seoul (red dots) (b) Remaining LPG (red dots) and Eliminated (black dots) by

all the three constraints. The blue markers are currently existing hydrogen stations, and the small gray dots are pre-defined random spots distributed to all the districts in Seoul, proportionally to the population of each district.

Optimal Solution

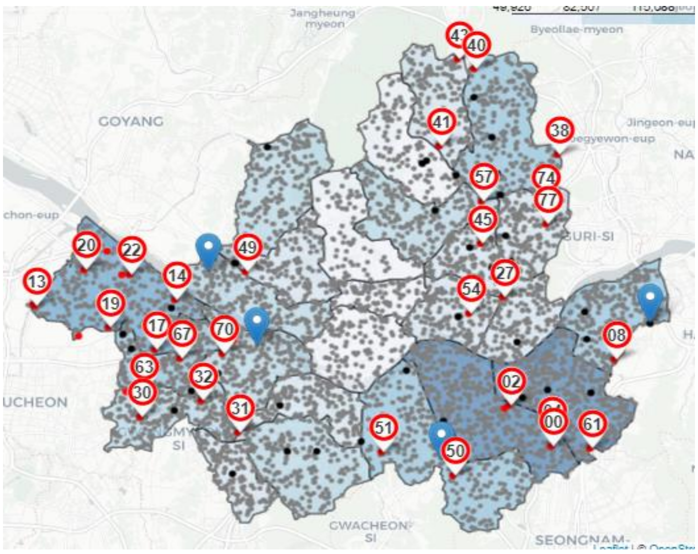


Figure 3. Green marker with exclamation is optimal LPG stations

Through the random brute-force algorithm, we were able to successfully find the optimal 30 LPG stations from the 38 that met all the given three requirements. The total number of combinations calculated equaled $\binom{38}{30} = 48,903,492$. From this number, we randomly selected 5,000,000 combinations and calculated the mean distance for each combination. We therefore were able to find the combination of LPG stations that minimized the mean distance. Although this does not guarantee the global optimum, we believed it was a fairly good approximation.

The optimal solution is described at the figure above. On the left extreme of the map, we are able to see the points that are not selected. The objective function value with this solution is 2409.93m, which means that in average a hydrogen car owner should travel about 2.4km to charge his/her car.

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4. Conclusion and Future Work

4.1. Conclusion

Our objective function was therefore able to identify the combination of 30 LPG stations that minimized the mean distance of a random point in Seoul to its nearest LPG station. The selection of the 30 LPG stations considered all regulatory constraints. Through the objective function we were able to come up with the optimal solution, which stated that the average distance of the optimal combination was 2.4 km.

However, as the findings and the formulation of the objective function were based under an unrealistic assumption that new hydrogen charging stations would only be built beside existing LPG stations, there exist difficulties in stating that our optimized results are directly applicable to real-life decision making situations. Furthermore, in our present state we are able to witness special cases of stations being built in locations that violate regulations, cases approved by regulatory sandbox. Again this implies that the optimization problem defined, as well as its solution, may not be immediately applicable to our real life circumstances. In order to consider such unexpected problems and alterations of the specified model due to reality, we would need a more thorough analysis, which would require information regarding the availability of land for construction.

4.2. Future Work

- Use a more sophisticated solving algorithm (e.g. genetic algorithm, reinforcement learning) other than random brute-force algorithm to obtain the optimal combination from the available options.

- Consider other constraints such as user's utility function regarding the distance to the stations, the price of land lease, or places other than LPG stations (such as petrol stations), etc.

Appendix 1) Data Sources and Github repository

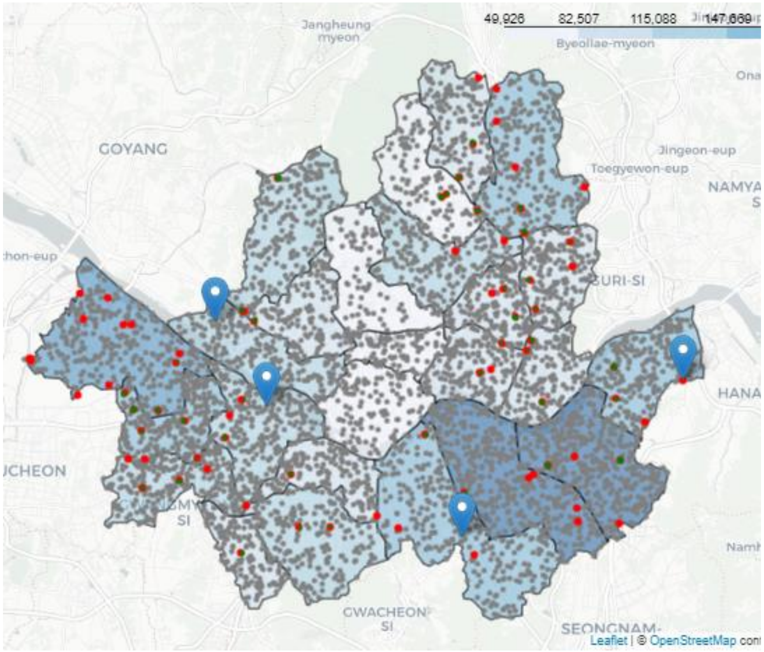
LPG stations: https://www.data.go.kr/data/15001643/fileData.do
Constraint [1] (House): https://www.data.go.kr/data/15057464/openapi.do
Constraint [2] (Culture):
https://www.cha.go.kr/html/HtmlPage.do?pg=/publicinfo/pbinfo3_0202.jsp&mn=NS_04_04_02
Constraint [3] (School): http://data.seoul.go.kr/dataList/OA-20502/S/1/datasetView.do

Codes and results are available at Github repository:
https://github.com/Sanghyeok-Choi/Management-Science-Team-Project

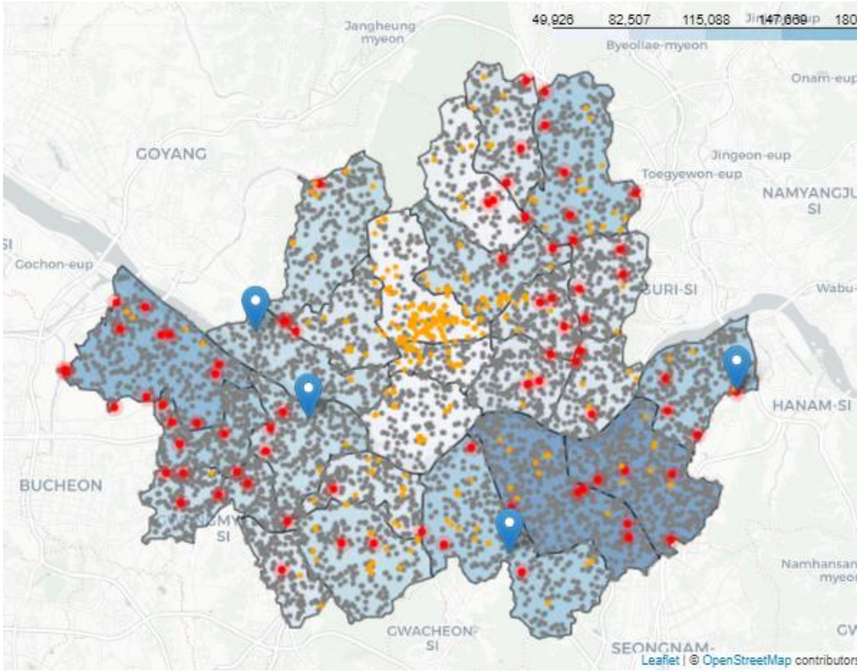
Appendix 2) Map on which points of each constraints are drawn

- Map with apartment houses, medical facilities, and facilities for elderly or children drawn (green polygon)

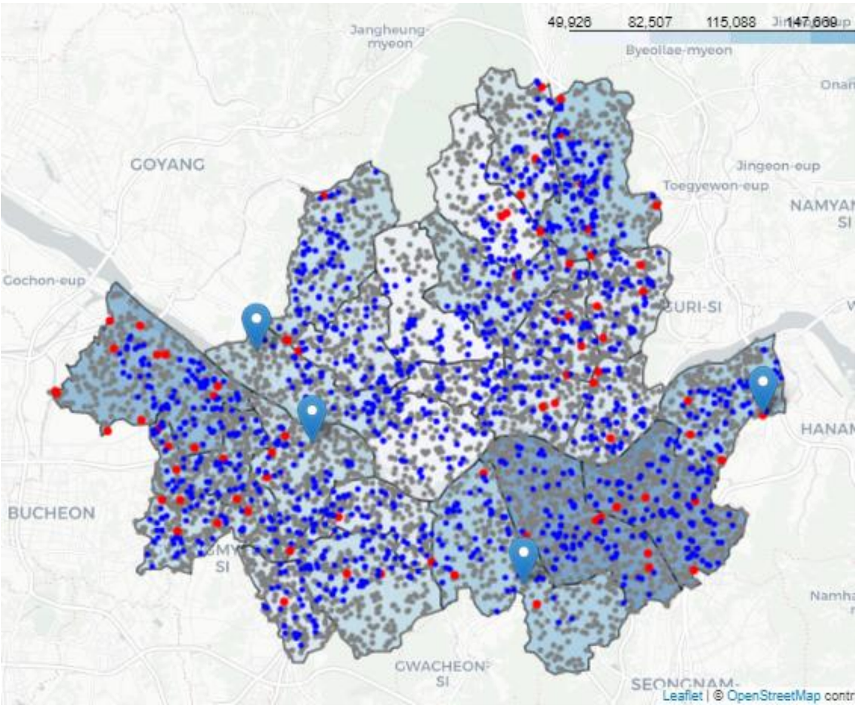
Note: As there are too many apartment houses and the facilities, we drew only those that are close enough (<=75m) to the LPG stations.



- Map with cultural assets drawn (orange dots, N = 922)



- Map with schools drawn (blue dots, N = 1414)



Appendix 3) Data for the optimum LPG stations.

The row index matches to each point on the map at Figure3.

	행정 구역	업소명	소재지	전화번호	관리구분	coords
0	서울 강남구	강남복지충전소	서울 강남구 자곡동 373-1 (1층)	02-445-3300	자동차충전	[37.4763744810253, 127.105459882197]
2	서울 강남구	대치에너지주식회사	서울 강남구 대치동 27-15	02-3412-2828	자동차충전	[37.4993371909186, 127.078104086886]
4	서울 강남구	(주)수서에너지	서울 강남구 자곡동 204-1	02-445-1083	자동차충전	[37.4828535323026, 127.105060577053]
8	서울 강동구	복지둔촌충전소	서울 강동구 둔촌동 115-1	02-488-4892	자동차충전	[37.5251370600419, 127.146533353423]
13	서울 강서구	강서가스충전소	서울 강서구 오곡동 593-2	02-682-9100	자동차충전	[37.5549368206352, 126.768987283185]
14	서울 강서구	대양가스충전소	서울 강서구 가양동 449-13	02-2668-5151	자동차충전	[37.5584437800742, 126.860708617203]
17	서울 강서구	대흥에너지산업(주)	서울 강서구 화곡동 898-3	02-2602-2448	자동차충전	[37.5301629369371, 126.847319107047]
19	서울 강서구	활주로충전소	서울 강서구 외발산동 384-2	02-676-8289	자동차충전	[37.542884007, 126.817080254]
20	서울 강서구	복지개화충전소	서울 강서구 개화동 509-4	02-2661-5151	자동차충전	[37.5752378697374, 126.801564748736]
22	서울 강서구	대영가스 충전소	서울 강서구 마곡동 761-2	02-2659-9520	자동차충전	[37.572254696, 126.830979503]
27	서울 광진구	중곡동충전소	서울 광진구 중곡동 611-7	02-467-4708	자동차충전	[37.5600856712017, 127.073725000557]
30	서울 구로구	대성산업(주)오류동충전소	서울 구로구 오류동 74-8	02-2612-0039	용기+자동차+13kg용기	[37.492740694809, 126.837953228246]
31	서울 구로구	동일석유(주)남부충전소	서울 구로구 구로3동 1123-2	02-830-0341	자동차충전	[37.48437303, 126.901962308]
32	서울 구로구	한일가스산업(주)	서울 구로구 구로동 600-6	02-2675-2614	자동차충전	[37.5018769163267, 126.877745152543]
38	서울 노원구	복지공릉충전소	서울 노원구 공릉동 26-69	02-3296-2903	자동차충전	[37.6389995094706, 127.109726783097]
40	서울 노원구	복지노원충전소	서울 노원구 상계동 1205-4	02-934-9077	자동차충전	[37.6872079261507, 127.05584077201]
41	서울 도봉구	동원가스충전소	서울 도봉구 창2동 643-2	02-902-1231	자동차충전	[37.644224122, 127.032635317]
43	서울 도봉구	(주)평안에너지 도봉충전소	서울 도봉구 도봉동 376	02-3494-5185	자동차충전	[37.6922489127105, 127.0444223666 1]
45	서울 동대문구	수도에너지(주)동서울충전소	서울 동대문구 휘경동 267-10	02-2244-6666	자동차충전	[37.5895873776523, 127.059448773846]
49	서울 서대문구	연일가스산업(주)	서울 서대문구 북가좌1동 392-27	02-3075-4114	자동차충전	[37.573825306, 126.906180273]
50	서울 서초구	(주)에이치앤디이-서울만남의광장	서울 서초구 원지동 10-16	02-573-7430	자동차충전	[37.4600883955452, 127.04208399514]
51	서울 서초구	서초충전소	서울 서초구 방배동 623-5	02-582-3636	자동차충전	[37.4731812157774, 126.995358181084]
54	서울 성동구	대성산업(주)동부충전소	서울 성동구 성수동2가 284-108	02-463-2202	자동차충전	[37.5505097815363, 127.052311969358]
57	서울 성북구	(주)장위가스	서울 성북구 장위3동 44-3	02-916-3233	자동차충전	[37.613271084, 127.060639378]
61	서울 송파구	MG새마을금고 송파충전소	서울 송파구 장지동 544-3	02-449-9123	자동차충전	[37.4755252508197, 127.131224015304]
63	서울 양천구	수도에너지(주)	서울 양천구 신정동 813-17	02-2060-7160	자동차충전	[37.5070385045915, 126.839080498525]
67	서울 양천구	목동충전소	서울 양천구 신정4동 994-4	02-2604-6141	자동차충전	[37.5256128672784, 126.864088616097]
70	서울 영등포구	양평동충전소	서울 영등포구 양평동3가 59	02-2672-1175	자동차충전	[37.5280394242985, 126.891167327773]
74	서울 중랑구	신내LPG충전소	서울 중랑구 신내동 317-8	02-2208-5151	자동차충전	[37.6127507837583, 127.100760717061]
77	서울 중랑구	망우충전소	서울 중랑구 망우동 340-16	02-432-5400	자동차충전	[37.6005788748545, 127.101918499648]

Appendix 4) De-regulation Results

To test the effectiveness of the algorithm and observe the effects of the constraints on the objective function value, we applied the same algorithm to additional experiments which ignored some or all of the constraints.

Constraints	# Remaining	# Selected	Obj. Function Value (m)
[1], [2], and [3]	**38**	30	2409.93
[1] and [3]	40	30	2386.62
[1] and [2]	44	30	2338.68
[2] and [3]	62	30	2213.96
No constraints	78	30	1994.86

Table 2. Th higher the number of remaining LPG stations, the lower the objective function value. This shows that the optimization algorithm works well to find a solution that is robust and close enough to global optimum. Furthermore, as we mentioned above, the [1] House constraint has the greatest effect to the objective function value. Without any constraints, in average, the hydrogen station should be located less than 2km away.