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Optimizing Electric Vehicle Charging Infrastructure: A Location-Based Analysis

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Abstract
Ecosystem changes driven by global warming have intensified efforts to reduce greenhouse gas emissions worldwide. As a result, the demand for environmentally friendly electric vehicles (EVs) is rising due to shifting domestic and international conditions, stricter environmental regulations, and increasing energy cost efficiency. Additionally, government policies are further driving market demand for EVs and other sustainable transportation solutions.
However, despite this growing demand, challenges persist—particularly the high cost of establishing essential infrastructure, such as EV charging stations. To address this issue, this study aims to determine the optimal charging capacity required to meet EV demand in the selected analysis area. The study evaluates the impact of charging facility distribution, to assess different placement scenarios.
The primary objective of this study is to identify the most efficient locations for EV charging infrastructure by considering factors such as travel cost and travel time across different models. By optimizing the placement of charging stations, this study seeks to enhance accessibility, improve efficiency, and support the broader adoption of electric vehicles.
Keywords: *Electric vehicles, Charging stations, Greenhouse gases.*

1. INTRODUCTION

The ecological system has been profoundly affected by global warming, driving global efforts to reduce greenhouse gas emissions. The Greenhouse Gases and Energy Goal Management System plays a crucial role in managing energy consumption and emissions by setting targeted reductions across various sectors.

To alleviate the immediate economic impact on industries, the government has prioritized greenhouse gas reduction initiatives in non-industrial sectors, with a focus on buildings and transportation. Additionally, there is a growing need to promote eco-friendly, low-emission transportation alternatives to support sustainable development.

On a global scale, countries have introduced stringent vehicle emission regulations to curb pollution. Automakers exceeding the prescribed emission limits face financial penalties, further accelerating the transition toward energy-efficient and sustainable transportation solutions.

With evolving domestic and international policies, along with rising environmental regulations and energy cost concerns, there is increasing demand for electric vehicles (EVs). To support low-carbon green growth, research initiatives worldwide are focusing on the development and commercialization of next-generation EVs, including advancements in instant charging technology. According to Bloomberg, EVs are projected to account for 3% of global annual automobile sales by 2020 and 11% by 2025, surpassing 10% for the first time in history.

To meet the growing demand for EVs, a well-planned charging infrastructure is essential to address user concerns and enhance convenience. However, the high installation costs of charging stations and the financial burden of equipping every gas station with chargers present significant challenges. Therefore, selecting the optimal locations and capacities for EV chargers with minimal investment costs is critical.

This study aims to determine the optimal charging capacity to meet EV demand in the target analysis area. By applying Location Theory models and utilizing TransCAD for spatial analysis, the study evaluates different charging infrastructure placement strategies. The goal is to identify optimal charging station locations based on factors such as travel costs and travel time, ensuring efficient, cost-effective deployment of EV charging networks.

2. LITERTURE REVIEW

The growing adoption of electric vehicles (EVs) has been driven by increasing environmental concerns, stricter government regulations, and advancements in battery and charging technologies. However, a critical barrier to widespread EV adoption remains the availability and accessibility of charging infrastructure. Studies indicate that insufficient charging stations discourage potential EV users and slow down market penetration (She et al., 2017). To address this, governments worldwide have introduced policies, including emission reduction targets, subsidies for EV adoption, and mandatory charging infrastructure requirements (OECD, 2018; European Commission, 2019). Furthermore, the financial feasibility of charging station deployment is a significant challenge due to high installation costs. Research highlights the need for public-private partnerships and optimal pricing models to make charging networks financially sustainable (Li et al., 2019). According to Bloomberg NEF (2020), EV sales are expected to surpass 10% of global automobile sales by 2025, reinforcing the urgent need for efficient and strategically placed charging infrastructure.

The location and spatial distribution of charging stations play a key role in ensuring accessibility and convenience for EV users. Several studies employ Location Theory models to optimize charging station placement. The P-Median Model minimizes the average travel distance for users (Hakimi, 1964), while Covering Models ensure adequate charging station coverage within a specific radius (Church & ReVelle, 1974). Additionally, flow-based models consider high-traffic areas to prioritize charging station placement along major travel routes (Kuby & Lim, 2005). These approaches have been widely applied in urban planning and transportation networks to enhance EV adoption. In addition, Geographic Information Systems (GIS) and spatial analysis tools such as TransCAD and ArcGIS are increasingly used to assess travel demand, vehicle movement patterns, and accessibility gaps in charging station distribution (Sathaye & Kelley, 2013; Zhang et al., 2021). These GIS-based models integrate real-world traffic patterns, ensuring data-driven decision-making in EV infrastructure planning (He et al., 2020).

Another significant aspect of EV charging infrastructure planning is cost minimization and investment strategies. Due to the high capital investment required, researchers have explored optimization techniques such as Mixed Integer Linear Programming (MILP) and Genetic Algorithms (GA) to reduce installation costs while maintaining optimal service coverage (Schneider et al., 2014). Furthermore, the adoption of dynamic pricing strategies for charging stations can improve financial sustainability and encourage off-peak charging, reducing pressure on the electrical grid (Sun et al., 2020). Studies also compare battery-swapping stations and fast-charging networks, highlighting their trade-offs in terms of user convenience, cost, and energy efficiency (Wang et al., 2018).

Seunghyun Kim, Jooyoung Kim and Seungjae Lee (2018) developed models for Optimal Site Selection of Electric Vehicle Charging Facilities through location theory.

With advancements in smart grid technology, the future of EV charging infrastructure is shifting toward grid integration and renewable energy sources. Researchers emphasize the importance of Vehicle-to-Grid (V2G) technology, where EVs can serve as energy storage units to balance grid demand (Liu et al., 2019). Additionally, solar-powered EV charging stations are being explored to enhance sustainability and reduce dependency on fossil-fuel-based electricity (Zhao et al., 2021). The incorporation of AI-driven demand forecasting models has also gained traction, allowing operators to predict charging demand trends and optimize station locations dynamically (Zhang et al., 2022).

3. SELECTION OF OPTIMAL LOCATION FOR A SERVICE FACILITY

When the charging service is provided by restrictive number of facilities in a certain area, it considers maximum distance(λ) between each demand and a facility, and decides the optimal location of the facility so that the maximum number of demand points can use the facility. Algorithm of Maximum Covering Location Problem is discussed below.

3.1 Model without Priority

Step-1: Load charging station data.

1. Read candidate station locations from the Excel file.
2. Store locations as a dictionary:
   Locations = {i : (latitude$_i$, longitud$_i$)}
3. Compute the distance matrix using the geodesic distance formula.

Step-2: Compute coverage matrix.

4. Define binary coverage matrix N_{ij} where:
   N_{ij} = 1 if distanced (i, j) ≤ λ_{max}, 0 otherwise

Step-3: Define decision variables

5. Define binary decision variables:
   - x_i = 1 if a station is selected at location i, else 0.
   - x_j = 1 if demand location j is covered, else 0.
   - y_{ij} = 1 if demand location j is assigned to station i, else 0.
6. Define integer and continuous decision variables:
   - s_i: Number of chargers at station i.
   - μ_i: Service rate at station i.
   - P: Total selected stations.
   - Service capacity service_capacity$_i$.

Step-4: Define constraints.

7. Demand coverage constraint: Each demand location is covered if at least one station is within range:
   $$\sum_i N_{ij} x_i \geq z_j, \qquad \forall j$$
8. Demand assignment constraint: Each demand location must be assigned to only selected station:
   $$\sum_i y_{ij} = z_j, \qquad \forall j$$
9. Valid assistant constraint: Demand can only be assigned to open stations:
   $y_{ij} \leq x_i$, $\forall i, j$
10. Station selection constraint: The number of selected charging stations must be within limits:
    $$10 \leq \sum_i x_i \leq 20$$
11. Service capacity constraints:
    service_capacity$_i \leq s_i \times \mu_{max}$
    service_capacity$_i \leq \mu_i \times s_{max}$
    service_capacity$_i \geq s_i + \mu_i - (1 - x_i)M$
12. System stability constraint: Ensure total service capacity meets demand:
    $$\sum_i \text{service\_capacity}_i \geq \lambda$$

Step-5: Define the objective function.

13. Maximize total covered demand:
    $$\max \sum_j z_i$$

Step-6: Solve the optimization model.

14. Solve the linear programming problem by considering the following inputs.
    Inputs:
    Charging station candidate location: Latitude and longitudes.
    Maximum coverage distance (λ_{max})
    Charging system parameters
    - Arrival rate

- Service rate
- Chargers/Sation
- Total Stations to be selected

As for the geographical scope for effect analysis resulted from optimal capacity and selection of optimal location, this study selected that currently has EV chargers. Candidate locations were selected from existing gas stations which installed EV chargers were selected for installation among chargers. This study aims to determine the capacity meeting the demands for EV charging stations and select their optimal location. For the purpose, it built a model for optimal capacity and selection of location. To determine the capacity of a charging station, M/M/s model was used. Under the hypothesis that all charging stations have same capacity, this study applied Maximum Covering Problem and compared them one another for the selection of optimal location.

The subjects of this study were quick chargers and existing gas stations were selected as candidate locations according to the plan to build EV charging infrastructure. Among the candidate gas stations, the selected gas stations were regarded as supply locations and the remaining candidates were regarded as demand locations. Gas stations having sufficient area for quick chargers were selected as candidate locations. This study set given gas stations as candidate locations that satisfied the condition of a certain area. The free speed was set as 50 kph for municipal roads, in consideration of speed limit on the roads. Maximum allowable coverage distance (in km) is 10. Average speed in km/h as 40.

To apply M/M/s model for calculating optimal capacity, number of arrived cars per hour should be calculated. Since EVs have not been specifically commercialized yet, it is hard to get time series data and sensitivity analysis. Number of arrived cars per hour was assumed different values.

3.2 Calculating Optimal Capacity (M/M/s applied)

15. Compute queueing metrics using M/M/s queueing model:
    - Utilization rate (ρ):

$$\rho = \frac{\lambda}{s \times \mu}$$

    - Probability of zero cars in system (P_0):

$$P_0 = \left(\sum_{k=0}^{s-1} \frac{(\lambda / \mu)^k}{k!} + \frac{(\lambda / \mu)^s}{s!(1-\rho)} \right)^{-1}$$

    - Expected customers in queue (L_q):

$$L_q = \frac{(\rho(\lambda / \mu)^s) P_0}{s!(1-\rho)^2}$$

    - Total customers in system (L):

$$L = L_q + \frac{\lambda}{\mu}$$

    - Average waiting time in queue (W_q)

$$W_q = \frac{L_q}{\lambda}$$

    - Total time in system (W):

$$W = W_q + \frac{1}{\mu}$$

3.3 Model with Priority

Objective function:

Maximize total priority-weighted coverage:

$$\max \sum_{j \in I} w_j \cdot z_j$$

4. RESULTS AND DISCUSSION

4.1 Parameters

arival_rate = 20 # Number of arrived cars per hour (lambda)
service_rate_min = 2 # Minimum service rate (cars per hour per charger)
service_rate_max = 5 # Maximum service rate (fast charging)
servers_min = 1 # Minimum number of charging ports per station
servers_max = 10 # Maximum number of charging ports per station
stations_min = 10 # Minimum number of charging stations
stations_max = 20 # Maximum number of charging stations

4.2 Data on Petrol Statin's Location

Table-1: Data on petrol statin's location

Station ID	Latitude	Longitude	Station ID	Latitude	Longitude
0	17.70074	83.171	50	17.63795	83.2405 7
1	17.6643	83.19082	51	17.70497	83.2222
2	17.71045	83.23617	52	17.66348	83.2326
3	17.72602	83.17719	53	17.64796	83.21198
4	17.67899	83.17148	54	17.68217	83.26388
5	17.65866	83.21904	55	17.72439	83.19484
6	17.63945	83.18838	56	17.68686	83.18637
7	17.70179	83.22299	57	17.72806	83.25555
8	17.65884	83.2 2 743	58	17.66664	83.23239
9	17.71774	83.16915	59	17.6977	83.18378
10	17.71738	83.23831	60	17.71305	83.22244
11	17.67083	83.18405	61	17.71466	83.22154
12	17.73252	83.20216	62	17.63686	83.2009 2
13	17.64607	83.17817	63	17.63875	83.26141
14	17.72155	83.2 2 887	64	17.72467	83.25167
15	17.71751	83.24147	65	17.66755	83.17429
16	17.69042	83.26581	66	17.7246	83.26319
17	17.67465	83.2237	67	17.64537	83.2171
18	17.71974	83.2 303 5	68	17.64372	83.2445 6
19	17.72297	83.2 2 62 4	69	17.71338	83.18134
20	17.70726	83.17308	70	17.68433	83.22348
21	17.65959	83.19744	71	17.66331	83.25574
22	17.64478	83.19178	72	17.67911	83.18968
23	17.6469	83.1963	73	17.69073	83.24149
24	17.70037	83.20498	74	17.65692	83.19967
25	17.67382	83.18945	75	17.73631	83.23349
26	17.6635	83.26217	76	17.68061	83.2 202 6
27	17.7016	83.22941	77	17.6489	83.19097
28	17.65391	83.24141	78	17.67061	83.22733
29	17.65314	83.20645	79	17.65981	83.19052
30	17.73575	83.2325	80	17.6439	83.23161
31	17.69249	83.23696	81	17.65969	83.25904
32	17.72109	83.2461	82	17.72276	83.17559
33	17.6597	83.17171	83	17.6606	83.2354
34	17.66835	83.19527	84	17.65822	83.18173
35	17.6579	83.2 6279	85	17.73035	83.2256
36	17.72444	83.19997	86	17.68407	83.24696
37	17.70234	83.20806	87	17.71755	83.18754

Station ID	Latitude	Longitude	Station ID	Latitude	Longitude
38	17.72825	83.21439	88	17.64649	83.21161
39	17.66329	83.19316	89	17.67916	83.2152
40	17.69294	83.19477	90	17.70971	83.23584
41	17.69526	83.25828	91	17.73522	83.17834
42	17.67674	83.19043	92	17.67706	83.20243
43	17.73655	83.21945	93	17.72297	83.19337
44	17.64589	83.17321	94	17.65582	83.21336
45	17.64776	83.23124	95	17.67899	83.19635
46	17.71601	83.21072	96	17.66178	83.2 6083
47	17.64315	83.20666	97	17.68111	83.25463
48	17.73641	83.22141	98	17.69183	83.17356
49	17.73391	83.2 545 8	99	17.73673	83.2521

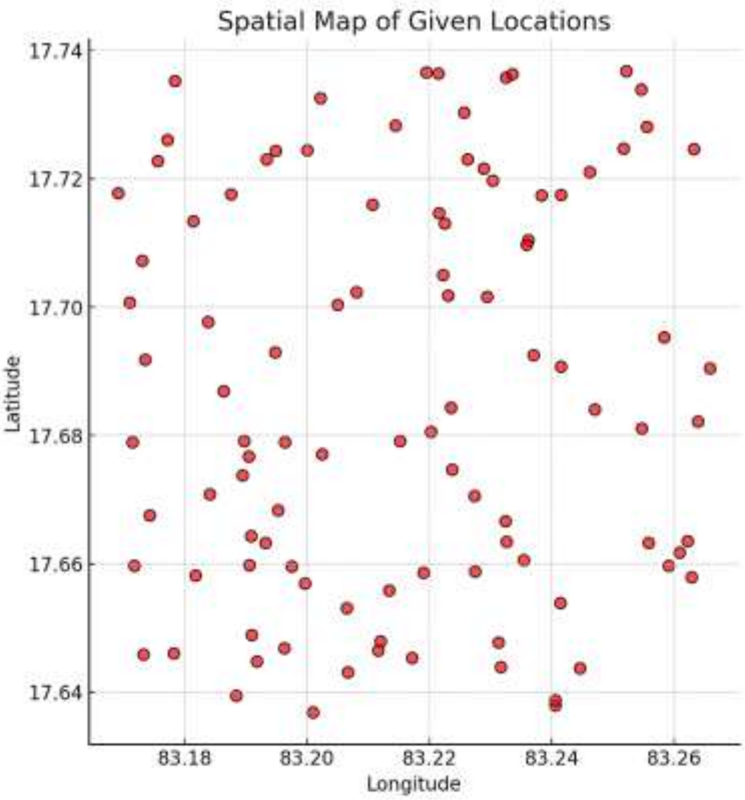

Fig. 1: Location map of the petrol stations

4.3 Assignment of Demand Location to Supply location (without Priority):

Assignment of Demand Location to supply Location model as discussed in section 3.1 is implemented to determine optimum assignment of demand location to supply location. The following table represent geographical locations of Petrol stations randomly generated between given latitude and longitude. Demand supply mapping is shown in Fig.2

Table-2: Assignment of Demand Location to supply Location

Demand Location	Demand Latitude	Demand Longitude	Supply Location	Supply Latitude	Supply Longitude	Demand Location	Demand Latitude	Demand Longitude	Supply Location	Supply Latitude	Supply Longitude
1	17.664303	83.19082	0	17.701	83.171	81	17.65969	83.25904	0	17.70074	83.171
2	17.710447	83.23617	0	17.701	83.171	83	17.6606	83.2354	0	17.70074	83.171
4	17.678992	83.17148	0	17.701	83.171	88	17.64649	83.21161	0	17.70074	83.171

Demand Location	Demand Latitude	Demand Longitude	Supply Location	Supply Latitude	Supply Longitude	Demand Location	Demand Latitude	Demand Longitude	Supply Location	Supply Latitude	Supply Longitude
7	17.701788	83.22299	0	17.701	83.171	89	17.67916	83.2152	0	17.70074	83.171
9	17.717743	83.16915	0	17.701	83.171	91	17.73522	83.17834	0	17.70074	83.171
10	17.717382	83.23831	0	17.701	83.171	92	17.67706	83.20243	0	17.70074	83.171
12	17.732521	83.20216	0	17.701	83.171	93	17.72297	83.19337	0	17.70074	83.171
13	17.646075	83.17817	0	17.701	83.171	94	17.65582	83.21336	0	17.70074	83.171
14	17.721549	83.22887	0	17.701	83.171	95	17.67899	83.19635	0	17.70074	83.171
15	17.717513	83.24147	0	17.701	83.171	96	17.66178	83.26083	0	17.70074	83.171
17	17.674653	83.2237	0	17.701	83.171	97	17.68111	83.25463	0	17.70074	83.171
18	17.71974	83.23035	0	17.701	83.171	98	17.69183	83.17356	0	17.70074	83.171
19	17.722971	83.22624	0	17.701	83.171	64	17.72467	83.25167	5	17.65866	83.21904
20	17.707257	83.17308	0	17.701	83.171	69	17.71338	83.18134	5	17.65866	83.21904
21	17.65959	83.19744	0	17.701	83.171	73	17.69073	83.24149	5	17.65866	83.21904
22	17.644779	83.19178	0	17.701	83.171	86	17.68407	83.24696	5	17.65866	83.21904
23	17.6469	83.1963	0	17.701	83.171	29	17.65314	83.20645	11	17.67083	83.18405
24	17.700368	83.20498	0	17.701	83.171	43	17.73655	83.21945	11	17.67083	83.18405
25	17.673818	83.18945	0	17.701	83.171	70	17.68433	83.22348	11	17.67083	83.18405
26	17.663498	83.26217	0	17.701	83.171	72	17.67911	83.18968	11	17.67083	83.18405
27	17.701604	83.22941	0	17.701	83.171	54	17.68217	83.26388	30	17.73575	83.2325
31	17.692495	83.23696	0	17.701	83.171	84	17.65822	83.18173	30	17.73575	83.2325
32	17.721085	83.2461	0	17.701	83.171	16	17.69042	83.26581	34	17.66835	83.19527
36	17.724437	83.19997	0	17.701	83.171	57	17.72806	83.25555	34	17.66835	83.19527
37	17.702344	83.20806	0	17.701	83.171	3	17.72602	83.17719	35	17.6579	83.26279
38	17.728255	83.21439	0	17.701	83.171	28	17.65391	83.24141	35	17.6579	83.26279
40	17.692937	83.19477	0	17.701	83.171	59	17.6977	83.18378	35	17.6579	83.26279
41	17.695259	83.25828	0	17.701	83.171	77	17.6489	83.19097	35	17.6579	83.26279
42	17.67674	83.19043	0	17.701	83.171	80	17.6439	83.23161	35	17.6579	83.26279
44	17.645891	83.17321	0	17.701	83.171	87	17.71755	83.18754	35	17.6579	83.26279
45	17.647765	83.23124	0	17.701	83.171	90	17.70971	83.23584	35	17.6579	83.26279
46	17.716008	83.21072	0	17.701	83.171	60	17.71305	83.22244	53	17.64796	83.21198
47	17.643153	83.20666	0	17.701	83.171	75	17.73631	83.23349	53	17.64796	83.21198
48	17.736412	83.22141	0	17.701	83.171	6	17.63945	83.18838	55	17.72439	83.19484
50	17.637948	83.24057	0	17.701	83.171	49	17.73391	83.25458	55	17.72439	83.19484
51	17.704971	83.2222	0	17.701	83.171	58	17.66664	83.23239	55	17.72439	83.19484
52	17.663483	83.2326	0	17.701	83.171	71	17.66331	83.25574	55	17.72439	83.19484
61	17.714663	83.22154	0	17.701	83.171	74	17.65692	83.19967	55	17.72439	83.19484
62	17.636857	83.20092	0	17.701	83.171	82	17.72276	83.17559	55	17.72439	83.19484
63	17.638748	83.24057	0	17.701	83.171	85	17.73035	83.2256	55	17.72439	83.19484
66	17.724601	83.26319	0	17.701	83.171	33	17.6597	83.17171	65	17.66755	83.17429
67	17.645365	83.2171	0	17.701	83.171	39	17.66329	83.19316	65	17.66755	83.17429
68	17.643721	83.24456	0	17.701	83.171	8	17.65884	83.22743	79	17.65981	83.19052
76	17.68061	83.22026	0	17.701	83.171	56	17.68686	83.18637	79	17.65981	83.19052
78	17.670609	83.22733	0	17.701	83.171	99	17.73673	83.2521	79	17.65981	83.19052

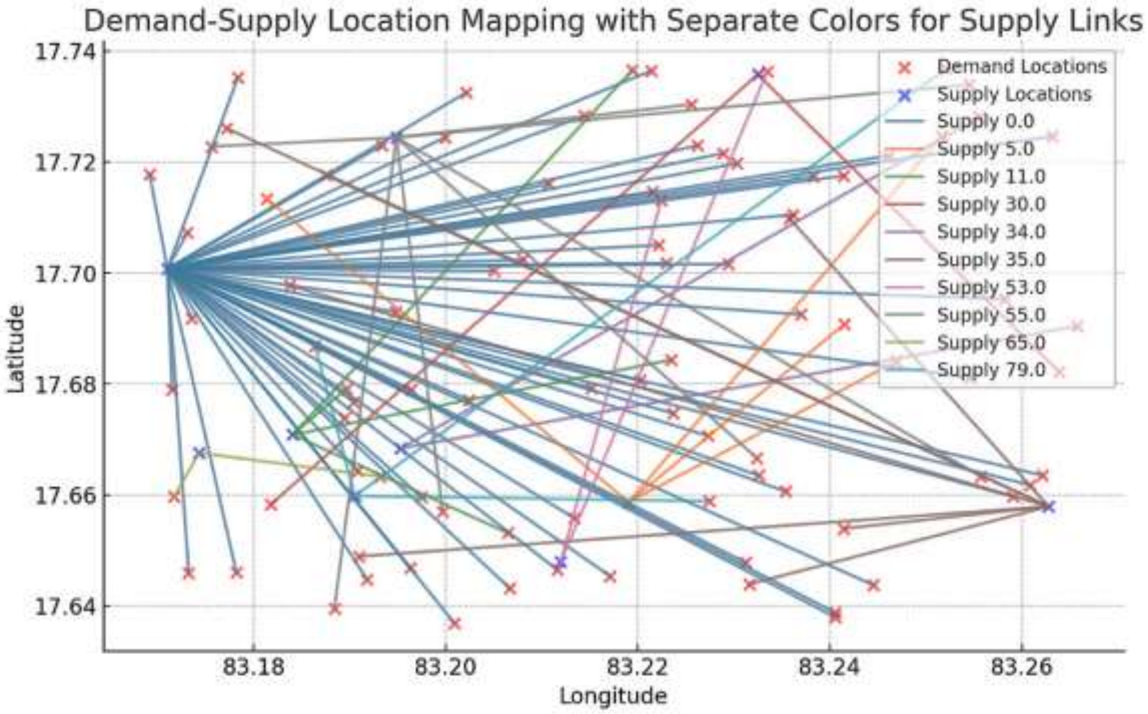

Fig. 2: Demand supply location mapping

4.4 Performance of Supply Location (without priority)

Optimum performance parameters are determines as discussed in previous section and are presented in the following table:

Table-3: Performance of supply location

Station ID	Latitude	Longitude	Servers	Service Rate	System Availability	Customers in Queue	Customers in System	Queue Time (hrs)	System Time (hrs)
0	17.70074268	83.17100108	2	2.5041	0.99979979	98.782294	108.76607	3.951292	4.350643
5	17.6586638	83.21903553	9	4.7884	0.9946972	0.1385939	5.3595715	0.005544	0.214383
11	17.67082505	83.18404795	10	3.3206	0.99952181	0.9506834	8.4795179	0.038027	0.339181
30	17.73575234	83.23249998	7	2.4314	0.99999591	97.659171	107.94145	3.906367	4.317658
34	17.6683453	83.19527409	8	2.0551	0.99999917	97.698631	109.8632	3.907945	4.394528
35	17.65789828	83.26279097	8	4.7285	0.99523309	0.4148188	5.701883	0.016593	0.228075
53	17.64795522	83.21197653	9	3.3298	0.99959424	2.5728191	10.080783	0.102913	0.403231
55	17.72438529	83.19483891	2	2.2201	0.99984258	98.808919	110.06946	3.952357	4.402778
65	17.66755141	83.17429252	1	2.1947	0.99912288	98.913165	110.30415	3.956527	4.412166
79	17.65981147	83.19052174	4	2.559	0.9999738	98.445231	108.21486	3.937809	4.328594

4.5 Assignment of Demand Location to Supply location (with priority)

Assignment of Demand Location to supply Location model as discussed in section 3.2 is implemented to determine optimum assignment of demand location to supply location. In this study, an integrated MCDM framework combining Hellwig's Method and TOPSIS – including its Mahalanobis-enhanced variant – for the systematic evaluation of relative weights of Electric Vehicle Charging Station (EVCS) locations are considered. Following table shows the relative weights of the Electric Vehicle Charging Station locations.

Table-4: Priority of EVCS locations

Station ID	Latitude	Longitude	Priority	Station ID	Latitude	Longitude	Priority
0	17.70074268	83.17100108	0.5819	50	17.63795	83.24057	0.5044
1	17.66430293	83.19082107	0.3902	51	17.70497	83.2222	0.6701
2	17.71044712	83.23616995	0.3651	52	17.66348	83.2326	0.4737
3	17.72601796	83.17719388	0.3846	53	17.64796	83.21198	0.6390
4	17.67899218	83.17147972	0.5355	54	17.68217	83.26388	0.3482
5	17.6586638	83.21903553	0.6261	55	17.72439	83.19484	0.4454
6	17.6394536	83.18838377	0.6861	56	17.68686	83.18637	0.4184
7	17.70178844	83.22299415	0.3460	57	17.72806	83.25555	0.7009
8	17.65884406	83.22742657	0.4919	58	17.66664	83.23239	0.5682
9	17.71774305	83.16914988	0.6407	59	17.6977	83.18378	0.8179
10	17.71738193	83.23831394	0.7799	60	17.71305	83.22244	0.5979
11	17.67082505	83. 18404795	0.4886	61	17.71466	83.22154	0.7950
12	17.73252131	83.20215945	0.3077	62	17.63686	83.20092	0.3458
13	17.64607458	83.17817164	0.1720	63	17.63875	83.24057	0.2857
14	17.72154944	83.2288726	0.2880	64	17.72467	83.25167	0.4807
15	17.71751283	83.24147318	0.5903	65	17.66755	83.17429	0.6635
16	17.69042281	83.26581158	0.5385	66	17.7246	83.26319	0.2890
17	17.67465344	83.22370406	0.6555	67	17.64537	83.2171	0.4236
18	17.71974047	83.23035198	0.2170	68	17.64372	83.24456	0.4826
19	17.72297069	83.22623521	0.6043	69	17.71338	83.18134	0.2428
20	17.70725718	83.17308244	0.3044	70	17.68433	83.22348	0.6415
21	17.65958983	83.1974388	0.4268	71	17.66331	83.25574	0.4220
22	17.6447792	83.19177909	0.4760	72	17.67911	83.18968	0.5448
23	17.64690014	83.19629736	0.3841	73	17.69073	83.24149	0.4584
24	17.70036844	83.20498322	0.5972	74	17.65692	83.19967	0.3448
25	17.6738181	83.1894507	0.4778	75	17.73631	83.23349	0.4681
26	17.66349778	83.26216546	0.7089	76	17.68061	83.22026	0.3663
27	17.70160354	83.2294131	0.6038	77	17.6489	83.19097	0.3301
28	17.65391386	83.24141268	0.5958	78	17.67061	83.22733	0.5489
29	17.65314025	83.20644554	0.3610	79	17.65981	83.19052	0.4605
30	17.73575234	83.23249998	0.4831	80	17.6439	83.23161	0.6765
31	17.69249497	83.23696143	0.7895	81	17.65969	83.25904	0.4211
32	17.72108519	83.24609999	0.4277	82	17.72276	83.17559	0.6330
33	17.65970481	83.17171002	0.6156	83	17.6606	83.2354	0.3695
34	17.6683453	83.19527409	0.3357	84	17.65822	83.18173	0.4711
35	17.65789828	83.26279097	0.4168	85	17.73035	83.2256	0.4238
36	17.72443676	83.19996779	0.3294	86	17.68407	83.24696	0.4353
37	17.70234387	83.20806319	0.4940	87	17.71755	83.18754	0.5209
38	17.72825476	83.21438519	0.5262	88	17.64649	83.21161	0.5646
39	17.66328802	83.19316275	0.6443	89	17.67916	83.2152	0.5995
40	17.69293681	83. 19477416	0.3931	90	17.70971	83.23584	0.5221
41	17.6952586	83.25828229	0.4519	91	17.73522	83.17834	0.4863
42	17.67674005	83.19043208	0.4947	92	17.67706	83.20243	0.5228
43	17.73655376	83.21945263	0.3983	93	17.72297	83.19337	0.6550
44	17.64589094	83.17321164	0.3981	94	17.65582	83.21336	0.5468

Station ID	Latitude	Longitude	Priority	Station ID	Latitude	Longitude	Priority
45	17.64776491	83.2312446	0.8831	95	17.67899	83.19635	0.5338
46	17.71600794	83.210716	0.4574	96	17.66178	83.26083	0.5033
47	17.64315277	83.20666193	0.5380	97	17.68111	83.25463	0.5375
48	17.73641214	83.22141143	0.7117	98	17.69183	83.17356	0.3703
49	17.73390784	83.25457797	0.6894	99	17.73673	83.2521	0.6392

The following table represent geographical locations of Petrol stations randomly generated between given latitude and longitude. Demand supply mapping is shown in Fig.2.

Table-5: Assignment of demand location to supply location

Demand ID	Demand Latitude	Demand Longitude	Assigned Supply ID	Supply Latitude	Supply Longitude
0	17.70074268	83.17100108	12	17.73252131	83.20215945
1	17.66430293	83.19082107	12	17.73252131	83.20215945
3	17.72601796	83.17719388	12	17.73252131	83.20215945
4	17.67899218	83.17147972	12	17.73252131	83.20215945
6	17.6394536	83.18838377	12	17.73252131	83.20215945
7	17.70178844	83.22299415	12	17.73252131	83.20215945
8	17.65884406	83.22742657	12	17.73252131	83.20215945
9	17.71774305	83.16914988	12	17.73252131	83.20215945
10	17.71738193	83.23831394	12	17.73252131	83.20215945
11	17.67082505	83.18404795	12	17.73252131	83.20215945
15	17.71751283	83.24147318	12	17.73252131	83.20215945
17	17.67465344	83.22370406	12	17.73252131	83.20215945
24	17.70036844	83.20498322	12	17.73252131	83.20215945
25	17.6738181	83.1894507	12	17.73252131	83.20215945
26	17.66349778	83.26216546	12	17.73252131	83.20215945
29	17.65314025	83.20644554	12	17.73252131	83.20215945
30	17.73575234	83.23249998	12	17.73252131	83.20215945
31	17.69249497	83.23696143	12	17.73252131	83.20215945
32	17.72108519	83.24609999	12	17.73252131	83.20215945
33	17.65970481	83.17171002	12	17.73252131	83.20215945
34	17.6683453	83.19527409	12	17.73252131	83.20215945
35	17.65789828	83.26279097	12	17.73252131	83.20215945
38	17.72825476	83.21438519	12	17.73252131	83.20215945
39	17.66328802	83.19316275	12	17.73252131	83.20215945
40	17.69293681	83.19477416	12	17.73252131	83.20215945
41	17.6952586	83.25828229	12	17.73252131	83.20215945
42	17.67674005	83.19043208	12	17.73252131	83.20215945
43	17.73655376	83.21945263	12	17.73252131	83.20215945
44	17.64589094	83.17321164	12	17.73252131	83.20215945
45	17.64776491	83.2312446	12	17.73252131	83.20215945
46	17.71600794	83.210716	12	17.73252131	83.20215945
47	17.64315277	83.20666193	12	17.73252131	83.20215945
48	17.73641214	83.22141143	12	17.73252131	83.20215945
49	17.73390784	83.25457797	12	17.73252131	83.20215945
52	17.66348252	83.23259618	12	17.73252131	83.20215945
53	17.64795522	83.21197653	12	17.73252131	83.20215945
54	17.68217237	83.26388159	12	17.73252131	83.20215945

Demand ID	Demand Latitude	Demand Longitude	Assigned Supply ID	Supply Latitude	Supply Longitude
55	17.72438529	83.19483891	12	17.73252131	83.20215945
56	17.68685861	83.18636519	12	17.73252131	83.20215945
57	17.72806278	83.25555186	12	17.73252131	83.20215945
59	17.69769702	83.18378393	12	17.73252131	83.20215945
60	17.71305108	83.2224379	12	17.73252131	83.20215945
61	17.71466265	83.22153537	12	17.73252131	83.20215945
62	17.63685719	83.20091561	12	17.73252131	83.20215945
64	17.72467219	83.25166655	12	17.73252131	83.20215945
65	17.66755141	83.17429252	12	17.73252131	83.20215945
67	17.64536535	83.21709905	12	17.73252131	83.20215945
68	17.64372125	83.24456022	12	17.73252131	83.20215945
71	17.66330566	83.2557433	12	17.73252131	83.20215945
72	17.67911379	83.18967982	12	17.73252131	83.20215945
73	17.69072961	83.24149311	12	17.73252131	83.20215945
74	17.65691511	83.19967163	12	17.73252131	83.20215945
75	17.73631494	83.23348781	12	17.73252131	83.20215945
76	17.68061001	83.22025758	12	17.73252131	83.20215945
78	17.67060856	83.22733087	12	17.73252131	83.20215945
79	17.65981147	83.19052174	12	17.73252131	83.20215945
80	17.64389931	83.2316103	12	17.73252131	83.20215945
81	17.65969418	83.259042	12	17.73252131	83.20215945
83	17.66060046	83.23539778	12	17.73252131	83.20215945
84	17.65822368	83.18173118	12	17.73252131	83.20215945
85	17.73035142	83.22560431	12	17.73252131	83.20215945
86	17.6840671	83.24696194	12	17.73252131	83.20215945
87	17.7175497	83.18754099	12	17.73252131	83.20215945
88	17.64649308	83.21160512	12	17.73252131	83.20215945
89	17.67915786	83.21520247	12	17.73252131	83.20215945
90	17.70970758	83.23583645	12	17.73252131	83.20215945
91	17.73521652	83.17834179	12	17.73252131	83.20215945
92	17.67706213	83.20243026	12	17.73252131	83.20215945
93	17.72296725	83.19336563	12	17.73252131	83.20215945
94	17.65582089	83.21336135	12	17.73252131	83.20215945
95	17.67898816	83.19635451	12	17.73252131	83.20215945
96	17.66178064	83.26082656	12	17.73252131	83.20215945
97	17.68111307	83.25463491	12	17.73252131	83.20215945
98	17.69183253	83.17355883	12	17.73252131	83.20215945
99	17.73672825	83.25210276	12	17.73252131	83.20215945
2	17.71044712	83.23616995	13	17.64607458	83.17817164
5	17.6586638	83.21903553	13	17.64607458	83.17817164
27	17.70160354	83.2294131	13	17.64607458	83.17817164
51	17.70497104	83.22219703	13	17.64607458	83.17817164
58	17.66664448	83.23239495	13	17.64607458	83.17817164
70	17.68432824	83.22348036	13	17.64607458	83.17817164
16	17.69042281	83.26581158	14	17.72154944	83.2288726
19	17.72297069	83.22623521	14	17.72154944	83.2288726
21	17.65958983	83.1974388	14	17.72154944	83.2288726
22	17.6447792	83.19177909	14	17.72154944	83.2288726

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Demand ID	Demand Latitude	Demand Longitude	Assigned Supply ID	Supply Latitude	Supply Longitude
23	17.64690014	83.19629736	14	17.72154944	83.2288726
28	17.65391386	83.24141268	14	17.72154944	83.2288726
37	17.70234387	83.20806319	14	17.72154944	83.2288726
50	17.6379481	83.24057218	14	17.72154944	83.2288726
82	17.72276354	83.17558573	69	17.71338344	83.18133915

4.6 Performance of Supply Location (without)

Optimum performance parameters are determines as discussed in previous section and are presented in the following table.

Table-6: Performance of supply location

Station ID	Latitude	Longitude	Servers	Service Rate	system Availability	Customers in Queue	Customers in System	Queue Time (hrs)	System Time (hrs)
12	17.73252131	83.20216	7	3.4899	0.9999	96.2454	103.4089	3.8498	4.1364
13	17.64607458	83.17817	9	3.4025	0.9995	2.0862	9.4339	0.0834	0.3774
14	17.7 2154944	83.2 2887	2	3.6889	0.9996	98.6659	105.4429	3.9466	4.2177
18	17.71974047	83.2 3035	3	2.4036	0.9999	98.6555	109.0566	3.9462	4.3623
20	17.70725718	83.17308	1	3.6057	0.9986	98.8574	105.7908	3.9543	4.2316
36	17.7 2443676	83.19997	7	4.4232	0.9974	2.1034	7.7555	0.0841	0.3102
63	17.6 3874767	83.24057	2	3.4164	0.9996	98.6934	106.0111	3.9477	4.2404
66	17.7 2460096	83.26319	2	3.0080	0.9997	98.7338	107.0450	3.9494	4.2818
69	17.71338 344	83.18134	3	2.1332	1.0000	98.7005	110.4200	3.9480	4.4168
77	17.64890042	83.19097	2	3.9198	0.9995	98.6422	105.0200	3.9457	4.2008

4.7 DISCUSSION OF RESULTS

The core objective of the study was to identify optimal locations for EV charging stations using two distinct strategies:(1) Distance-based optimization without priority, and (2) Multi-Criteria Decision-Making (MCDM) integrated optimization with priority weights.

In case of Selection Without Priority, The non-priority model, based on the Maximum Covering Location Problem (MCLP), prioritized geographical proximity and maximum coverage. The algorithm selected locations such as Station ID 12—located at *(Latitude: 17.7325, Longitude: 83.2021)*—due to its central position relative to demand nodes. Over 70% of the demand points were allocated to this single station, resulting in a clustered deployment strategy. While this approach ensures minimum travel distance for a majority of users, it creates a centralized dependency. Any operational failure or overload at Station 12 could disrupt access for a large segment of EV users. Additional selected locations under this model were spatially close to Station 12, reinforcing redundancy at the center but ignoring peripheral demand regions.

For selection with priority, the priority-based model integrated MCDM weighting (Hellwig + Mahalanobis-TOPSIS) to evaluate each candidate site based on: Anticipated demand density, Land suitability, Access Road quality, Strategic importance in future EV uptake etc, led to a more geographically diverse set of selected stations:

- Station 12 was retained, owing to its centrality and strong performance score.
- Station 13 *(Latitude: 17.6461, Longitude: 83.1782)* and

- Station 14 *(Latitude: 17.7215, Longitude: 83.2289)* were also selected due to their priority ranking, even though they were less central.

This diversification served outlying demand clusters more effectively and reduced spatial congestion in the core area. Selected locations with priority consideration also offered better access to municipal roads, adequate land area for fast-charger installation, and minimized queue buildup through load balancing.

4.7.1 Comparative Implications

The comparative analysis of location selection with and without priority reveals distinct planning trade-offs in terms of coverage efficiency, load balancing, and infrastructure resilience.

Aspect	**Without priority**	**With priority**
Spatial Spread	Highly centralized	Moderately decentralized
Redundancy	High only in center	Balanced redundancy across nodes
Risk Exposure	High if central node fails	Lower due to distributed infrastructure
Demand Matching	Uniform allocation	Weighted to high-demand or strategic zones
Adaptability	Rigid-proximity only	Adaptive to policy, infrastructure, and demand
Example Nodes Selected	Station 12 (dominant)	Stations 12, 13, and 14 (weighted selection)

5. CONCLUDING REMARKS

This study focused on location of EV charging stations Empirical data on existing Petrol stations are considered identification and deployment of supplier and demand locations based on the arrival rate. To determine the optimal capacity for EV charging facilities, the study applied the M/M/s queuing model. The optimal number of facilities required to meet this demand was calculated using the Location Theory Model Maximum Covering Location with and without considering relative weights of the locations of the petrol stations.

A maximum coverage distance was set to ensure accessibility to charging stations, and a sequential decision-making model was proposed to integrate capacity planning with optimal site selection using shared arrival rate. The study determined the best locations by evaluating number servers, service rate, system availability, customers in queue, customers in system, queue time and system time of the supplier locations.

Under the assumption that all chargers across different locations have the same type and functionality, the study determined the required charging capacity (i.e., the number of chargers) to meet demand. However, demand was distributed evenly across all demand points, without distinguishing between high-demand and low-demand areas. This limitation resulted in a lack of targeted distribution. Additionally, a comparative analysis incorporating demand distribution should be conducted to refine location selection and improve overall accessibility. Incorporate time-varying and stochastic demand patterns using real-time traffic and usage data to simulate peak/off-peak loads may also be explored.

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