Project Report On

OPTIMIZATION OF EV CHARGING STATIONS IN ERNAKULAM DISTRICT

Submitted

in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF SCIENCE

in

MATHEMATICS

by

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CERTIFICATE

This is to certify that the dissertation entitled OPTIMIZATION OF EV CHARGING STATIONS IN ERNAKULAM DISTRICT is a bonafide record of the work done by **PRAJNAA PRAVEEN** under my guidance in partial fulfillment of the award of the degree of **Bachelor of Science in Mathematics** at St. Teresa's College (Autonomous), Ernakulam affiliated to Mahatma Gandhi University, Kottayam. No part of this work has been submitted for any other degree elsewhere.

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DECLARATION

I hereby declare that the work presented in this project is based on the original work done by me under the guidance of Dr. Susan Mathew Panakkal, Assistant Professor, Department of Mathematics, St. Teresa's College(Autonomous), Ernakulam and has not been included in any other project submitted previously for the award of any degree.

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Place : Ernakulam

Date : 29/04/2024.

ABSTRACT

Leveraging Graph Theory for Optimizing EV Charging Infrastructure Deployment in Ernakulam District

The transition towards sustainable transportation, particularly Electric Vehicles (EVs), necessitates a robust infrastructure for charging stations. However, the efficient deployment of EV charging stations requires careful consideration of various factors, including geographical distribution, demand patterns, and cost-effectiveness. Our project addresses the optimization of Electric Vehicle (EV) charging station deployment in Ernakulam district using Graph Theory principles. We model Ernakulam's geography as a graph, where potential charging station locations are vertices and connectivity between them are edges. Novel algorithms are developed considering factors like population density, traffic flow, and existing infrastructure to pinpoint optimal charging locations. Real-world data analysis, including demographic information and transportation patterns specific to Ernakulam, informs our approach, ensuring alignment with the district's needs. The methodology involves graph representation of the district's geography, enabling efficient graph optimization techniques to solve the placement problem. Optimization algorithms, grounded in Graph Theory, aim to maximize coverage and minimize costs, adaptable to Ernakulam's unique characteristics. Extensive data analysis informs algorithm design and validates effectiveness within the district.

Our project contributes to sustainable transportation in Ernakulam by facilitating EV adoption. By leveraging Graph Theory and data analysis tailored to Ernakulam, we aim for efficient deployment of charging infrastructure, fostering a greener future for the district.

CONTENTS

CHAPTER 1

Introduction

Transportation is something we all need in today's life. Most of the people can't keep up with the increasing cost of fuel. The diesel or gasoline vehicles are producing a lot of pollution in the environment. So electric vehicles are more important in this situation. There are not enough public EV charging stations as compared to the gas, diesel and petrol stations. The emphasis is placed on making charging stations easily accessible to the public.

There are only a few public EV charging stations for electric vehicles which is a challenge for those who drive constantly outside and need to recharge while on move .

Objective

The project titled optimization of EV charging stations in Ernakulam district utilizes the concept of k domination from graph theory. The project aims to find the optimal location for the placement of EV charging stations using k distance and its related algorithms. The primary goal is to enhance accessibility by strategically placing charging stations , ensuring convenience for EV users while promoting a cleaner and greener mode of transportation . The project utilizes k-distance and associated algorithms to achieve optimal placement, contributing to the seamless integration of electric vehicles into our daily lives.

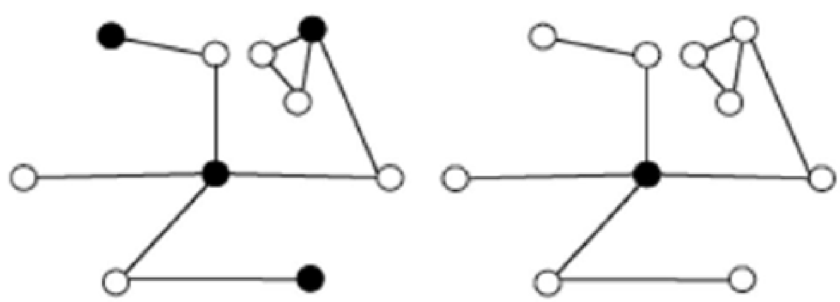
CHAPTER 2

Preliminary

Our project delves into the intricate domain of graph theory, a cornerstone of modern mathematics with applications spanning from computer science to network optimization. At the core of our investigation lies the concept of a dominating set, a fundamental notion in graph theory. A dominating set D is a set of vertices such that each vertex of G is either in D or has at least one neighbor in D which is from the paper 'Domination and its type in graph theory' by Dr.Shoba Shukla and Vikas Singh Thakur[1] .This pivotal construct plays a crucial role in network analysis, offering insights into connectivity and efficiency.

In graph theory a dominating set for a graph *G* is a subset *D* of its vertices, such that any vertex of *G* is either in *D*, or has a neighbor in *D*. The domination number $\gamma(G)$ is the number of vertices in a smallest dominating set for *G*[6]. Every graph has at least one dominating set: if $D \subset V$, where V is the set of all vertices, then by definition D is a dominating set, since there is no vertex u element of $V \setminus D$.

The k-domination number of a graph G G(V,E), Yk(G), is the least cardinality of a set $X \subset V$ such that any vertex in V X is adjacent to at least k vertices of X[5].



The dominating set (black vertices) for $k = 1$ (left) and $k = 3$ (right)

Figure 1

Expanding upon this foundation, we introduce the concept of a distance dominating set. In essence, a distance dominating set ensures that every vertex in the graph is either directly part of the set or lies within a specified distance from a member of the set. This nuanced extension enables us to gauge the robustness and reachability of our network configuration.A set $D \subseteq V$ is called a distance k-dominating set of G if each $x \in V(G) - D$ is within distance k from some vertex of D. The k-domination number of G, denoted by $\gamma k(G)$, is the minimum cardinality over all distance k-dominating sets.which is sited in the paper 'A note on distance domination numbers of graphs' by Fang Tian and Jun -Ming Xu[3].

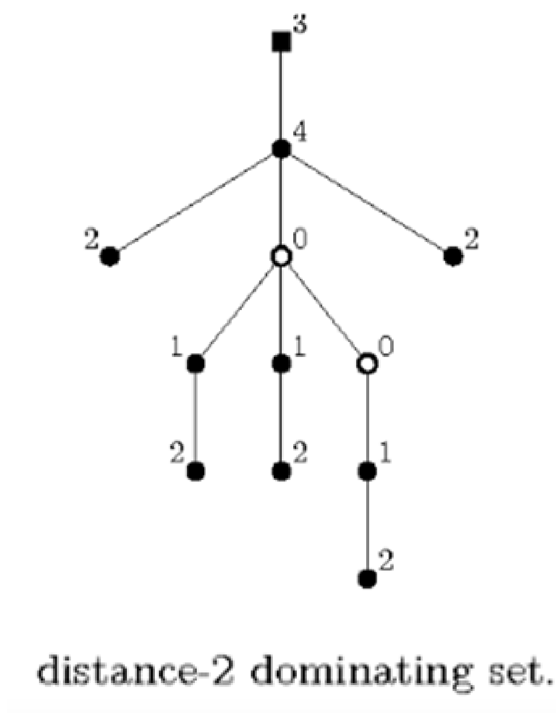


Figure 2

CHAPTER 3

METHODOLOGY

1.Research Design

The research problem seeks to understand what locations are most suitable for EV charging stations, taking into account factors such as accessibility, traffic impact, and strategic placement. The use of a quantitative method is driven by the need for numerical data, as that can be systematically analyzed. The research design includes a comprehensive approach to data collection, leveraging maps of state Highways and National Highways in Ernakulam district and GIS analysis is employed to map the quantitative data, facilitating a visual representation of geographical coordinates and infrastructure.

The foundation for the study is the application of Distance K-Dominating Set Theory in order to identify the locations that meet the criteria for being an optimal solution. The quantitative data, mapped information, and graph theory principles are collectively used to graph the solutions with the help of algorithms and programming codes.

This approach not only facilitates the identification of easily accessible locations for EV consumers but also considers the critical aspects of minimizing traffic congestion and avoiding junctions. The quantitative data-driven methodology provides a structured and objective foundation for achieving the overarching goal of establishing efficient EV charging stations in Ernakulam district.

2.Data Collection and Procedures

2.1 Formation of Roads as a network

Data collection:

Data for the road network was collected primarily from Google Earth, a widely utilized mapping tool known for its accuracy and updated information. The platform provided detailed satellite imagery and geographical data, facilitating the identification and marking of vertices for State Highways (SH) and National Highways (NH). The latitudes and longitudes of each position were directly extracted from Google Earth, ensuring the precision of the collected data.

Procedure:

The procedure for transforming roads into a network using Google Earth and converting them into a graph involves several key steps. First, data is collected on the total number of State Highways (SH) and National Highways (NH) in Ernakulam district. There are 5 National Highways and 10 State Highways, which are considered for vertex placement. A total of 220 vertices are manually plotted along these highways, with each vertex assigned a sequential number, beginning with '1,' and spaced at regular intervals of 2 km. This process ensures that the vertices are strategically positioned to accurately represent the road network. Exclusive consideration is given to SH and NH to maintain precision. Latitude and longitude coordinates are recorded for each plotted vertex using Google Earth. The resulting graph represents the road network, where vertices correspond to specific locations along the highways, and edges denote the road segments. The collected quantitative data is then analyzed to understand the spatial distribution of the road network.

2.2 Formation of Algorithms and Codes

The foundation of the optimization process rested on the utilization of the Distance k-Dominating Set Theory, a key theoretical framework sourced from comprehensive research textbooks and validated through internet-based data. This theory was translated into a Python code, executed in Google Colab, to systematically analyze and refine the plotted vertices.

To further enhance the precision of the optimal solution, the Greedy-Reductant Algorithm[2] and Heuristic Algorithm[2] were incorporated into the methodology. These algorithms, extracted from existing research studies and referenced materials, played a pivotal role in eliminating unwanted vertices from the graph. This refinement process was essential for creating a streamlined and effective road network representation, facilitating the identification of ideal locations for EV charging stations.

The conclusive phase of the procedure involved the execution of the algorithms and codes, resulting in the generation of graphs that illustrated both the road network and the optimal vertices for EV charging stations.

3.Tools and Technologies Used

Google Earth and Google Map:

Google Earth and Google Map served as the foundational mapping tool, enabling the visualization and tracing of State Highways (SH) and National Highways (NH) in Ernakulam district. The specific features and tools in google earth facilitated the manual plotting of 231 vertices at 2 km intervals along the highways. The latitudes and longitudes of each vertex are taken as ordered pairs from google earth.

Python Programming Language:

Python was employed as the programming language of choice for the implementation of algorithmic solutions. The “Distance k-Dominating Set Theory”, essential for optimizing the road network, was translated into Python code. The codes were executed in Google Colab, leveraging the power of this cloud-based platform for computational efficiency.

Greedy-Reductant Algorithm and Heuristic Algorithm:

The Greedy-Reductant Algorithm[2] and Heuristic Algorithm[2] played a crucial role in refining the plotted vertices. Extracted from existing research studies and references, these algorithms were instrumental in eliminating unwanted vertices, ensuring the accuracy of the road network graph.

Google Colab:

Google Colab provided a collaborative and cloud-based environment for executing Python code. It facilitated the efficient running of algorithms and codes, contributing to the generation of graphs representing both the road network and the optimal vertices.

4.Data Analysis

The combined performance of theories and technologies, enabled an effective analysis on the data collected such as road network, vertices and placements. The graphical representation of the optimized graph allowed us to visualize and interpret the results effectively. Through this visual analysis, we gained a comprehensive understanding of the road network's structure and identified strategic locations for optimal Electric Vehicle charging stations.

4.Validity and Reliability of the Study

Theoretical Validity:

The study draws upon well-established graph theory principles, specifically the k-dominating set problem and distance k-dominating sets, ensuring a strong theoretical foundation. These concepts have been extensively validated and utilized in similar research studies, enhancing the theoretical validity of the methodology.

Data Source Validation:

Quantitative data, such as the number of SH and NH, their total extended kilometers are collected from reliable and official resources. Also data including latitude and longitude coordinates of vertices, was collected from reliable sources and online databases. The use of accurate and verified data sources contributes to the overall validity of the study.

Algorithmic Validity:

The algorithms employed in the study, including the Distance k-Dominating Set Theory, Greedy-Reductant Algorithm, and Heuristic Algorithm, were selected based on their effectiveness in similar research contexts.

Code Verification:

The Python code executed in Google Colab for implementing the algorithms has been rigorously tested and verified. The code undergoes systematic debugging and validation processes to ensure its accuracy in reflecting the intended algorithmic operations.

CHAPTER 4

MAPS, CODES AND ALGORITHMS

Since the project mainly focuses around mapping charging stations on optimized locations the maps of both state highways and national highways running through Ernakulam district, Kerala has been used profusely. The map data utilized in this project serves as the critical analysis of our analysis. We collected a comprehensive dataset containing geographical data , including latitude and longitude coordinates, which forms the basis for identifying and optimizing electric vehicle (EV) charging station locations.

Ernakulam(figure 3) is one of the 14 districts of Kerala. It has an area of 2924km^2. The district has a total 16 highways, which includes 11 State Highways(SH) and 5 National Highways(NH)(figure 4). These highways are 459.01km long.

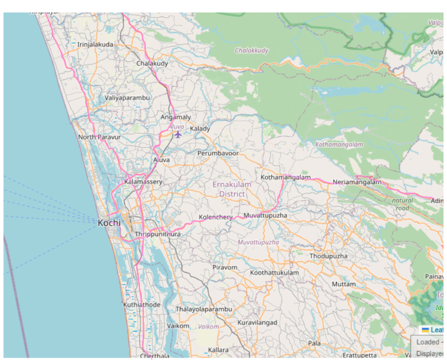


Figure 3

Figure 4

Here figure 3 shows the regular map of Ernakulam district and figure 4 shows the satellite view of Ernakulam district.

Currently, Electric vehicle (EV) charging ports are dispersed in clusters and exhibit an uneven distribution across the district. Figure 5 illustrates the spatial arrangement of the current charging port distribution.

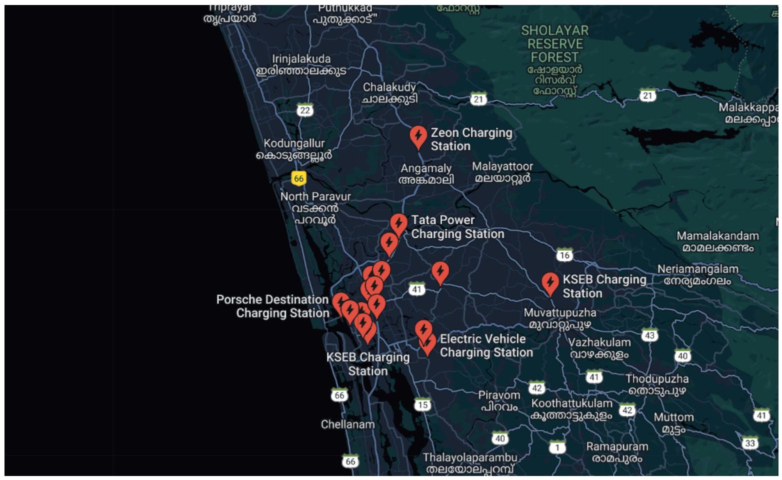


Figure 5

As such in an effort to optimize this distribution we use distance k domination to find the suitable locations for these charging ports.

From figure d we can see that the highways from Ernakulam district enters the neighboring district at 20 points respectively

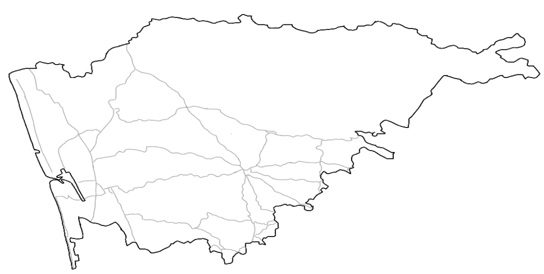


Figure 6

The following table A gives the details on each SH and NH.

HIGHWAY	LENGTH (in m)	Number of vertices
SH1	51373.43	24
SH 8	16803.17	8
SH 15	32155.13	18
SH 16	39981.49	19
SH 40	16605.27	8
SH 41	45790.69	23
SH 42	28588.19	14
SH 43	15993.12	13
SH 44	10278.71	4
SH 63	22599.47	12
SH 66	20430.89	10
NH 66	42225.69	20
NH 85	66612.49	33
NH 544	28729.13	14
NH 966A	14967.88	8
NH 966B	5883.59	3
Total	**459018.34**	**231**

The below figure depicts the initial vertice placement , each 2 km apart,

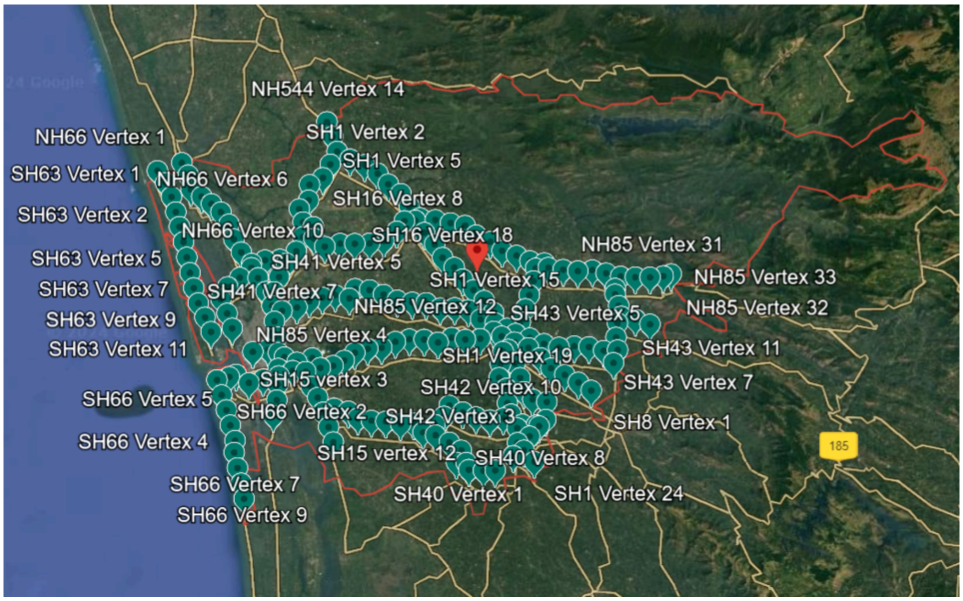


Figure 7

ALGORITHM

To identify optimal locations for EV charging stations, we employed graph theory and implemented various algorithms. Key among them is the k-domination algorithm(finding k dominating set for a large scale network), which determines sets of vertices ensuring that every vertex either belongs to the dominating set or shares adjacency with a dominating vertex. There were five phases for this algorithm :

1. Pre-processing Phase (Algorithm 1):

   Reduces the graph size while maintaining a k-dominating set, a subset of vertices ensuring every non-selected vertex is adjacent to at least one selected vertex.

Solving the k-dominating set problem on very large-scale networks

Algorithm 1: Pre-processing Phase

```
[ ] !pip install networkx
```

```
Requirement already satisfied: networkx in /usr/local/lib/python3.10/dist-packages (3.2)
```

```
import networkx as nx
```

```
[ ]
def pre_processing_phase(G, k):
    D = set()
    V_prime = set(G.nodes())
    E_prime = set(G.edges())

    for v in G.nodes():
        k_neighbors = set(G.neighbors(v))
        k_plus_1_neighbors = set(G.neighbors(v, k=k + 1))

        if len(k_neighbors) == len(k_plus_1_neighbors):
            V_prime -= k_neighbors
            E_prime -= {(v, u) for u in k_neighbors}
            D.add(v)
```

2. Modified Pre-processing Phase (Algorithm 2):

   A more efficient version of the pre-processing phase for large-scale graphs, addressing specific cases for improved optimization.

Algorithm 2: Modified Pre-processing Phase

```
[ ] import networkx as nx
```

```
def modified_pre_processing_phase(G, k):
    D = set()
    V_prime = set(G.nodes())
    E_prime = set(G.edges())
    f = {}

    for v in G.nodes():
        k_neighbors = set(G.neighbors(v))
        k_plus_1_neighbors = set(G.neighbors(v, k=k + 1))

        if len(k_neighbors) == len(k_plus_1_neighbors):
            f[v] = True
        else:
            f[v] = False

    for v in G.nodes():
        if f[v]:
            k_neighbors = set(G.neighbors(v))
            V_prime -= k_neighbors
            E_prime -= {(v, u) for u in k_neighbors}
            D.add(v)
        else:
            for u in G.neighbors(v, k=k + 1):
                if f[u]:
```

3. Heuristic Algorithm (Algorithm 3):

Provides a quick solution to the k-dominating set problem by selecting vertices based on their degrees, offering a fast but not necessarily optimal solution.

Algorithm 3-Heuristic Algorithm

```
import networkx as nx
```

```
def heuristic_k_dominating_set(G, k):
    D = set()
    V = set(G.nodes())  # Initialize V with all nodes in the graph G

    while V:
        v = max(V, key=lambda x: len(set(G.neighbors(x))))
        D.add(v)
        V -= set(G.neighbors(v))

    return D
```

4. Post-optimization Phase (Algorithm 4):

   Refines the initial k-dominating set obtained from the heuristic algorithm by adding vertices that are not initially dominated and iteratively removing redundant vertices.

Algorithm 4: Post-optimization Phase

```
import networkx as nx
```

```
def post_optimization_phase(G, k, D):
    D_prime = set(D)

    for v in G.nodes():
        if v not in D_prime and not is_dominated(v, D_prime, G):
            D_prime.add(v)
            if len(D_prime) > k:
                u_to_remove = select_vertex_to_remove(D_prime, G, k)
                D_prime.remove(u_to_remove)
                if len(D_prime) <= k:
                    break

    return D_prime
```

```
def is_dominated(v, D, G):
    for u in D:
        if v in G.neighbors(u):
            return True
    return False
```

5. Greedy Redundant Vertex Removal (Algorithm 5):

   Further optimizes the k-dominating set by removing over-dominant vertices and strategically selecting new vertices to maintain the desired set size.

   Algorithm 5: Greedy Redundant Vertex Removal

```python
import networkx as nx
```

```python
def greedy_redundant_vertex_removal(G, k, D):
    D_prime = set(D)

    for v in D:
        if dominates_more_than_k(v, D_prime, G, k):
            D_prime.remove(v)
            for u in G.neighbors(v):
                if u not in D_prime:
                    D_prime.add(u)
                    if len(D_prime) <= k:
                        break
            if len(D_prime) > k:
                u_to_remove = select_vertex_to_remove(D_prime, G, k)
                D_prime.remove(u_to_remove)
                if len(D_prime) <= k:
                    break

    return D_prime
```

```python
def dominates_more_than_k(v, D, G, k):
    count = 0
    for u in G.neighbors(v):
        if u not in D:
```

This approach aims to streamline the deployment of EV charging infrastructure, ensuring comprehensive coverage with a minimal number of charging stations. The algorithms provide a flexible framework adaptable to diverse geographical and infrastructure considerations, contributing to the sustainable development of EV charging networks.

CHAPTER 5

RESULT

The optimisation of EV charging stations was done using graph theory specifically k distance domination and optimal placement of charging stations throughout Ernakulam has been done.

The application of the K-Dominating Set algorithm on the road network of Ernakulam district yielded significant results in identifying optimal locations for Electric Vehicle (EV) charging stations. Out of the initial 231 vertices representing potential charging station locations, the algorithm selected a subset of 162 vertices as the most suitable sites for deployment. These vertices were strategically chosen based on various factors such as population density, traffic flow, and existing charging infrastructure within the district.

The selection of these 162 vertices ensures comprehensive coverage across Ernakulam district, facilitating enhanced accessibility for EV users. By strategically placing charging stations at these locations, the project aims to address the challenge of inadequate public charging infrastructure, thereby promoting the widespread adoption of electric vehicles in the region.

Furthermore, the optimization process prioritized efficiency and cost-effectiveness, minimizing the overall costs associated with charging station deployment while maximizing their utility. This approach ensures optimal resource utilization and lays the foundation for a sustainable and scalable EV charging infrastructure network.

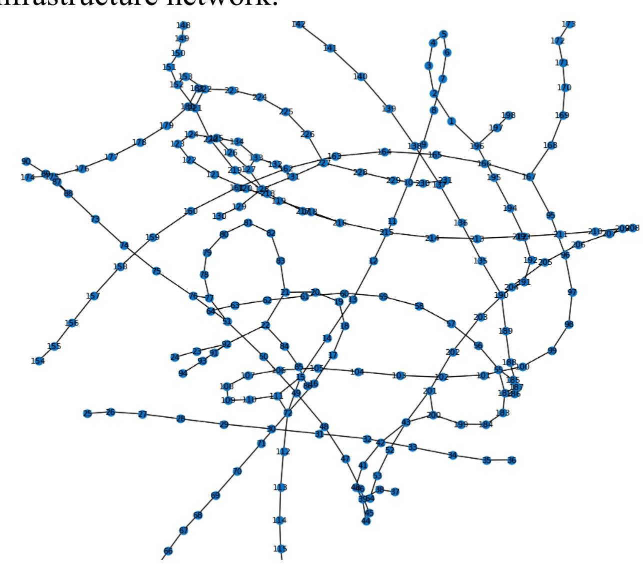


Figure 8

CHAPTER 6

DISCUSSIONS AND CONCLUSIONS

A problem faced by the EV owners today is that charging stations are not available at optimal distances, making long distance travel difficult. Our project tackles this problem using k-distance domination.

A graph was plotted using k- distance domination covering regions across the Ernakulam district . This had to be done manually by measuring distances between various locations to find out optimum distance at which charging stations can be placed within the map of the district . The measuring was done using Google maps and Google earth .

The main problem faced by us while handling the project was the plotting of locations across the map as the location given by k-distance domination sometimes would be at the middle of the road . So to tackle this problem each location had to be located by measuring the distance manually . This is an area where there is scope of development for future projects using graph theory to optimize EV charging stations.

Some of the other struggles we faced were unavailability of updated map of state highways and national highways running through the district, lack of less research on graph theory especially the k Distance domination theory, less number of algorithms for solving k dominating set in larger networks, trying to derive vertex of each point as ordered pair of its latitude and longitude of all the 230 vertices.

The project can be improved further if the project was collaborated with the government, then accurate data of details of state and national highway maps can be obtained. We can optimize the project further by making the initial vertex placement on map more accurate by incorporating codes that would require the use of programming languages like java, etc. The results can be improved by considering qualitative data from surveys and by finding a more optimized algorithm for k Distance domination the location of charging stations can be optimized.

In conclusion, the project successfully leveraged the K-Dominating Set algorithm to optimize the placement of EV charging stations in Ernakulam district. The results obtained highlight the effectiveness of the algorithm in identifying strategic locations that ensure extensive coverage and accessibility for EV users.

By promoting the adoption of electric vehicles through improved charging infrastructure, the project contributes to reducing pollution and greenhouse gas emissions in the region. Moreover, the optimization process prioritized efficiency and cost-effectiveness, ensuring optimal resource utilization and long-term sustainability.

Moving forward, further research and collaboration with local authorities and stakeholders are essential to implement the proposed charging station locations and enhance the EV ecosystem in Ernakulam district. Overall, the project's outcomes align with the broader goal of promoting sustainable transportation solutions and fostering a cleaner and greener future for the region.

CHAPTER 7

REFERENCES

1. Shukla, S., & Thakur, V. S. (2020). Domination And It's Type In Graph Theory. *Journal Of Emerging Technologies And Innovative Research (JETIR)*, *7*(3).
2. Nguyen, M. H., Hà, M. H., Nguyen, D. N., & Tran, T. T. (2020). Solving the k-dominating set problem on very large-scale networks. *Computational Social Networks*, *7*, 1-15.
3. Tian, F., & Xu, J. M. (2009). A note on distance domination numbers of graphs. *Australas. J Comb.*, *43*, 181-190.
4. Deepa V.G. , Aparna Lakshmanan and Sreeja V.N -“Identification of optimum public EV charging stations” [https://link.springer.com/chapter/10.1007/978-981-13-7150-9_7]
5. Caro, Y., & Roditty, Y. (1990). A note on the k-domination number of a graph. *International Journal of Mathematics and Mathematical Sciences*, *13*, 205-206.
6. Balakrishnan, R., & Ranganathan, K. (2012). *A textbook of graph theory*. Springer Science & Business Media.