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Strategic Placement of Electric Vehicle Charging Infrastructure for Sustainable Mobility in Maharashtra

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Abstract— India is committed to reduce its carbon footprints massively by undertaking several projects. Central to this endeavor is the National Electric Mobility Mission Plan 2020 which promotes adoption of electric vehicles and aims at forming a blueprint for electric vehicle infrastructure. But the biggest hurdle for a seamless transition into a more sustainable future is the placement of charging stations country wide. Unlike petroleum-based stations, current electric vehicle charging infrastructure is not so widespread. The objective of this study is to analyze and predict the optimal location for placement of electric vehicle chargers within the expansive state of Maharashtra. These locations are affected by several factors such as poor connectivity, poor power network distribution etc. The proposed solution uses a dual-method approach, giving consideration to a multitude of factors that impact these locations, thereby, to enhance precision of our prediction. A greedy algorithm is applied to process and evaluate the critical data. The evaluation obtained provides a foundation upon which further analysis is done by applying the Steiner Tree method. Through rigorous analysis we predict the optimal number of electric vehicle chargers in each district of Maharashtra. Our predictions align harmoniously with what would conventionally be considered accurate according to the real-world requirements. This study lays the foundation for future strategic blueprints for development of electric vehicle infrastructure in India which plays a pivotal step in a more sustainable future.

Index Terms—Electric Vehicle Adoption, Electric Vehicle Charging Infrastructure, Multi-Modal Analysis, Road Distance Optimization

I. INTRODUCTION

Global warming poses an imminent peril to life on Earth. A significant contributor to this is the automotive industry. Paradoxically, these vehicles responsible for 15% of total global carbon emissions, stand as both a crisis and a pivotal solution. Thus, the clarion call for a transition to electric vehicles is necessary. Electric Vehicles have gained massive significance since the global shift to sustainability gains momentum. However, the current infrastructure for electric vehicles faces a multitude of challenges ranging from improving the poor road conditions to bridging the gap in the poor power distribution. These factors complicate the strategic deployment of an efficient electric vehicle charging infrastructure in the country. At initial stages, the cost of construction and development is significant. Proper deployment of initial electric vehicle charging facilities commands the progress of this mission and forms the basis for how the later stages unfold. Meticulous optimization giving due cognizance to these factors for mapping a way to predict optimal locations for electric vehicle chargers is of utmost importance. The objective is to provide the smoothest journey for the least amount of tribulations. The main areas of this study focuses on analyzing how factors influence prediction of these locations, providing precise predictions of strategic placement of charging stations for proper growth, mapping and analyzing the accuracy of predictions in accordance with real world conventions, suggesting improvements and providing future alternatives for refining the predictive methodologies.

II. METHODOLOGY

Our methodology is structured into 2 phases, each designed to address the complexities inherent to our final objective. Firstly, we focus on interpreting the data for a systematic analysis. Districts of Maharashtra are transformed into a weighted graph. The weights are devised based on critical parameters after an optimized selection for higher accuracy. These parameters are Average income of the district, Distance between the district, Electricity rate of the district, Electricity consumption of the district. Subsequent to this transformation, the problem has been transposed into a subset of the well-known Travelling Salesman problem which can be addressed by using Steiner Tree algorithms.

A. DATA COLLECTION

The dataset comprises data spanning three years encompassing 2020-2021, 2021-2022, 2022-2023 for each district in Maharashtra based on the parameters mentioned earlier. This data was collected from diverse online sources, each presenting its own unique forms and variations. Thus, data preprocessing to normalize the heterogeneous dataset was a critical step. Each district was then assigned an index for further analysis.

TABLE 1: INDEXING OF DISTRICTS OF MAHARASHTRA

Index	**District**	**Index**	**District**
0	Sindhudurg	17	Dhule
1	Sangli	18	Thane

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2	Solapur	19	Jalna
3	Satara	20	Jalgaon
4	Wardha	21	Chandrapur
5	Latur	22	Gadchiroli
6	Ratnagiri	23	Kolhapur
7	Yeotmal	24	Aurangabad
8	Mumbai	25	Osmanabad
9	Bhandara	26	Ahmednagar
10	Buldhana	27	Alibag
11	Beed	28	Amravati
12	Pune	29	Akola
13	Parbhani	30	Gondia
14	Nanded	31	Washim
15	Nashik	32	Hingoli
16	Nagpur	33	Nandurbar

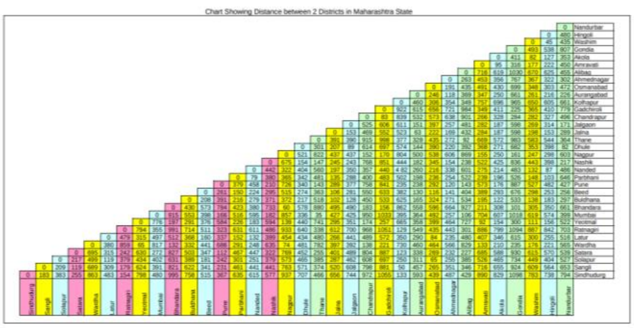

Fig. 1. Chart showing distance between two districts in Maharashtra[8]

B. ALGORITHM

Our initial approach involved a raw analysis based on the road distance between two districts that was obtained from the above graph as seen in Figure 1. We implemented a greedy algorithm for generation of the Minimum Spanning Tree for the graph.

The algorithm we followed was:-

1. Start with the original graph with vertices and edges.
2. Sort all edges in the graph in non-decreasing order of their weights.
3. Initialize an empty set for the MST.
4. Begin adding edges to the MST one by one in the sorted order, as long as adding the edge doesn't create a cycle in the MST.
5. Repeat step 4 until the MST contains all vertices of the original graph.

The weight of the minimum spanning tree (MST) can be calculated by summing the weights of the selected edges. If T is the minimum spanning tree, and w(e) represents the weight of an edge e, the formula is.

$$\text{Cost of Minimum Steiner Tree}=\sum e \in T\, w(e) \qquad (1)$$

Then we also dynamically tried to apply the Steiner tree to the Generated graph to get results accurately.

Here's the overview of the algorithm.

1. Given a set of terminal nodes (representing locations where you want to place charges) and a graph (network) with weighted edges, create a smaller, fully connected graph containing only the terminal nodes.
2. For each node in the graph, compute the minimum spanning tree (MST) that connects it to all other terminal nodes using the MST algorithm. This forms a set of partial Steiner trees.
3. For every subset of terminal nodes S, calculate the minimum cost of connecting all nodes in S. This can be done using dynamic programming, where you iteratively combine partial Steiner trees and update the minimum cost.

The minimum cost obtained in step 3 represents the cost of the minimum Steiner tree, which is the optimal way to connect all terminal nodes.

The cost of the minimum Steiner tree is determined by the sum of the edge weights used to connect the terminal nodes. If T is the minimum Steiner tree, and w(e) represents the weight of an edge e in the graph, the formula for the cost is:

$$\text{Cost of Minimum Steiner Tree}=\sum e \in T\, w(e) \qquad (2)$$

Then the weights of each edge were modified according to the income, road density, electricity consumption, electricity rate. By taking the average of the mentioned condition between two states to set the edge weight between them.

If e∈R is the edge weight between two districts a and b, and α, β, γ, δ be the normalized average income, normalized average road density, normalized average electricity consumption, and normalized average electricity rate respectively.

$$e = (\alpha + \beta + \gamma + \delta) \qquad (3)$$

Then the priority was assigned based on the maximum weight of the edge between any two nodes in the resulting minimized tree.

III. RESULTS

We initiated our approach by constructing an initial graph where we used the road distance as the edge data, resulting in representation shown in Figure 2a. This graph (Fig. 2a.) represents the distance between each district, forming the basis for our subsequent analysis. From this initial graph, we construct an optimized MST presented in Figure 2b, that is usable in the Steiner tree methodology to place electric vehicle charger placement.

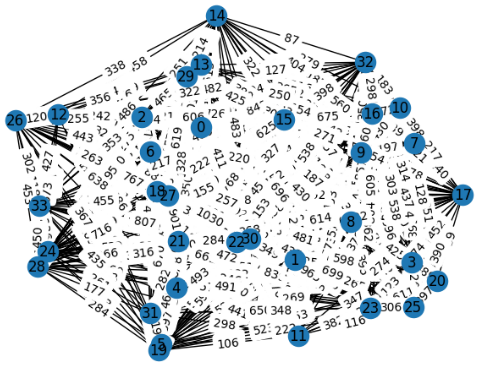

Fig. 2a. Raw graph using Edge Weight

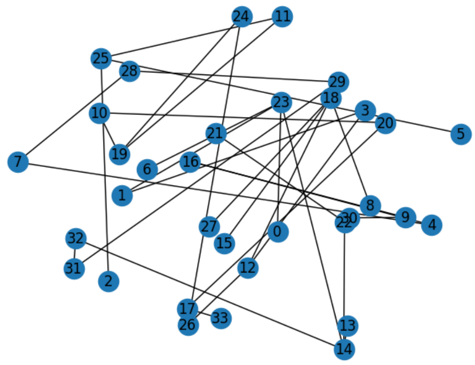

Fig. 2b. Resulting MST generated

Through this approach, we obtain top 10 preferred placements of chargers which can be seen from Table 2. The distance between districts plays as the deciding factor in representing the likelihood of a charger placement.

TABLE 2: TOP 10 OPTIMAL LOCATIONS BASED ON SINGLE MODE ANALYSIS

District 1	**District 2**	**Edge Weight**
Sindhudurg	Gondia	1098
Ratnagiri	Gondia	1094
Mumbai	Gadchiroli	1033
Thane	Gadchiroli	998
Mumbai	Gondia	1018
Sindhudurg	Gadchiroli	1055
Ratnagiri	Gadchiroli	1051
Ratnagiri	Bhandara	991
Alibag	Gondia	1030
Sindhudurg	Bhandara	995

And the generated histogram for all the districts is shown below (Fig. 3). The rank for each district was calculated based on its occurrence in the resulting sorted list and its cumulative value reveals the prioritized locations. Notably, the highest priority through this method has been assigned to Gondia, Sindhudurg and Ratnagiri which when pinpointed on the map is on the borders of Maharashtra. This does not match with the real-world scenarios and hence we transitioned to a multi modal analysis.

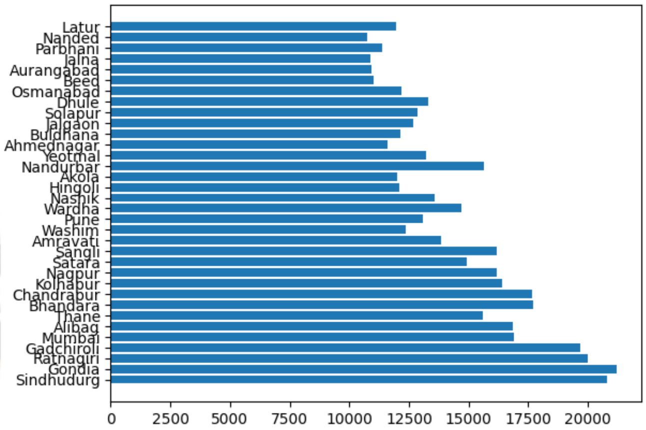

Fig. 3. Raw Distance Based Analysis Histogram

In our multi-mode analysis, we introduce factor-based analysis by considering the average income, road density, electricity consumption and electricity rate of each district and ranking it accordingly. Using this approach, we got a raw graph shown in Figure 4a. After optimization it led to a graph in Figure 4b.

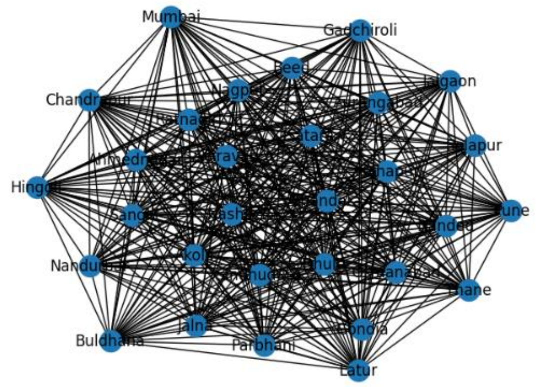

Fig. 4a. Raw graph using multi-modal Edge Weights generated using custom function

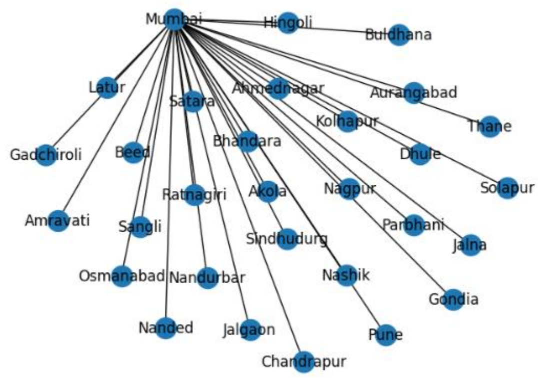

Fig. 4b. Resulting MST generated

These graphs substantiate Mumbai as the central hub within the network due to its status of major metropolitan city. This prediction matches well with the real-world circumstances.

TABLE 3: TOP 10 OPTIMAL LOCATIONS BASED ON MULTI MODE ANALYSIS

District 1	**District 2**	**Edge Weight**
Mumbai	Thane	3.95
Mumbai	Pune	3.74
Mumbai	Nagpur	3.57
Pune	Thane	3.31
Mumbai	Kolhapur	3.28
Solapur	Mumbai	3.24
Mumbai	Nashik	3.23
Mumbai	Ahmednagar	3.14
Nagpur	Thane	3.14
Sangli	Mumbai	3.09

The insights from Table 3 above clearly highlight the advantages of using a multimodal function for assigning weights. By taking into account important routes and dense roadways, the method provides a more comprehensive analysis of all the states as shown below in Figure 5. Furthermore, it reinforces the point that a suitable model can be built with remarkably high precision in the placement of the electric chargers down to the specific road and city.

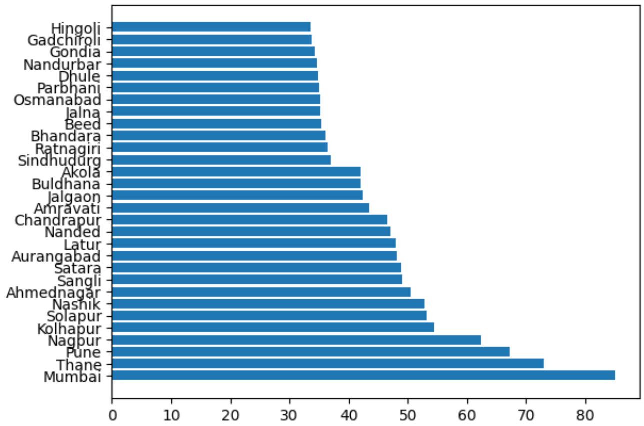

Fig. 5. Multi-Mode Analysis Histogram

Observing the consideration of all the factors within our edge weights, we are able to bring out the significance of densely populated and urban areas that play a major role in the electric charger use. Thus, the model accurately portrays the real-world scenario. We can assign the electric chargers to each district based on their respective levels of importance that were derived from the graph. The strategic allocation contributes to the optimal placement of electric chargers, effectively enhancing the charging infrastructure.

IV. CONCLUSION

Our study analyzed optimal ways for placement of electric chargers within a state based on many factors. We compared the outcomes of a single factor approach such as distance with a more comprehensive approach of multi-mode factors. When pivotal and distinguishing factors are taken into consideration, the mathematical predictions tend to align with real world scenarios. As seen from our prediction ranking, Mumbai emerged as prime consideration for charger placement, followed by Thane and Pune. This is a strong indication of the feasibility of a functional model. Such a model when integrated with a diverse array of relevant factors can be used to predict, with a remarkably high accuracy, the number and precise location for electric chargers. Furthermore, our study also successfully identified potential places for electrical chargers and ranked their relevance, which will be helpful in large scale optimization of the larger network that is mathematically proven to provide coverage and reliability.

V. FUTURE WORK

The current approach can be further optimized with a more sophisticated custom function that simulates the relation between various coefficients. By evolving the graph representation from an undirected graph into a directed multi-edged graph, that has diverse conditional factors, can be varied, and optimized automatically to better predict the optimal charger locations. Furthermore, different optimization algorithms can be used to more effectively judge the locations drawing inspiration from other research papers. For instance, usage of genetic algorithms to simulate real time traffic dynamics. It has scope to incorporate different types of chargers in the model like fast chargers or slow chargers.

REFERENCES

1. Sui, Y., Yi, P., Liu, X., Wang, W., & Zhu, T. (2017). Optimization for Charge Station Placement in Electric Vehicles. Energy Network, Volume(Issue), 1-6. https://dl.acm.org/doi/pdf/10.1145/3132479.3132480
2. Mathew, D., & Barai, S. (2022). A Comprehensive Analysis of Electric Vehicle Charging Infrastructure: Standards, Policies, Aggregators, and Challenges for the Indian Market. Sustainable Energy Technologies and Assessments, 52, 101607. https://www.sciencedirect.com/science/article/pii/S2666660X22000706
3. Jangra, S., Yadav, R., & Kumar, A. (2021). A Comprehensive Analysis of Electric Vehicle Charging Infrastructure: Standards, Policies, Aggregators, and Challenges for the Indian Market. ResearchGate. https://www.researchgate.net/publication/371912673_A_Comprehensive_Analysis_of_Electric_Vehicle_Charging_Infrastructure_Standards_Policies_Aggregators_and_Challenges_for_the_Indian_Market
4. Mathew, D., & Barai, S. (2022). A Comprehensive Analysis of Electric Vehicle Charging Infrastructure: Standards, Policies, Aggregators, and Challenges for the Indian Market. Sustainable Energy Technologies and Assessments, 52, 101607. https://www.sciencedirect.com/science/article/pii/S2352484722001809

5. Puthiyachirakkal, P., Krishnasamy, V., Rambabu, K., & Lokesha, G. (2019). A review of electric vehicle charging infrastructure and technology. Procedia Computer Science, 165, 147-154. https://www.sciencedirect.com/science/article/pii/S1877050919316618
6. Das, B., & Singaravel, A. (2019). A review on electric vehicle charging infrastructure: Recent developments and issues. Procedia Computer Science, 163, 703-710. https://link.springer.com/article/10.1007/s10668-023-03373-z
7. Mirhosseini, A., & Sharifi, A. (2023). Electric vehicle charging station location-allocation problem: A new multi-objective bi-level approach. Environment, Development and Sustainability, 1-26. https://www.mdpi.com/1996-1073/16/4/1781
8. Chart Showing Distance between 2 Districts in Maharashtra State http://www.mahapwd.com/faq/distance_btn_prominent_citiesin_maharashtra.pdf

VI. ACKNOWLEDGEMENTS

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