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Adoption of Electric Vehicles: Challenges and Solutions

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Abstract:- The ever-increasing population, rising global warming and depleting non-renewable resources indicate the pressing need of shifting to more sustainable and environment friendly ways of transportation. Electric Vehicles have zero tailpipe emissions and very low dependency on fossil fuels. Widespread EV adoption is hence the key to advancing sustainable mobility. However, there are multiple challenges hindering EV adoption, especially in India. In our research, we have investigated what range anxiety is and how it inhibits people from purchasing Electric Vehicles. This research is in alignment with the United Nations Sustainable Development Goal 9 of industry, innovation and infrastructure and Sustainable Development Goal 12 of responsible consumption and production. The Indian Government aims to make India a 100% electric-vehicle nation by 2030. In order to achieve the aforementioned aim, an extensive charging infrastructure will be essential so that range anxiety of EV's can be tackled. We have proposed a way for providing optimal locations of charging stations by using genetic algorithm. We have applied the algorithm only to the city of New Delhi for the purpose of this research, however its application can be extended to other cities as well. We've focused on the optimal placement of electric vehicle charging stations after taking into consideration many aspects and constraints in the model without excessive technical details. There are a few limitations in our research such as the geographical area into consideration and we've also assumed that consumers will not be biased towards any charging station based on time and cost factors, which may not be the case in reality. Further research bridging these gaps will allow us to arrive at a more real-life like problem and thereby more accurate solutions.

Keywords:- *Electric Vehicles; Range Anxiety; Genetic Algorithm; Charging Infrastructure; Charging Stations; Operations Research; Climate Change;*

I. INTRODUCTION

In order to keep the worst and most devastating effects of climate change from battering human societies, the Intergovernmental Planet on Climate Change has warned that the global temperature rises should be limited to 2.7 degrees Fahrenheit beyond the pre-industrial levels; for this the green-house gas emissions need to start dropping by 7.6% each year from now until 2030 and of course beyond it. (Keishamaza Rukikaire, 2019) India is the second most populous country in the world and is now also the third largest emitter of carbon dioxide. It is no surprise that a large portion of this emission – about 25%, comes from the transportation sector. Thus India's actions with regard to more sustainable ways of transporting will make an impact globally. The above-mentioned statistics point towards the imminence of shifting from internal combustion engines to battery powered vehicles. However there are multiple challenges in widespread Electric Vehicle(EV) adoption in India, primarily that of range anxiety. Range anxiety is when a person driving an electric vehicle worries that the battery will run out of power before the next charging station or the desired destination is reached.

In order to make widespread adoption of EV's in India a reality, an extensive charging infrastructure is required. We've used genetic algorithms to provide the optimum locations of charging stations in Delhi, to reduce the range anxiety. We've focused on the optimal placement of electric vehicle charging stations after taking into consideration many aspects and constraints in the model without excessive technical details.

This paper endeavours to develop a genetic algorithm model to find the best possible location for electric vehicle charging stations, so as to reduce range anxiety. Genetic algorithm, as the name suggests, is inspired by Charles Darwin's theory of natural evolution which reflects the process of natural selection. The natural selection process begins with the selection of individuals which are the fittest, from a population. The offspring which they produce will inherit the characteristics of the parents and will be added to the next generation. If parents have better fitness, obviously their offspring will be better than parents and hence will have a better chance at surviving. This process continues and at the end, a generation which has the fittest individuals will remain and be found. This technique can be applied to select the best solutions out of a very large pool of solutions.

We have tested this algorithm on a portion of the city of Delhi to demonstrate its effectiveness. Using this algorithm, we have tried to minimize distance between random settlements, and the charging stations. Since fuel cost, time cost etc. is proportional to distance, our algorithm will automatically optimize them. In this study the total number of settlements which are considered is 50. Selection of a different number of settlements is possible within the same methodology, without disrupting the algorithm, as the algorithm takes any given set of settlements in the area.

In order to adopt genetic algorithms to find optimal locations of charging stations, the concept of genes and chromosomes needs to be defined first. Furthermore, dynamics of crossover and mutation must be determined. Firstly, we describe the problem in the form of a mathematical equation called "Objective Function" or "Fitness" function. The entire goal of application of the genetic algorithm is optimization of the fitness function. It starts by generating a population of random answers, which is called initial population (Initialization). Each member of this population represents a random answer. The structure of these potential answers is considered the chromosome of an individual in the population. All these properties are observed to be a gene. Thus, each possible answer is represented as a string of digits or characters. A chromosome, which is one answer to the problem, is considered as an array of coordinates, with an x and y value, and every pair is a gene. The second step is to calculate the fitness or optimality of these individuals by means of a fitness function that we want to maximize or minimize (Evaluation). The next step is to sort these individuals by their fitness. The final step in this process is to pick pairs among these answers. Thus, in the end we obtain the fitness proportionate selection which is affected by two factors: chance and goodness of answers (Parent Selection).
This research will help in finding the optimal location of charging stations in Delhi and thus help in widespread adoption of EV's.

II. LITERATURE REVIEW

To buy or not to buy an Electric Vehicle is the ultimate dilemma we are facing today. Globally most researched factors affecting the adoption of EV are - driving distance per charge, availability of charging points, time taken to recharge the battery, incentives offered by different governments and range anxiety. The main focus of this paper is going to be range anxiety in New Delhi, India. In simple words, range anxiety is a sense of uneasiness that stems from the fear that the EV does not have enough charge to reach the desired destination or the next charging station and thus might result in the driver getting stranded in the middle of nowhere. Previous studies have indicated that range anxiety is one the major hurdles in widespread adoption of electric vehicles not just in India, but globally.

Widely available charging infrastructure is needed to fasten up the pace of EVs adoption. It has also been observed that financial incentives like tax reductions and rebates have a much greater positive impact on adoption of EVs as compared to non-financial incentives like free parking and toll reduction. (Wentao Jing, 2016; Katie Laufenberg, 2010)

Studies have also shown that people's awareness of environmental problems and their desire to address it also influences consumer adoption. Kahn (2007) established that people who are concerned towards the environment are more willing to adopt EVs, supporting these findings were Pierre, Jemelin, and Louvet (2011). People who are inclined to energy conservation and environmental protection exhibit higher intention for adoption. Pro-environmental consumers are the probable EV adopters (Geng, 2021; Anil Khurana, 2019; Aayog, 2021)

The lack of skilled personnel is also a significant challenge in the EV market in India. It is especially difficult in India, because the EV market is in its nascent stage. There is also a lot of uncertainty in consumer behaviour due to the high cost of EV's. An electric vehicle's typical starting price in India is roughly USD 18000 (INR 13 lacs), while a normal gasoline-powered vehicle's average starting price is around USD 6000. (Rs. 4.5 lakhs) The approximate 3X price is a substantial market entry barrier that demands a complete India market entry plan to assist in identifying the appropriate consumer group, as well as their wants and preferences, in order to generate a long-term profit in a short period of time. Also, due to a lack of Lithium, India's EV battery manufacture is still heavily reliant on imports, which is a key barrier for companies looking to engage in the country's EV industry. Though Indian firms are attempting to acquire holdings in abroad resources and relocating more raw material production chains to India, there is limited synergy because battery manufacturing capacity still requires appropriate planning. (Soni, 2019; Abbot, 2019; Tornekar, 2019; Ganesh Sankaran, 2020)

The above challenges make it imperative that the EV's receive a push from the Government. As for India, the Central Government offered multiple incentives under Faster Adoption and Manufacturing of Electric Vehicles in India Phase II(FAME II) launched in 2019. The incentives offered include upto 40% rebate on purchase of electric two-wheeler vehicles, a maximum of 1.5 lakh in case of a 4 wheeler electric vehicle. Additionally, EVs have been specially placed in a lower GST Bracket at 5% of cost compared to 24% of cost for traditional Internal Combustion Engine vehicles. First time buyers can also avail tax benefits under section Section 80 EEB if they borrow to purchase the vehicle. (18, 2021)

India can also follow the lead of European countries in terms of offering more beneficial incentives. Many European countries came up with benefits to stimulate purchases of EVs. Norway is considered to be a country with one of the highest amounts of incentives. These benefits are fiscal as well as local. To promote EVs, they offer tax exemption on the registrations of fully electric cars, along with Value added tax exemptions. Among all the vehicles, EVs have the least amount of annual license fees. Other local benefits would be free public parking, lesser and no amount of road tolls on EVs and having access to bus lanes. Apart from fully electric vehicles, there are incentives on hybrid vehicles like reduction in registration tax and free charging in public charging points. (Assum, Kolbenstvedt, & Figenbaum, 2014). Ireland also has some incentives like free home charging installations, exemptions on taxes like Vehicle registration taxes and some grants towards purchase prices of the Electric vehicles. (Morrissey, Weldon, & Mahony, 2015). In the UK, there is an exemption on London congestion charge and road tax for Electric Vehicles. Italy offers exemption on their annual circulation tax or ownership tax for 5 years starting from the day of registration. (Zhou, Wang, Hao, Johnson, & Wang, 2004)

However the initiatives will be of little use if people are apprehensive of owning EV due to lack of proper charging infrastructure in the country. To make EV the future, adequate charging stations need to be ensured. Not only should they be available in abundance but they should be easy to use and overall less expensive. With a dynamic technological industry, one fails to ensure which charging stations will be the best for the future. The Harvard Research paper talks about how some people would be willing to use the Level 1 charging stations which is the cheaper alternative, but consumes a lot of time. A 24 kWh Nissan Leaf via level 1 chargers, it would take almost 10-12 hours, just to recharge half of the battery. However the cost would be around $60 per month. However the level 2 chargers would have a higher voltage and thus would charge the same vehicle in 7 hours. This could be useful for impatient drivers but the costs would rise up to $1500-$2200 a month. Level 1 and level 2 operate using alternating current (AC), and the electricity can be drawn directly from the local distribution system. The other alternative is the Level 3 chargers which operate using direct current (DC). This can eliminate the need of an inverter and deliver higher power. (Lee & Clark, 2018; Schaal, 2019)

There are two categories of charging stations for EVs: Home charging and Public charging. At the moment, for a household owning an electric vehicle, a home charging station would be necessary due to a lack of public charging stations. However, this could mean that some households may not be able to go the EV route due to lack of a dedicated parking space. Also, lower public charging stations means more electricity load in the evenings when people charge their vehicles at home. (Bakker, 2011) Public EV charging stations can be installed at places of entertainment and restaurants, malls etc. where people expect to stay longer. It is expected that as EVs are adopted more, the requirements of charging stations per EV will decrease. A survey found that two of the most important concerns for people considering purchasing an electric vehicle were battery concerns and servicing of the vehicle. It also found that more public charging stations would increase people's willingness to consider purchasing an electric vehicle. Although a home charging station was still deemed important to people for convenience, privacy and safety. (Joseph S.Krupaa, 2014; Banerji, 2020)

We've explained in depth how to optimise locations of charging stations to overcome range anxiety, in methodology and analysis below. However there are still a couple of alternatives to building an extensive charging infrastructure in order to reduce range anxiety. Battery swapping is an up and coming alternative in solving the critical problem of range anxiety. It offers a swift solution in addressing Range Anxiety where each battery swap takes around 5 to 10 minutes and the space it requires is much smaller than what would be needed to install a charging station. Offering EV Battery as a subscription based service is also a solution that has gained considerable traction, given how much it helps in reducing the high upfront cost of EVs by reducing the cost of a battery. Instead of owning batteries, people can subscribe to battery swapping plans to meet their specific needs. (DUBLIN, 2021) Another very interesting possible solution to completely solving range anxiety has propped up in the United States of America. Indiana State and Purdue University are working in collaboration with a German company Management to build roads made up of magnetised cement which can help charge EVs while they drive over such roads. Magment's official site states that the concrete mixture is filled with magnetic particles. Moreover, the German company also claims that it features a staggering wireless transmission efficiency of up to 95%. Lastly, Magment's website also goes on to claim that their roads accept universal charging, they work in irrespective of the weather conditions, offering high thermal conductivity and importantly, the roads are also vandalism proof. (Newswire, 2021)

Total EV sales in all vehicle segments will exceed 100 million units by FY30, according to the CEEW-CEF estimate. According to the report, achieving this goal will necessitate an annual battery capacity of 158 GWh by FY30, creating a significant market opportunity for domestic manufacturers. 1,800 public charging stations are available across the country. In order to achieve the above- mentioned feat, India would require a network of over 2.9 million public charging stations by FY30. (Kapoor, 2021; Lee & Clark, 2018)

III. OBJECTIVES

We chose to research on Electric Vehicles because it is a topic that is very relevant in today's day and age. Addressing climate change is the need of the hour and electric vehicles will help greatly, if we are able to produce energy from renewable and non-polluting sources. It is only logical to assume that if we need to advance EV adoption, the challenges need to be investigated and thus we've based our research on it. We identified range anxiety as the most important factor inhibiting the adoption of EV. There are many gaps in research material relating to the proper infrastructure required to resolve the issue of range anxiety. The motive of this study is to find feasible solutions for the problem of range anxiety using operations research techniques and make Electric Vehicles more accessible to people in India.

IV. METHODOLOGY

For this paper, we have used a genetic algorithm approach and modified it to find the best possible location for electric vehicle charging stations, so as to reduce range anxiety. We have tested this algorithm on a portion of Delhi to demonstrate its effectiveness. Using this algorithm, we have tried to minimize distance between random settlements, and the charging stations. The distance formula that we have used and that is to be minimized is given below (Milad Akrabi, 2018):

D= n∑i=1 [(x−ai)2+(y−bi)2]1/2

Since fuel cost, time cost etc. is proportional to distance, our algorithm will automatically optimize them. In this research, we have considered the number of settlements to be 50, and initialized it at random to test the algorithm. Selection of a different or even a random number of settlements could be simply possible without imposing any contradiction or limitation to any other step of this process or methodology.

The above genetic algorithm technique has been implemented in Python using a framework for genetic algorithms called "geneai" (Chaves, 2020). The results have been visualized using the pandas and matplotlib libraries.

Analysis

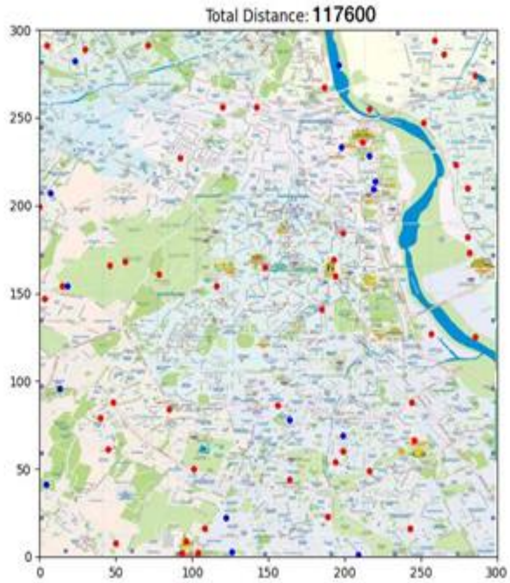
Genetic algorithm: It uses principles of natural selection and genetics to find an optimal solution to a complex problem that may otherwise be impractical to solve. The particulars of our genetic algorithm is as follows:

- Genetic material: In our study the genetic material is a list of coordinates for possible charging stations.
- Population: A population consists of multiple possible solutions to our problem, which is initially taken at random. Thus, it consists of several different possibilities of arrangements of the fixed number of charging stations around the city.
- Fitness: In our problem, the fitness of an individual solution is defined by the total distance of all the charging stations in that particular solution from random settlements in the city. These random settlements represent areas of demand where households with electric vehicles are concentrated. Since the exact placement of such settlements is not covered in this paper, we have taken random settlements for the purpose of our example. The genetic algorithm works to minimize this fitness function, so as to provide such a placement of charging stations that minimizes their distance from our set of settlements.
- Selection and crossover: From our population, random parents are selected to breed, and produce an offspring based on their combined genes (in this case, charging station points). Parents with higher fitness are more likely to be selected so as to produce better offspring for the next generation. The selection technique used is Biased random selection, and crossover is done using one point crossover.
- Mutation: To provide variation to the population and to avoid local optima, the offspring have a random chance of being mutated or changed slightly by a random number.

We have taken an example of Delhi to demonstrate the algorithm.

We initialized random settlements for our algorithm (indicated by the red dots) and also initialized the charging stations at random (indicated by the blue dots). The results have been shown in Random Initialization.

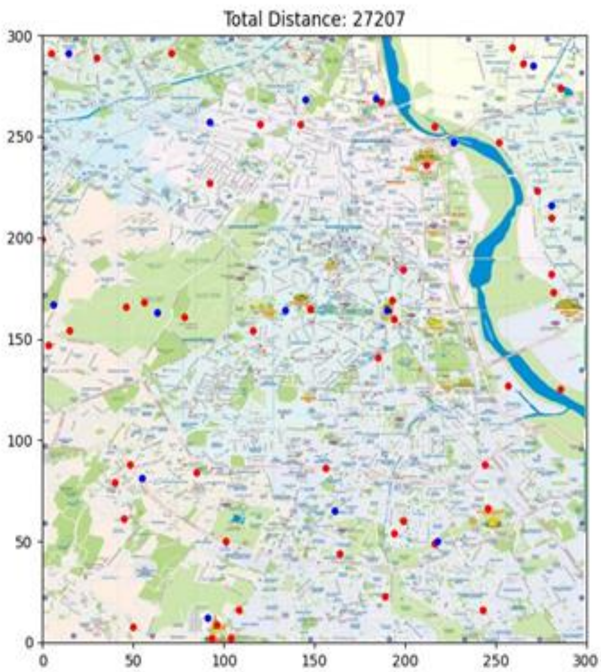
Random initialization



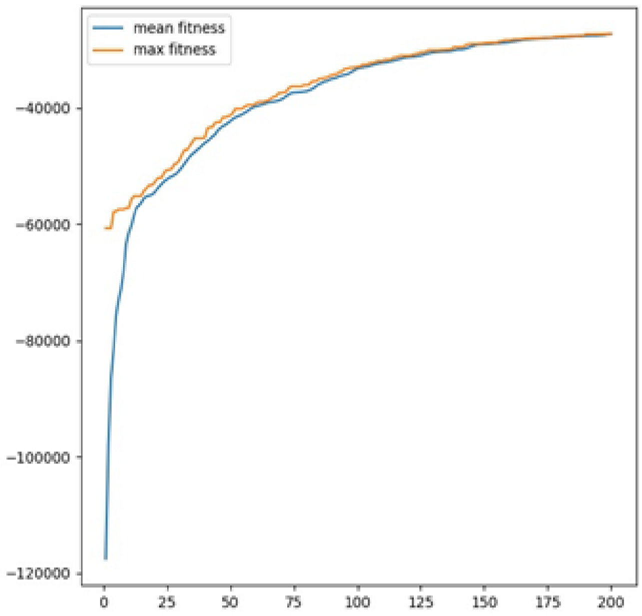
source: Delhi Tourism

Next, we ran the genetic algorithm as described above, using the same settlements given in Random initialization. As you can see in Final optimized locations of charging stations, the algorithm provides the optimum locations for the charging stations, which seem to be distributed throughout the city.

Final optimized locations of charging stations



Graph of fitness over 200 generations



The fitness of the entire population over the generations is given in Graph of fitness over 200 generations. The algorithm was run for a population of 100 for 200 generations, and as seen in the graph, it seems to have converged at an optimum.

Random initialization as shown above has randomly distributed charging stations. Final optimized locations of charging stations shows charging stations found by our algorithm. It shows a more uniform distribution of charging stations which ensures a lower level of range anxiety, due to the stations being more accessible throughout the city. This algorithm can be applied to other areas with specific settlements to find the most optimal placement of EV charging stations.

V. FINDINGS AND CONCLUSION

To alleviate range anxiety, we devised a genetic algorithm approach to determine the best possible position for electric vehicle charging stations. We put this technique to test on a small section of Delhi to see how effective it is. We tried to decrease the distance between random settlements and charging stations using this approach. The genetic algorithm demonstrates a more equal distribution of charging stations, which ensures a reduced level of range anxiety due to the stations being more accessible across the city, by initialising random settlements and charging stations marked in red and blue dots, respectively. As a result, with this method, you may lessen range anxiety in whichever location you want.

LIMITATIONS

Despite solving the major concern which people have in general regarding EV, there are a few gaps. The first one being that of geographical area. We have estimated the number of charging stations which will be needed in Delhi, if people move from the traditional fuel based vehicles to electricity based vehicles. However, we have not covered the entire country. We have also assumed that the buying behaviour for EV in India will rise due to our aim of decreasing carbon emission by 2035. However, the pandemic has affected the purchasing power and thus the ability of mass to afford an EV remains vague. We have not assumed the cost and the time factors in our problem. This means that we have considered that all the charging stations in Delhi will be the same company and therefore the cost of charging the vehicle will be the same at each and every charging station. The consumers will not be biased towards any charging station based on cost. We have also assumed that the time taken for all the cars will be the same and will not vary from one charging station to another. With the absence of these assumptions, the problem proved to become multidimensional and complex.

RECOMMENDATIONS

For getting the correct estimate of the charging stations needed in Delhi, we used a genetic algorithm. However, we performed the algorithm on Delhi and not the whole country. Thus if there is any future research conducted on the same topic, it would be more beneficial if it is done for the whole country. Due to the lack of available data on demand and purchasing power, we had forecasted it. However, had the actual data been available, the algorithm would have been more accurate. In the future, apart from distance, cost and time dimensions will make this extremely similar to a real life problem. This will help us understand range anxiety more clearly.

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