Optimal Placement of Charging and Swapping Stations for Electric Vehicles

A Thesis Submitted in partial fulfillment of the requirements for the degree

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In

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Abstract

Smart planning is the need for the hour to smooth transitioning of dependency on fossil fuel-based vehicles to renewable energy-based vehicles. Electric Vehicles(EVs) are the most promising clean-energy transport medium in the upcoming future. These require charging facilities frequently across the city. Numerous advancements and studies are done to increase the driving range of Electric Vehicles. Some cities possess Fixed Charging Stations, but due to the continuous increase in the number of EV users, they will be overburdened. One possible solution to overcome this load is to use mobile charging stations in places of increased demand. This work focuses on placing those Mobile Charging Stations along with the upcoming Fixed Charging Station so that the EV charging demand can be met. Mobile Charging Stations will also be beneficial to charging station owners owing to more customer coverage with lesser fixed capital costs. A Modified Genetic Algorithm is used to fit the optimal location of charging stations based on minimizing the distance of demand points from their nearest charging station. The shortest path was found using Dijkstra's Algorithm. The algorithm was performed over the map of an Indian city, Guwahati to analyze the realistic outcomes. The algorithm was tested for a different number of runs performed, and an analysis based on the results was made. Interpretations regarding the right choice of the number of Mobile Charging Station to be deployed are achieved in the end.

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Chapter 1 : Introduction

1.1 Background

Electric Vehicles are the future of transportation, owing to depleting fossil fuel left or the pollution control reasons. In mechanical engineering point of view, there exists two reasons why EVs have such bright future. Firstly, internal combustion engines have lower torque at low rotational speed as compared to the electric vehicles. EVs save the power at temporary stops while combustion engines continue wasting energy throughout. This is a huge concern in populated metropolitan areas. Secondly, combustion engine has narrow low torque output range compared to EVs. So, the transmission system becomes simpler and energy conservative in case of EVs. According to Miller et al. (2011) report, the power station to wheel conversion efficiency of EVs is around 60% while that of combustion engines is around 20%, which is a green flag for EVs.

Under the government scheme it is evident that EVs are very soon to be seen running on the streets. Government of India, under its **Faster Adoption and Manufacturing of Electric Vehicles(FAME)** scheme, aims to penetrate 30% of EVs to the roads by 2030. Subsidized buying option and tax resumption for using EVs will attract new buyers to the table.

Along with the fast growing EV market, the battery demand have gone through the ceiling in past few years. A huge amount of public and private funds are ready to be invested in establishing the charging station network in the coming days. Along with the power producing giants, the battery manufacturers have a lot of space to grow.

According to the Public Notice issued by Government of Assam, "the State will target and support the deployment of the first two lakh electric vehicles either under individual use or commercial use during the policy duration of 5 years".

Vehicle Type	Target Units by GOI
2 wheelers	100000 units
3 wheelers	75000 units
4 wheelers	25000 units

"All the buses, government vehicles, commercial fleets and logistic vehicles will mandatorily be battery based by 2030" says the Government of India's article.

Incentives not only for EV adoption, but also to establish Charging Infrastructure is planned by Government of India. "Commercial public EV charging stations for 2 wheelers, 3 wheelers, 4 wheelers will be eligible for 25 % capital subsidy on equipment/machinery subject to maximum limit of Rs. 10 lakhs per station" which is a huge decision towards EV adoption.

Chapter 2 : Optimal Placement of Fixed Charging Stations

2.1 Introduction

As Government bodies have adopted cleaner fuel consumption to reduce greenhouse gas emissions in the current day, there are high demands of substitution of fossil fuel based vehicles to Electric Vehicle in the near future. In a city like Guwahati, India with minimal existing charging station facility it is observed that there is a lack of motivation for fossil fuel based vehicle owners to switch to more clean fuel based vehicles like EVs. For the managing body to take decisions on deploying appropriate number of charging stations and their locations, proper planning need to be made that emphasis on each and every practical challenges that it might face in future.

The right placement of charging stations may not only help the vehicle owners to upgrade to EVs but also increase the driving range of electric vehicle in a single charge. This will directly impact on the battery's 'State of Charge' and improve the battery life commendably.

<u>Types of Electric Vehicles and Electric Vehicle Charging Stations</u>-

Among other developed technologies, EVs have attracted a lot of interest as an alternate mode of transportation that is becoming a component of the modern transportation system. The EVs are mainly classified into three types, based on the source of electricity for the vehicle's propulsion, namely-[1]

a) Hybrid Electric Vehicles(HEVs)

b) Plug-in Electric Vehicles(PEVs)
c) Fuel Cell Electrical Vehicles(FCEVs)[1]

HEVs use both an electric propulsion system and an internal combustion engine for propulsion. Compared to conventional internal combustion engine vehicles, this is done to obtain higher fuel economy, lower emissions, and a more extended driving range, among other benefits.[1]

The BEV is powered entirely by rechargeable batteries and has an electric propulsion system. PHEVs have an electric propulsion system powered by a battery, but they also have a gasoline engine that can be utilized as a backup if the battery runs out. FCEVs have an electric propulsion system that uses fuel cell technology instead of a battery, or in addition with a battery or supercapacitor. [1]

Electric vehicle supply equipment (EVSE) is an essential element of the charging infrastructure for electric vehicles. It provides EVs with electrical energy for charging from various energy sources. Its classification is determined by many parameters, including the type of power supply, charging station integration with the power grid, charging power levels, charging infrastructure, mobility, and power flow direction. The following is a classification of EV charging stations based on many factors. [1]

a) Alternating current (AC) power supply based EVCS
b) Direct current (DC) power supply based EVCS

<u>Types of Charging Ports</u>

<u>Slow charging</u>- Constant Current (CC) charging uses a single low-level current to charge an exhausted battery. The current level is set at 10% of the battery's

maximum rated capacity. Nickel-cadmium and nickel-metal hydride batteries are the ideal choices for this method of charging. If the battery is overcharged, gassing and overheating may happen. In Taper Charging, little current is applied to compensate for the battery's self-discharge. Taper charging uses uncontrolled Constant Voltage (CV) charging, which can cause catastrophic battery damage if done incorrectly. On the other hand, Float charging uses the Constant Voltage(CV) approach below the battery's upper limit. This charging method is suited for lead-acid batteries and is commonly used for emergency power backup systems. [1]

Rapid Charging - Since Lithium-ion batteries have better power and energy densities than traditional batteries, most commercial chargers employ the Constant-Current(CC) & Constant-Voltage(CV) charging approach to charge them. The CC-CV technique has the advantage of limiting charging current and voltage through a battery controller, which prevents over-voltages and reduces thermal stress. A CC is used to charge a battery until it reaches a pre-defined voltage level, and then a CV is employed to attain a termination condition. Charging in CC mode is faster than charging in CV mode. Over-voltage charging can cause b-cell loss. Hence the CV mode is employed to prevent it. [1]

2.2 Literature Review

In the previous studies, researchers have worked to address major problems that are encountered in finding the right method to place charging stations

In the study proposed by Henrik et al, the possibility of an Electric vehicle running out of energy without being given a chance to reach the nearest charging station is emphasized as the top priority and minimizing the total number of charging station with keeping this constraint in mind. As inside an urban city it is more likely that an EV owner may consider a round trip more than a trip with distinct initial and final positions. Henrik's work focused on Non-Urban & Long distance non-cyclic trips.[2]

The traffic flow behavior & data is considered using link flow models, which is the average number of vehicles travelling across each of the links in the known network using sensors such as pneumatic tubes.

An iterative approximation technique using Route-Node Coverage method is adopted in Henrik's study. A "random walk" is done and the distance walked is measured continuously. As soon as this measured distance crosses a certain limit, a charging station is allocated at that place. The distance variable is reset to 0 and the process is repeated until sufficient iterations. As a result, a map consisting charging stations placed at constant distance is obtained. The problem of a vehicle running out of energy with not a charging station in its driving range is hence solved here. But, this may not be the optimal number of charging station.

The major drawback in this approach was the scarcity of resources. Developing nations like India, there are very limited funds to develop the infrastructure. Hence, with this huge number of charging facilities it becomes infeasible for the governing authority to take actions.

Huag Kai et al observed in the most reserces done before, demand is take in discrete points, but this is not particularly true. Because demand can be anywhere Hence only partial coverage is addressed.[3]

The approach given in his paper was to use 'Lease common demand coverage units(LCDCUs)' that either cover the candidate's location or do not cover it at all. Now another question may arise that how the demand is defined. In Huang Kai's research, each road weight is taken as road length multiplied by road traffic. Then minimize the total cost of charging stations with constraints like each point is covered by one charging station. Fast and Slow charging stations are allocated in Huang Kai's work. Since fast charging stations have larger coverage than a slow charging station as per convention, both fast and slow charging stations are fitted such that there is the least common coverage area and the least uncovered area.

Another study by Ying-Wei Wang et al gives an approach to use Mixed Integer Linear Programming to solve the charging station placement problem. The main objective taken in this approach is that a vehicle starting from one node should have sufficient if not less amount of fuel to cover the distance to next charging station else it shall refuel to current charging station only. [4]

As linear models focusses on maximizing/minimizing each objective functions in the constraints, which may not give global optimum with non-ideal combinations of objectives. It is in this context Heuristic Algorithms are adopted to get the global optimum.

Yantao Huang el al’s study, assumes that most Electric Vehicle owners wish to charge their vehicles during the journey or on highways. Aiming to increase the EV owner's profit and convinience, the traffic congession is taken into consideration as a deciding factor for an EV owner to charge a vehicle at a particular charging station. On the other hand, Charging station profit is also maximized by analyzing appropriate number of charging cord and session of chargings. [5]

Another study by Long Pan et al, worked on developing an algorithm that analyse the behaviour of EV owner in charging his electric vehicle. After the analysis, the coverage of the charging station is taken into consideration for optimal placement. Then a case study is done on a large scale of Bejing metropolitian to validate the results. from the study it is evident that an increase in the home charging facility may decrease the missed trip chances. [6]

The introduction of Electric Vehicles in the market shall bring an additional load to the existing electrical power grid system. While coverage area of fast charging station have a direct impact on the load and disturbances generated by charging stations. Locating Charging station problem needs to consider this issue. In Jian Liu's work this problem is addressed and a model is given in the accordance for the same. [7]

2.3 Methodology

Definitions and Notations-

I. Roads as edges- A digraph is used and the major road network is taken as edges and the road length (i.e. length between two end points of a road) is taken as the edge weight.

II. Road end points as Nodes- The meeting point of two roads are taken as Nodes of the graph

III. Distance between two nodes- The shortest distance between two nodes is taken as the distance between two nodes. To calculate the shortest path, Dijkstra's Algorithm for two pair shortest path is used (as edge length is always positive, hence Dijkstra's Algorithm works well here)

IV. Distance between a point on an edge(AB) and a node(C), $d(x_{AB}, c)$- This distance is calculated by taking the minimum of the distances obtained from each node of given edge to the node(C).

V. Charging Station Location(c_j)- As charging station can both present on an edge or a node, hence the charging station location is specified accordingly. The charging station location can range as integer values that exists as distance between two nodes of the edge. For initialization, the charging station location is taken randomly over the map.

VI. Edge based demand to Node based demand- In worst case scenario, the EV owner decides to go to refill when his vehicle battery meter falls below a threshold limit. Now he should be able to reach the nearest charging station without exhausting its battery charge. As this work focuses on demand based placement of charging station the data for demand over an edge is converted to node based by dividing demands on an edge to the two adjacent nodes and subsequently generating the demand weights.

VII. For each demand point, the distance to its nearest charging station should be minimized according to its demand weight. Hence, a function 'Best cost' is defined as-

$$\sum_{j=1}^{m}\sum_{i=1}^{n} D_i * d(x_i, c_j)$$

Where,

If $x_i = demand\ node\ location$

$c_j = charging\ station\ location$

$D_i = demand\ weight\ of\ the\ demand\ node\ 'i'$

<u>Optimization-</u>

Genetic Algorithm(GA) is used to optimize the location of charging station to get the best possible combination.

- Each gene of a chromosome contains the information of location of a single Charging station

- Each chromosome carries the location of all the charging stations and their respective locations
- We define the fitness function by calculating the objective function for each chromosome and saving the results to 'Best cost'.
- The chromosome length is varied from 2 to 8 which is also the number of charging stations.
- The population size is taken 50 and the parents for GA operations are randomly selected from the pool of best population obtained the least fit are discarded at every iteration
- The proportion of the children to the main population is kept to be 1
- One-point crossover is chosen to operate on the two parents selected, the point of crossover is chosen randomly through random module
- For mutation operation $\mu = 0.30$ is taken for this problem(because on an average, to change one gene out of 4 we need to keep μ above 25%)
- While iterating it is seen that the solution converges at 500 iterations

<u>Results & Discussion</u>

Figure1(a), 1(b) and 1(c) are semi-log plots with log ('Best cost') vs Iterations performed. The figures show the convergence of the 'Best cost' function over the run of 500 iterations for different number of charging station chosen. The 'Best cost' obtained for varied number of charging stations are-

Number of Charging stations taken	'Bestcost' function value
2	83.83
3	65.02
4	52.67
5	42.87
6	37.56
7	32.06
8	27.42

Figure 1(a)

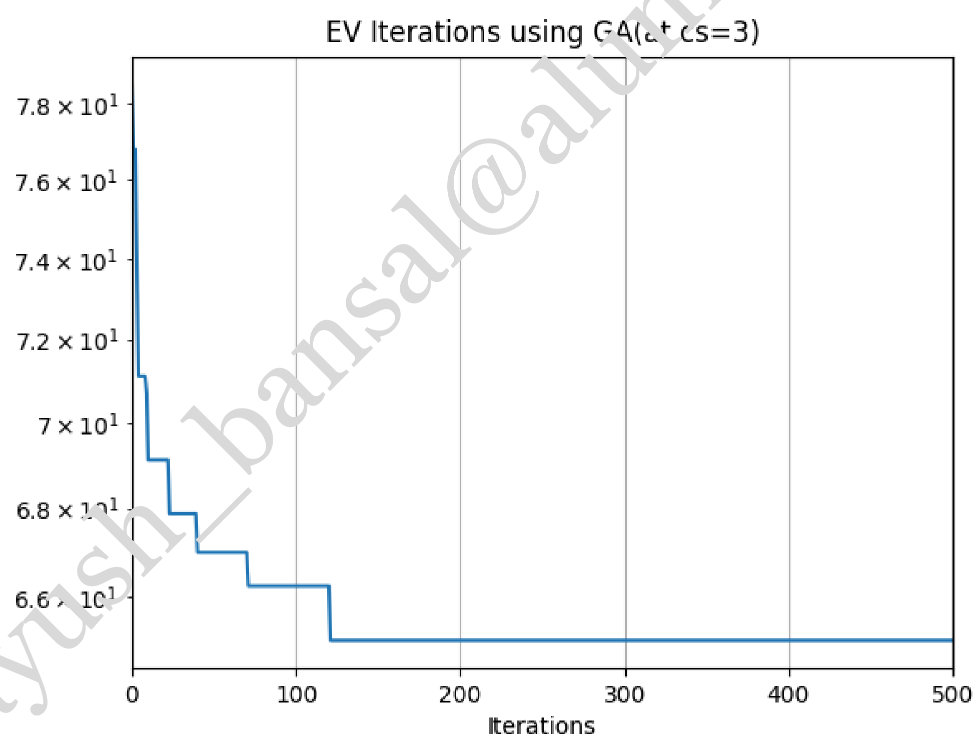


Figure 1(b)

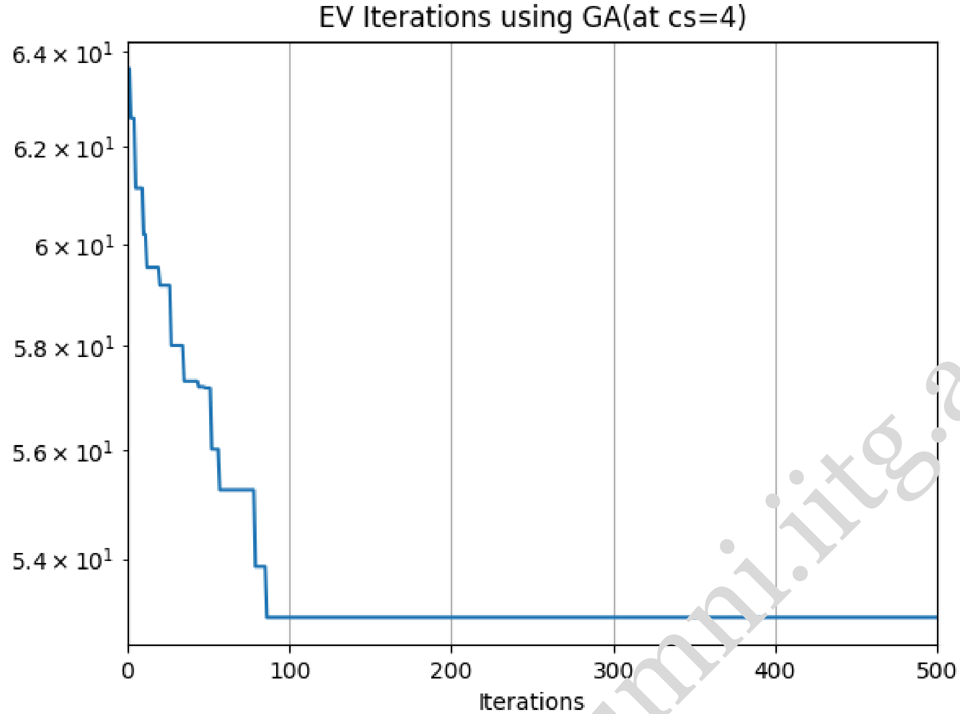


Figure 1(c)

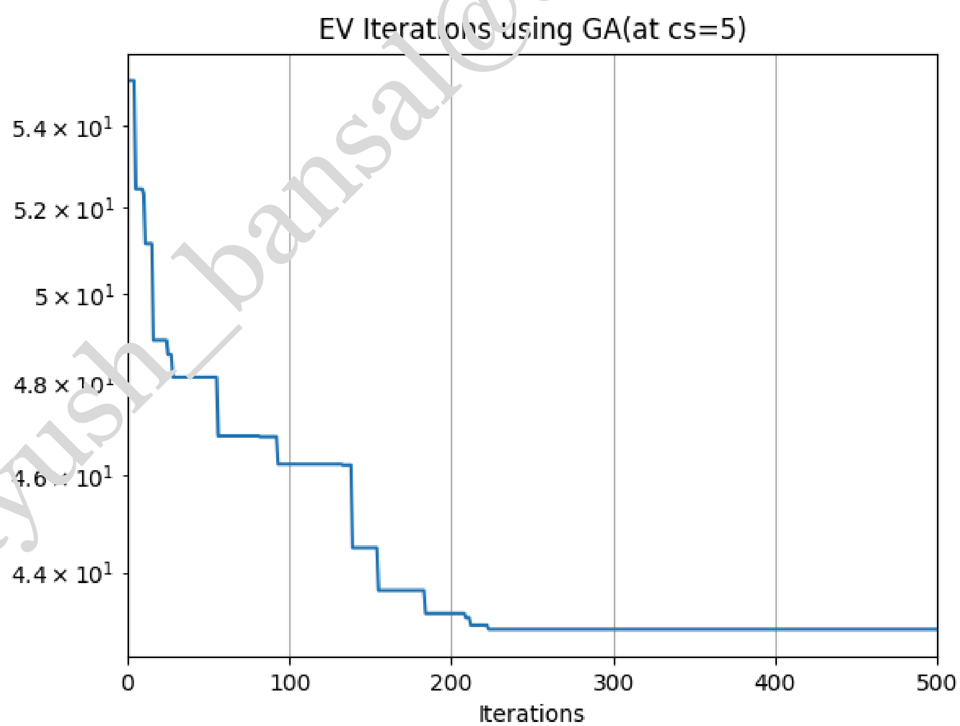


Figure 2(a), 2(b) and 2(c) shows the optimized location of charging stations in the Sioux Fall's plot of 24 nodes.

Figure	Number of charging station placed
Figure 2(a)	3
Figure 2(b)	4
Figure 2(c)	5

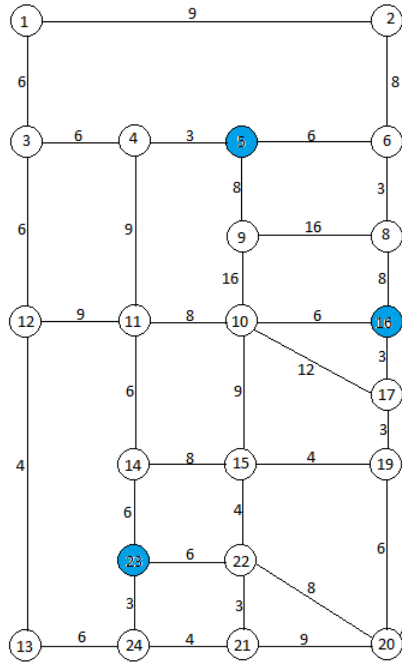


Figure 2(a)

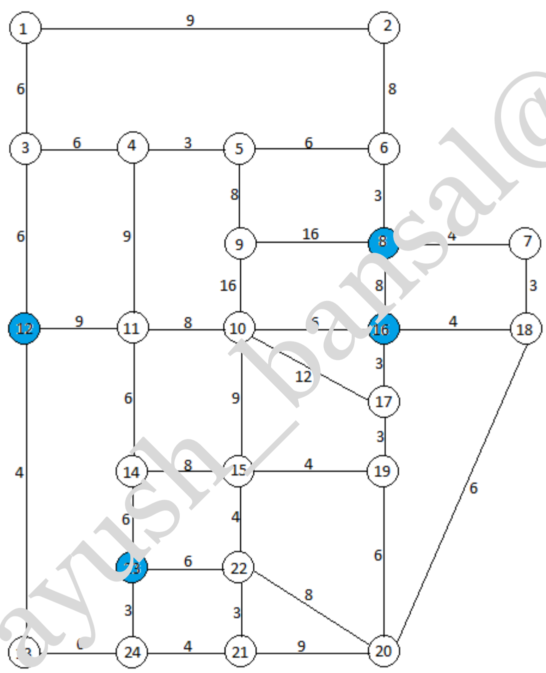


Figure 2(b)

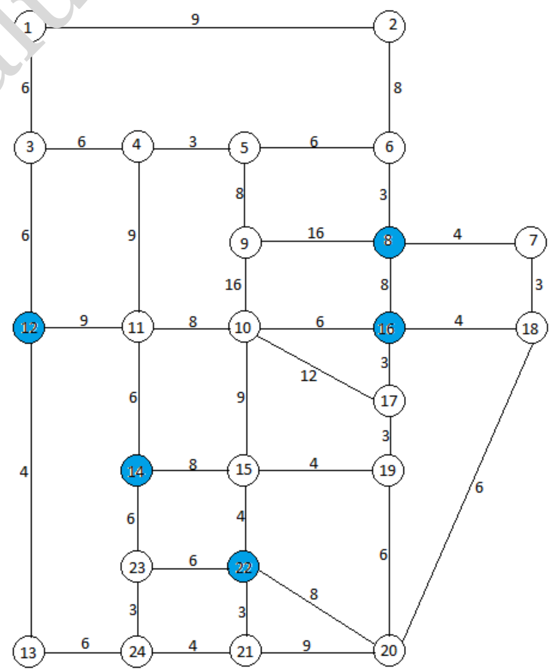
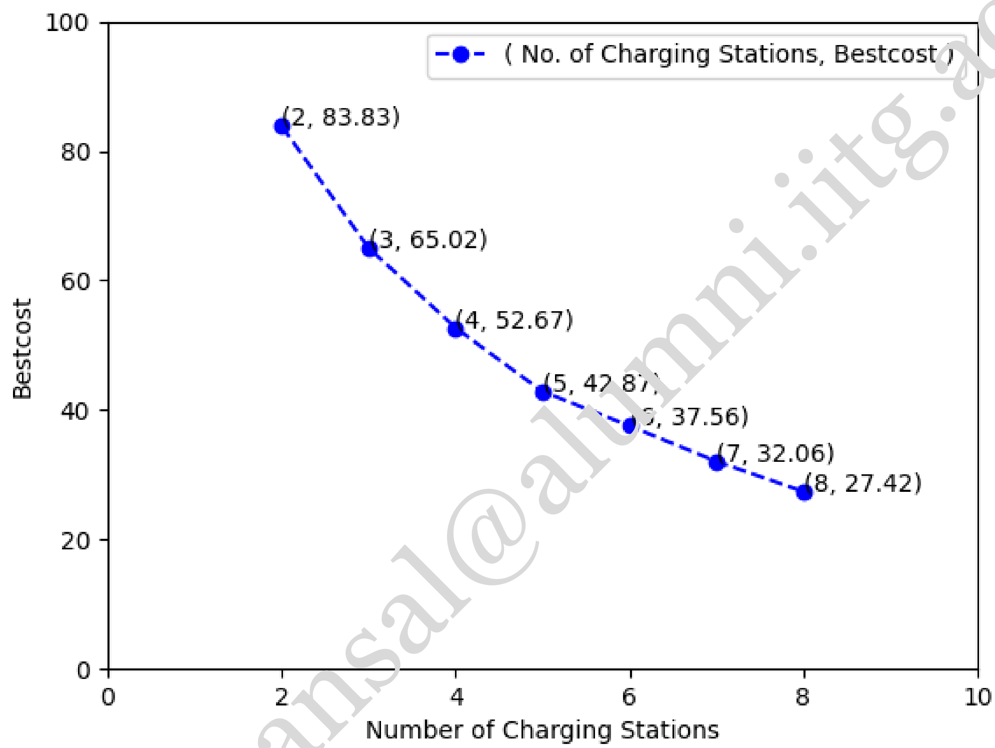


Figure 2(c)

Figure 3 is a plot of ‘Best cost’ vs the number of charging stations. ‘Best cost’ gives the overall cost of reaching the nearest charging station from the current position of an EV owner. It is clear from this plot that as the number of charging stations are increased for placement, the ‘Best cost’ is decreased.

Figure 3



2.4 Conclusion

Finding good optimal outcomes for this problem using revolutionary meta-heuristic techniques is quite challenging. There are numerous approaches of allocating charging stations based on various objectives. However, employing Genetic Algorithm to solve this problem is a more powerful technique than using linear models. The demand points data generated have a significant impact on the accuracy of CS location prediction.

Future steps may include study in mainly three directions.

- ✔ Firstly, more accurate and easy data collection for predicting the promising results needs more attention.
- ✔ Secondly, considering more practical problems that may be encountered over the time should be taken into account while solving the problem.
- ✔ Thirdly, the EV driver behavior need to be studied more closely through some agent based simulations which may bring more practical validation to the work.

Chapter 3 : An Optimization model to allocate mobile charging stations along with the existing Fixed Charging Stations

3.1 Introduction

There is enough evidence of Electric vehicles making it to the automobile market and replacing gasoline-based vehicles. However, with limited funds and resources, it is also clear that charging demands will be hard to satisfy fully until the supply is established adequately. In the hours of increased demands, the 'Fixed Charging Stations' may get burdened and may excessively increase the waiting time of the EV owners. It results in a huge mess and fewer chances of EV success in the transportation area. With the uneven distribution of electric vehicles across the city, the prediction of demands is also tough to predict. So in order to ensure the 'Range anxiety' of EV owners is taken care of, a more foolproof plan is required.

An easy solution to this problem is using Mobile Charging Stations along with fixed charging stations. Mobile Charging Stations are vans and trucks that carry batteries large enough to charge an electric vehicle so it can continue its journey. In the economic view, Mobile Charging Stations would be quiet cheaper than the existing Fixed Charging stations which have land cost, large capital investment cost, equipment cost, maintenance cost etc. Beside the economic perspective the sudden heavy load on power grids due to installation of Fixed Charging Station in the city is unavoidable. In the case of shifted traffic from a particular zone in a city, it is possible that a charging station may be left underutilized with empty charging slots for a long time which may result in huge losses. Furthermore, in the case of high demand and low supply, the Fixed Charging Stations will be burdened heavily. For a developing country like India with a huge population, it is advantageous to introduce Mobile Charging Stations as it may also bring employment opportunities to the table.

3.2 Modeling and Solution Approach

The model proposed in this work is an optimization model that gives the best location to place the chosen number of Mobile Charging stations and the existing Fixed Charging Station. The model uses the idea of Genetic Algorithm, which keeps on updating a better solution through subsequent iterations. Since the city graph data is quite big, hence it is wiser to choose Genetic Algorithm over linear programming due to the high computational time and cost. However, the problem can still be modeled in linear programming.

3.2.1 Required Input Data and Data Processing

A lot of geographical data is available for a city map. However, to work upon in our model, we require the meeting point of roads as 'nodes' with their appropriate ids. The nodes are provided with their latitude and longitude measurements to be traced back to the actual map itself. The road connected from the source node to the target node will be called the 'edges'. Some roads may be one-way only; hence only one-sided node-to-node distance is provided. The foot travel lane, bike travel lane, and car travel lane defines how wider is the road network. This information helps predict the traffic flow and the possibility of probable demand on that road. And at last the longitude-latitude of the source and destination nodes.

Besides these data, the vehicle population data taken at different time intervals of the day is required. This will help us predict the demand and maximize the coverage across the city map. The data for blocked roads, construction sites, private roads, and no traffic zones may help the model to give more relevant results. As the objective is to maximize the number of Electric Vehicles covered, the data for the number of Electric Vehicles sold and running in the city, along with the total number of vehicles, including fossil fuel-based ones, will help the model precisely decide the right coverage. The data for the daily running capacity of the fixed charging stations with the faulty ones may help to lessen the burden on fixed charging stations by assigning Mobile Charging stations near them accordingly. The data for the approved funds to set up new charging stations can be used for further planning purposes. The weather data may help decide the requirement of the number of Mobile Charging Station to deploy on that day.

The data processing can be cumbersome for a large city. It is advisable to make its appropriate sizable chunks so that the algorithm can be run parallel and save time and computational effort. Sometimes the over-precision in the location (latitude-longitude) of the node can create a problem by making the graph disconnected. So adjusting the precision values can help connect the data. The same need to be updated in the edges data. Even after data cleaning, it is possible that there are disconnected edges and sparse graph areas. These areas can further be corrected by several graph theory techniques. Some researchers have used tour record data to identify the rush on a particular road, but the content of EVs in the total vehicle volume remains undetected. This can be solved using a regression model that can specify the EV share geographically.

3.2.2 Assumptions

Assumption 1: Shortest path taken every time

An Electric Vehicle is assumed to take the shortest path from its origin to its destination journey. Although our Mobile Charging Station allocation is based on capturing model, still it is evitable that random walk through the map may bring exceptional points that may be left uncovered.

Assumption 2: Threshold limit of Electric Vehicle (lim%)

To counter the range anxiety, an EV owner will go for en-route charging only if his EV battery State of Charge falls below the Threshold limit assigned to the particular vehicle type. It is assumed that an EV owner starts his journey with a full charge or sufficient charge to cover his journey. This battery threshold will be decided by the vehicle maker or certain organization that has calculated the safe zone for recharging the battery.

Assumption 3: A mobile charging station gives enough charging to let EV complete its journey only inside the city area

Once the battery SOC of the EV owner falls to the threshold limit, it is known that he looks to recharge his EV battery. As the mobile charging stations are also limited and they need to provide charge to other demands that may occur simultaneously, the charging limit of the mobile charging station needs to be defined beforehand.

Assumption 4: The radius of Mobile charging station is fixed as ‘r’ units of length

As mobile charging stations would only be allowed to sit on the nodes and travel to different directions, they can only go up to a distance 'r' from their starting point. Else too much energy would be utilized by the charging vehicle to do its job. Also, it is hard to cover different directions if the radius is too long.

Assumption 5: Conversion of edge demand to node based demand

As the vehicle population of the road is known, it was divided into two halves and assigned to the two nodes connecting the edge. This is done for all the edges of the city map so that a demand based on number of vehicles is obtained.

3.2.3 Objective Function

As the aim of this model is to maximize the coverage of EVs across the city map, hence the part-1 of the objective function gives the sum of the demands from each node where a mobile charging station is placed.

$$f(x) = \sum_{i=1}^{n} dmd(i)$$

n = number of mobile charging stations

$dmd(i)$ = demand of the i^{th} node where mobile charging station is placed

Now, as we get the demand of the current node, our mobile charging station will move to the connected paths and cover the demand of the approachable nodes.

The part-2 of the objective function gives the coverage by moving the mobile charging station-

$$g(x) = \sum_{i=1}^{n} \left(\sum_{R=0}^{r} dmd(j) \right)$$

r = radius of the mobile charging station

R = distance travelled by the mobile charging station from its parent node

$dmd(j)$ = demand of the j^{th} node where mobile charging station have reached

Coverage Function :

```
Coverage(node,r,set):
    if r<0 or (node not in graph):
        return
    for ele in graph(node):
        if graph(node,ele)<r and (ele not in set):
            set = set U {ele}
            Coverage(ele,r-dist(node,ele),set)    (recursive call)
```

To max utilize the fixed and mobile charging station it is best to use place them at least '3r' distance apart unless the demand of the node is too high to satisfy.

Hence the part-3 of the objective function becomes-

$$h(x) = -\ l_1 * \sum_{i=1}^{n} \left(\sum_{j=1}^{m} dist(mcs(i), fcs(j)) \right)$$

the $dist(mcs(i), fcs(j))$ is considered only if it is less than '3r' else 0

$mcs(i) = i^{th}$ mobile charging station

$fcs(j) \ = j^{th}$ fixed charging station

n, m = number of mobile and fixed charging stations resp.

Now, we want the mobile charging stations to be dispersed out and be at least '2r' distance from each other unless the demand of the node is too high to satisfy.

$$k(x) = - l_2 * \sum_{i=1}^{n-1} \left(\sum_{j=i+1}^{n} dist(mcs(i), mcs(j)) \right)$$

Here the $dist(mcs(i), mcs(j))$ is considered only if it is less than '2r' else 0

$mcs(i) = i^{th}$ mobile charging station

n = number of mobile charging stations

l_1 and l_2 values are chosen so that the model can fit appropriately

So fitness function becomes-

$$F(x) = f(x) + g(x) + h(x) + k(x)$$

3.2.4 Solution Technique

The idea of the Genetic Algorithm was used to solve the problem. Each gene contained the location of a set of the mobile charging station and the fitness function value assigned to it. Firstly, the population of these genes was initialized with the number equal to 'n_{pop}' . The fitness function values for these members was then calculated and stored in the respective gene. Then, iterations were started.

Parents were randomly selected from the general population and mated to get two new offspring. This crossover was done on a random point over the genes.

The fitness function of these offspring is calculated, and the 'best solution' is updated if their fitness function has a higher value.

Then the offspring are mutated to check if a better value can be obtained. The mutation was performed at multiple points selected randomly over the gene length. The fitness function of the resultant genes was checked and updated to the 'best solution' if a better solution is obtained.

Algorithm:

1: t = 0;
2: InitPopulation[P(t)]; {Initializes the population}
3: EvalPopulation[P(t)]; {Evaluates the population}
4: **while** not terminate **do**
5:     P'(t) = Variation[P(t)]; {Creation of new solutions}
6:     EvalPopulation[P'(t)]; {Evaluates the new solutions}
7:     P(t+1) = ApplyGeneticOperations[P'(t) U Q]; {Next generation pop.}
8:     t = t + 1;
9: **end while**

3.2.5 Case Study

A case study on the city map of Guwahati, India, was done to see how the algorithm works on the real city map. As the basic requirements of the algorithm are quite simple data, it can be extended to any city. The Guwahati city-data had 16,292 edges and 12,311 nodes. The data needed to be cleaned first as there existed a lot of unconnected edges. As the precision of locations was too high, it made the graph to be disconnected, and the duplicacy of the nodes.

After making the data ready for use, it was imported and worked upon. Since the $(number\ of\ edges) << (number\ of\ nodes)^2$, we avoid Floyd Warshal's algorithm(time complexity $O(V^3)$) for calculating shortest path. Dijkstra's Algorithm with the time complexity of O(E*logV) was used to calculate the shortest path.

Dijkstra's Algorithm:

```
Dijkstra(G,w,s):
   Initialize-Single-Source(G,s)
   S = Ø
   Q = G.V
   while Q ≠ Ø:
      u = Extract-Min(Q)
      S = S U {u}
      for each vertex v ε G.Adj[u]:
         RELAX(u,v,w)
Relax(u,v,w):
   if v.d>u.d + w(u,v):
      v.d = u.d + w(u,v)
      v.π = u
```


3.2.6 Case Study Analysis and Results

Many iterations were performed to know 'the sufficient number of iterations required to get the optimized results. A 'Best Cost vs. Number of Iterations' graph was plotted to know the same (see figure 1). This curve is known as the convergence curve. So, this curve shows as iterations progress how much improvement is seen in the objective function value. In this case, it seems to have converged to global optima, so there is not much visible change seen in the fitness function value. So the performance of the algorithm can be seen as iterations proceed how we are improving in the best solution we have. The curve is monotonically increasing as it is a maximization coverage problem.

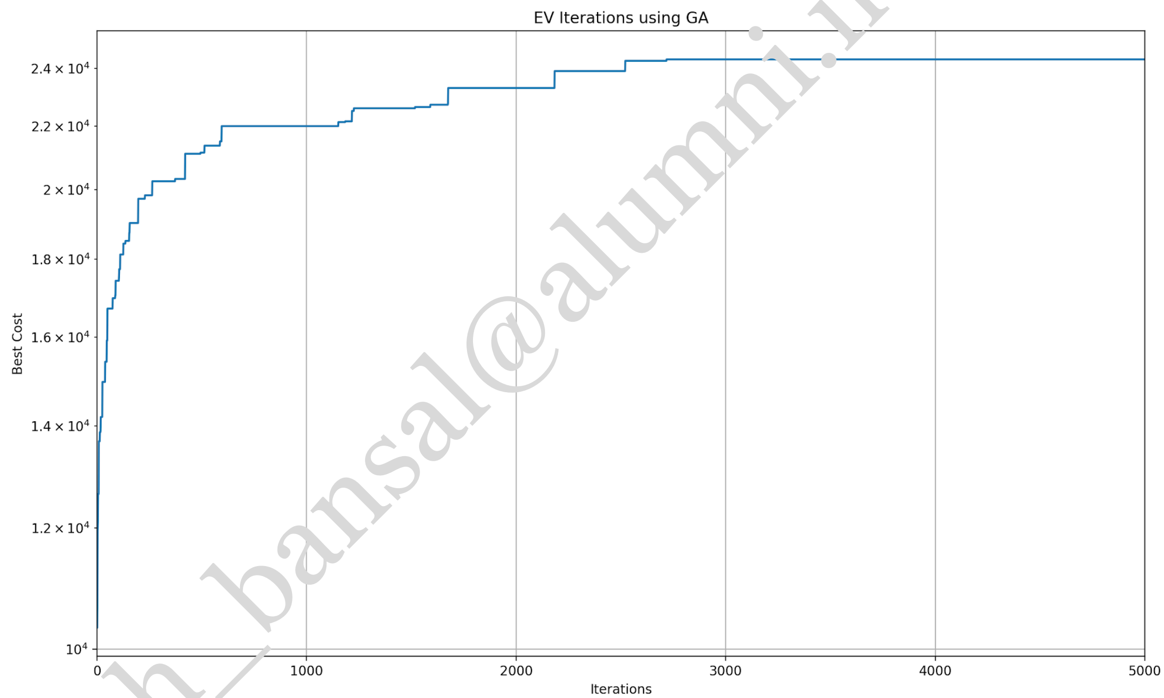


Figure 1

After the iterations are performed, we get the best locations of the charging stations as a result. The location coordinates are then plotted on the real map of Guwahati city, as shown below in Figure 1.1. There are 20 numbers of Mobile

Charging Stations (in blue) placed along with the existing Fixed Charging Stations (in yellow).

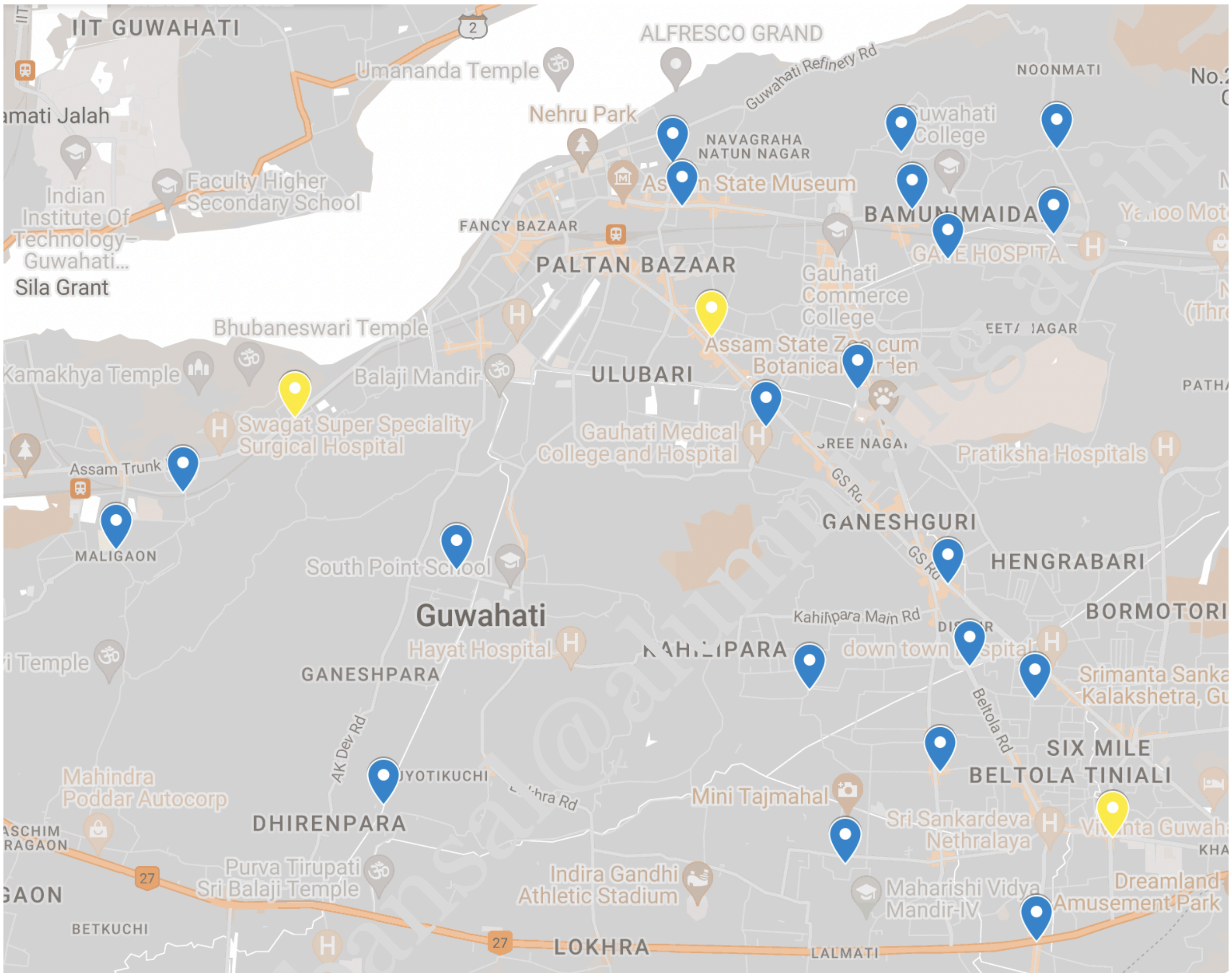


Figure 1.1

It may be noted that a Mobile Charging Station can cover the neighbor nodes until they are within the specified coverage radius of the Mobile Charging Station. More the Number of Mobile Charging Stations deployed across the city, more will be the coverage. It tends to maximize the covered number of vehicles running on the roads when vehicle population data is collected. Figure-2 shows the coverage as a function of Number of Mobile Charging Stations. This graph will help us determine what is the optimal number of Mobile Charging stations need to be deployed without over-deploying them (reduces resource wastage).

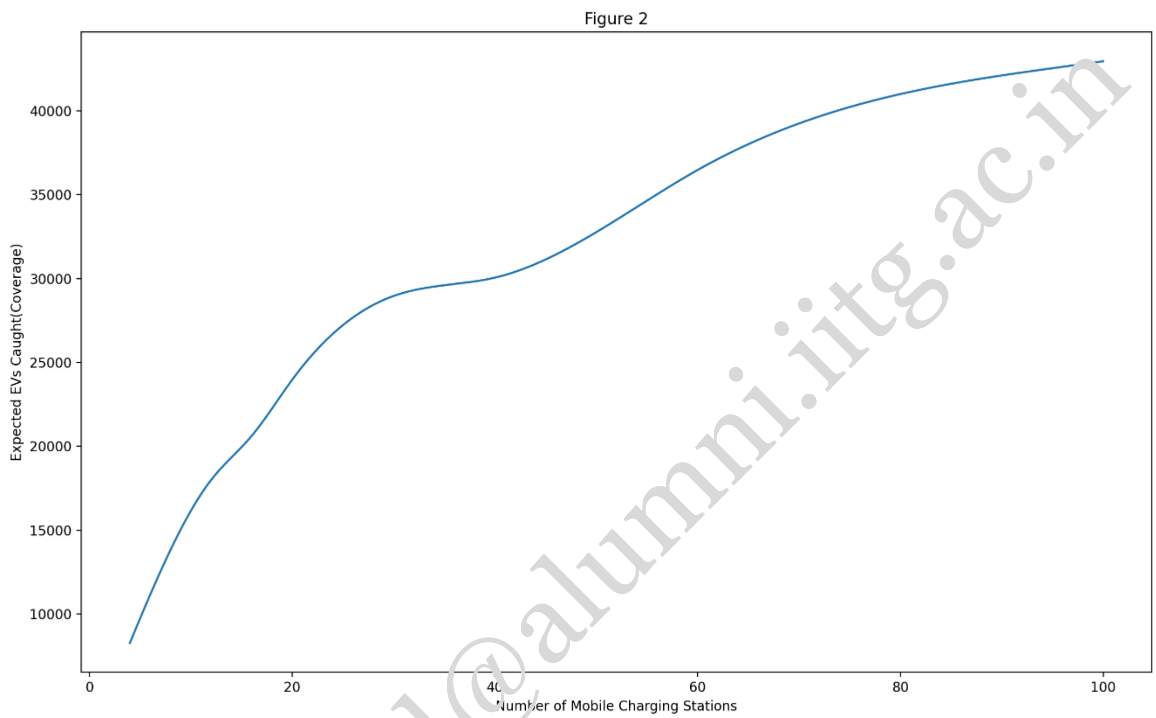
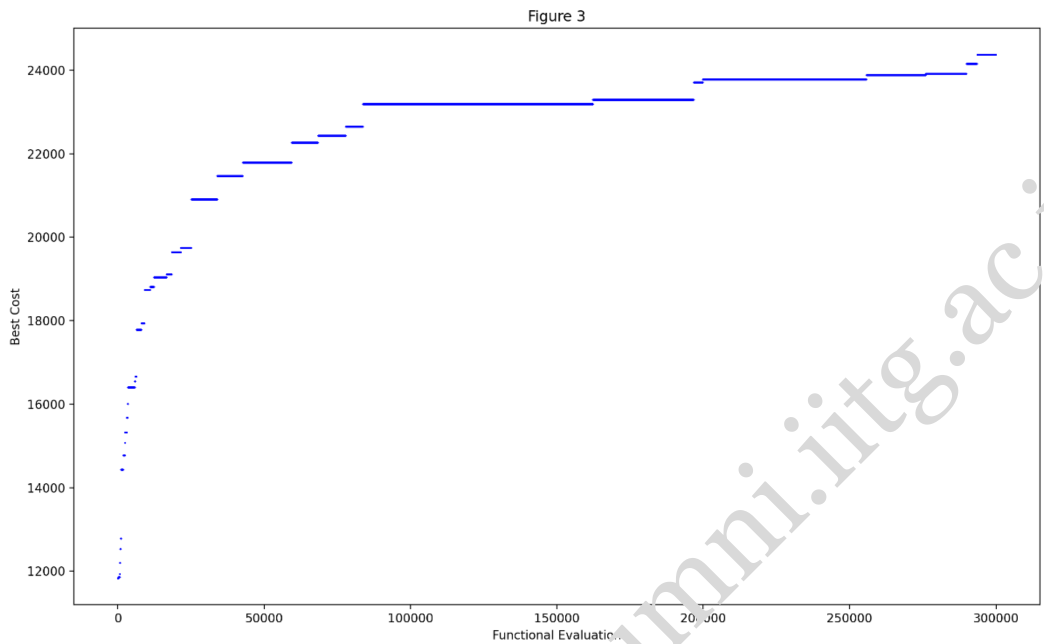


Figure-3 shows the coverage as a function of 'Functional Evaluation' which is the value of Best solution at every time the Fitness Function was evaluated. The Algorithm was run Multiple times for $n_{var} = 20$ and $iterations = 3000$ and keeping all other variables to be constant. It can be seen that the graph is monotonically increasing, which is a sign of convergence to maximize the coverage.



3.2.6 Conclusion and Future Works

This chapter introduces a ‘Coverage Maximization’ approach to tackling the demand, which is unpredictable across the city map. As the Electric Vehicle can reach its threshold limit at any place across the city, the coverage approach gives a better solution to this problem. The idea of the Genetic Algorithm is used to get the optimal location of these charging stations. The placed Mobile Charging Stations can reach the neighbor nodes and increase the coverage. The demand for these neighboring nodes was added to the fitness function using a ‘Recursive Function’. It is also evident now that, given the cost-effectiveness, the Mobile Charging Station can be used temporarily in the areas where Fixed Charging stations are yet to be built. Also, in the cases of increased demands, Mobile charging stations can lessen the burden on existing Fixed Charging Stations. An important feature of this algorithm is that it uses very basic and easily available data to give the optimal locations. Hence, it is easily scalable to other cities and can also be modified according to the need. For finding the shortest path over a large network, we use ‘Dijkstra’s Algorithm for shortest path’, which itself is an optimized algorithm. The time needed to run the algorithm, even for a huge data, is bearable. The management body can obtain the locations multiple times in a day and assign the Mobile Charging Stations accordingly. This algorithm can be clubbed with other processes of transportation research.

The algorithm was used to find the Optimal Mobile Charging Station locations for the Indian city of Guwahati. The city map of Guwahati consists of 16,292 junctions and 12,311 roads as edges. With a total 4-wheeler population of 3.8 lakhs, the government targets to reach 30% EV penetration by 2030. The analysis shows the convergence of the function and maximization of the Number of Electric Vehicle coverage. The location of these Mobile Charging Stations was plotted on the real map. This work will also help the decision-making body to choose the right number of Charging stations to be deployed each day.

The future work may include studying the existing EV population using demographic and geographic data and predicting the same. This may help us to locate the charging station in more accurate way. Also, the goal of reducing the ‘range anxiety’ of EV owners shall be accomplished. Furthermore, with the increase in charging demand, the power supply need to match. Hence, sufficient planning need to be done to resonate the demand and supply between power production houses and EV consumers.

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