City specific Cost Minimization for EV charging centers

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Abstract - *This research paper aims to identify the most suitable charging locations for electric vehicles (EVs) to meet the increasing demand. The suitable charging location should have minimal installation costs and can achieve maximum utilization, reaching the break-even point as quickly as possible. To accomplish these, the authors implement a cost minimization algorithm to optimize the overall expenses involved in establishing EV charging stations in Mumbai and Delhi. The primary cost factors considered in this optimization process are installation costs, land acquisition expenses, transportation cost, and maintenance costs. Furthermore, the study sets boundary parameters, such as the maximum capacity of EV stations, to ensure that the proposed cost minimization solutions are practical and realistic. The study findings reveal that the break-even point for Delhi is achieved in 420 days, while Mumbai is projected to reach the break-even point in 503 days. These results highlight the potential viability and financial feasibility of the proposed charging station locations in both cities, providing valuable insights for addressing the growing demand for EVs in an economically efficient manner.*

Key Words: **Electrical vehicles, charging stations, cost optimization**

1. INTRODUCTION

The rising demand for Electric Vehicles (EVs), particularly in metropolitan areas, has led to a corresponding increase in the demand for charging stations to facilitate seamless charging [1-8]. There have been attempts to mitigate the issue of optimized location-based installation of the EV stations. Li et al [2] have provided a break-even analysis for the battery swapped EV stations and have calculated the threshold price on the basis of construction plans and model facilities for a given district. A recent report by the Indian government have also identified and emphasized on the need of an efficient and cost-effective EV station installation to meet the growing demand of electric vehicles in India [3]. Attempts have been made to provide a cost optimization model for the EV station installation. Wherein the factors of assets and liabilities are fed into the optimization model and the overall cost is minimized [4-8]. This surge in EV installations presents new challenges that need to be addressed. The key challenges include: 1. Identifying location-specific demand for charging stations: Understanding the specific areas with high EV adoption and demand for charging infrastructure is crucial for efficient station placement. 2. Conducting a cost evaluation for EV charging station installation: Assessing the expenses associated with setting up charging stations, including installation, land acquisition, and other related costs, is essential for cost-effective deployment. 3. Implementing an optimization algorithm/model: Utilizing optimization techniques to strike the most competitive balance between investment costs and potential profits is vital to ensure the viability and success of charging station projects.

Addressing these challenges will pave the way for a well-organized and economically sustainable expansion of charging infrastructure, promoting the widespread adoption of EVs in urban environments. To initiate the process of identifying suitable charging locations and determining the cost parameters for the charging stations, data from various sources was collected. It was observed that in larger urban agglomerations, the inclination of people to own an EV is higher, resulting in a greater demand for EV charging stations. Subsequently, a thorough cost evaluation was conducted for the EV charging stations. This evaluation encompassed several factors, such as the expense of acquiring the land, maintenance cost, analyzing the demand patterns in different areas, and considering the transportation costs associated with bringing the necessary charging station components to the intended locations. Taking all these aspects into account, a comprehensive cost analysis was performed to determine the overall setup cost for each EV charging station.

After determining and finalizing all the relevant variables mentioned above, the next step involves employing an optimization algorithm to achieve the most cost-effective combination of process variables and installation time for the successful operation of an EV charging station. To accomplish this, a specialized algorithm known as the "capacity facilitated location problem" will be utilized to optimize the current situation. In this optimization problem, the cost of supply will be calculated as the manufacturing cost of the equipment, specifically the chargers. This cost will then be combined with transportation charges, maintenance cost and subsequently with expenses related to land acquisition and installation. The primary objective of this optimization process is to strike a balance that maximizes profitability while considering the overall cost of setting up and running the charging station. By implementing the "capacity facilitated location problem" algorithm, the research aims to find an optimal solution that ensures efficient charging station placement, cost-effectiveness, and long-term profitability for supporting the growing demand for EVs.

2. METHODOLOGY

The workflow planning for the work can be as follows:

- Identifying the parameters which shall determine the location of the EV charging stations: 1. The size of the city, 2. People's mindset (are they willing to switch to EV), 3. Costs and finances of setting up the station
- Capacity facilitated location problem should be used [1]. This model will encompass the demand of EV stations (which will depend on the number of EVs at a given place) and the supply capacity. For the supply capacity, we must see or find the companies which shall manufacture the charging stations.
- These parameters shall be bought together and an optimization function shall be developed. This optimization function will optimize the cost and logistics parameters and provide the best results.

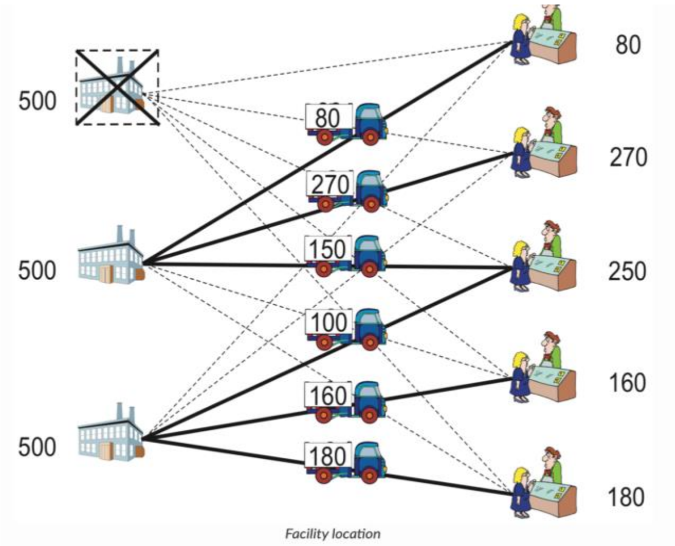

Figure-1: Representation of demand-supply chain for a facility location problem [1]

In the present case the city of Mumbai and Delhi shall be taken. Both the cities are tier 1 mega cities, so it will be interesting to see which city turns out to be more profitable with regard to the EV station business.

Let us assume that the number of cars in Mumbai be Nm and the number of cars in Delhi be N_d. So let us apply the necessary conditions:

Let number of manufacturing units for the EV charging station be G. Now, let the cost of manufacturing of an EV for a given 'ith" manufacturing unit be assumed to be as: C_i

Let the transportation cost of the EV station from the location of manufacture be T_m and T_d respectively.

Let the activation cost which is the yearly leasing expense of an EV station be A_m and A_d for Mumbai and Delhi respectively.

Let the cost of land over which the EV station has to be installed be L_m and L_d respectively. And finally, let the maximum number of the EV stations to be installed be M and J for Mumbai and Delhi respectively

Let us define a binary function yi which shall be 1 if the installation was successful and 0 otherwise.

Let X_{ij} be a continuous function depicting the amount of EV serviced from source to destination Also, there shall be a certain cap on the manufacturing of the EV station depending on the capacity of the manufacturing unit. Let that cap be Di for a given "ith" industry

Maintenance cost of the EV charging stations is also needed to be incorporated: Let the maintenance cost of an EV station be M_m and M_d in Mumbai and Delhi respectively.

So we need to minimize:

1. For Mumbai

$$\sum_{j=1}^{N_m}(\mathrm{Lm}+\mathrm{Am}+\mathrm{Mm}).y_i+\sum_{i=1}^{G}\sum_{j=1}^{N_m}\mathrm{Tm}x_{ij} \quad (1)$$

Equation 1 gives the optimization function for the city of Mumbai. Here the parameters considered are the land cost (Lm), installation cost (Am) and the maintenance cost (Mm). Further the transportation cost is also needed to be optimized which is reflected in the second part of equation 1. Eq.1 takes care of both the cost and installation of the charging station. This over-all cost has to be optimized. Next step is to provide the necessary boundary conditions. Which are illustrated in equation 2-4.

Subject to condition:

$$\sum_{j=1}^{N_m}x_{ij} \le \mathrm{M}y_j \quad \text{j=1 to m} \quad (2)$$

And

$$x_{ij} \ge 0 \quad (3)$$

$$y_{ij} \in \{0,1\} \quad (4)$$

Equations 2-4 describe the boundary conditions to be imposed in order to optimize the overall cost. Eq. 2 imposes an upper limit on the manufacturing capacity of EV stations. The maximum production can be M but it shall be aided with the depreciation function (y_{ij}) which realizes the total manufacturing capability and hence the actual amount of EV station delivered from the source to destination $\sum_{j=1}^{N_m} x_{ij}$).

Similarly for the city of Delhi a similar equation shall be formed and shall be optimized. Here all the parameter functions shall be unique for the city of Delhi and similar boundary conditions shall be imposed.

$$\sum_{j=1}^{N_m} (\mathrm{Ld} + \mathrm{Ad} + \mathrm{Md}).\, y_i + \sum_{i=1}^{G} \sum_{j=1}^{N_m} \mathrm{Tj}.\, x_{ij} \quad (5)$$

Subject to condition:

$$\sum_{j=1}^{N_m} x_{ij} \leq \mathrm{J}.\, y_j \quad \text{j=1 to m} \qquad (6)$$

And

$$x_{ij} \geq 0 \qquad (7)$$

$$y_{ij} \in \{0,1\} \qquad (8)$$

3. RESULTS AND DISCUSSION

The future of transportation is the electric vehicles (EVs). Just like the fuel powered vehicles required refueling stations, there should be an optimum amount of the EV charging stations. However, in India these EV stations and their installation protocols are still new. Hence for initialization of such installations, a robust optimized procedure is needed.

Minimization of the cost of the EV station installation is the prime aim of the study. For this, the parameters affecting the cost of the entire exercise of manufacturing, transporting and installing are being analyzed and put into the formation of the facility location problem. The 1st step in the minimization of the problem was to develop the minimization expressions for the cities of Mumbai and Delhi (Eq. 1and Eq. 4). The reason for choosing the cities is that one is a mega-city and the other is a relatively smaller city which makes the understanding of a region centric understanding of the cost optimization much better.

The expression has considered the land cost at the two given cities and added it with the transportation and associated maintenance cost of the respective city. The maximum cap on the production capacity of the EV for a particular city are associated with the actual quantity of EV's serviced from the manufacturing unit to the respective city. For this the maximum production capacity of EV station is to be realized, the maximum production cap on the EV station is identified and then related to the actual delivery of the units considering a reasonable depreciation function.

Once the minimization equation is formulated, boundary conditions have to be applied in accordance with the demands of the situation. Eqs. 2-4 and Eqs. 6-8 are the boundary condition for the total amount services to be lesser than the maximum manufacturing capacity if EV station at the manufacturing unit.

Finally, it can be compared that once both Eq. 1 and Eq. 4 are minimized, then how what are the minimum overall cost compared to the two cities and how the geographical location shall affect the overall cost of EV station installation.

A comparison has been made to between the cities of Mumbai and Delhi, with the aforesaid factors required in the cost model. The population of Mumbai and Delhi are taken as 27M and 33M respectively. Further the number of EV's in Mumbai and Delhi are 135500 and 165000 respectively [9, 10]. Further, the estimate of the land cost has also being made for both the cities. For Mumbai, the average land cost per sq feet 35000 and for Delhi it shall be 28000.

Cost of manufacturing the components of an EV station shall be around 13000000 for Mumbai and 15000000 for Delhi respectively. Each ev station shall require a certain amount of area for installation and operation, it is estimated that the area required by the ev station shall be 4500 sq feet.

Now, let us assume that the average time an electric car takes to be fully charged is 40 hours. Hence the number of the car which can be charged in a day from a particular EV station can be calculated by the following relation:

$$\textit{Number of cars charged} = 24 * 60 * \textit{No. of charging ports} * \textit{utilization factor}/40$$

On an average there are 7 charging ports in a single EV station. assuming and utilization factor of 0.7 the number of cars being charged in a day shall be: 176.

Now the number of EV stations required for a particular city can be estimated from the following relation:

$$\textit{No. of EV charging station} = \frac{\textit{total no.of EV's in the city}}{\textit{number of cars charged per day}*(3.5)}$$

It is assumed that that on full charge, the car will run for 100KM for 3.5 days.

Hence with regard to the above equation the number of EV charging station in the city shall be 267 for Delhi and 219 for Mumbai.

the next step is to implement the cost analysis to calculate the break-even point considering the assets and liabilities.

First the liabilities are listed for the city of Delhi:

transportation cost per charging station: 4000000

Installation cost per charging station: 2000000

Maintenance cost per charging station: 1500000

similarly for the city of Mumbai

transportation cost per charging station: 3500000

installation cost per charging station: 2000000

maintenance cost for charging station: 1500000

These liabilities shall be added to the force said factors of the cost of manufacturing and land cost for both the cities.

Hence the total cost incurred for the city of Delhi and Mumbai shall be: 148500000

and 177500000 respectively.

The profits shall be listed down:

Total income per day from the EV stations for the city of Delhi and Mumbai can we calculated from the following relation:

Total income per day = income per car * total number of cars charged per day

From the above relation it is assumed that the income per car in both the cities is constant and is equal to 2000.

hence the total income per day for the city of Delhi and Mumbai shall be 352800

Now the break-even days can be calculated from the given relation

$$days\ to\ reach\ break\ even\ point: \frac{total\ cost}{total\ income\ per\ day}$$

The total cost incurred is already calculated in the previous part of this discussion

Hence with the help of the above relation break-even point for the city of Delhi shall we achieved in 420 days whereas for the city of Mumbai it will be in 503 days.

Figure 2 shows how the profit surpasses the cost graphs for both the cities. The points where the profit line intersects the liability cost line is the breakeven point for that city. The above result is quite interesting as it can be seen that the number of days for the break-even point to reach for the case of Mumbai is greater than the case of Delhi this makes the city of Delhi a more profitable place for the business of EV to start as it would lead to a profitable venture faster as compared to Mumbai.

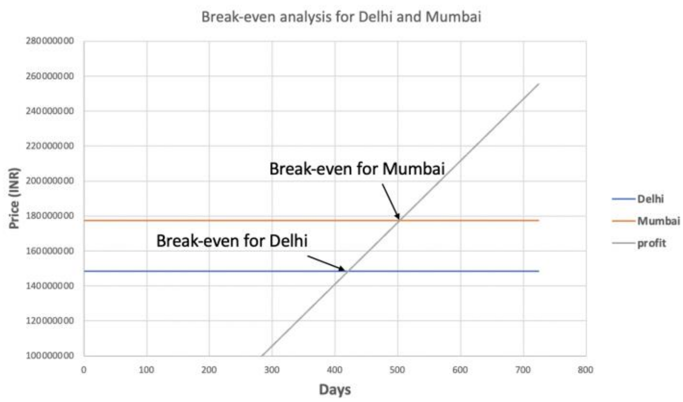

Figure-2: Plot of the price vs the number of days for Delhi and Mumbai and the corresponding break-even days when profit surpasses the liability costs.

3. CONCLUSIONS

- With the growing demand of the E-cars, there is a corresponding need for the decent availability of the EV charging stations.
- There are liability costs involved in the manufacture, transportation and maintenance of an EV station. The above liability cost shall be mitigated via the profits generated from the charging station and hence the determination of the break-even is necessary.
- In the current study, a cost-based analysis was done for Delhi and Mumbai. It was found that the break-even point is reached earlier in Delhi compared to Mumbai. Hence, it may be safely concluded that Delhi may be a better destination for the EV charging station business.

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