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APPLICATION OF OPERATIONS RESEARCH FOR EMERGING ELECTRIC VEHICLES IN INDIA

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Abstract : With increasing global warming, people's awareness towards carious environmental issues have also increased. One of the biggest emitters of greenhouse gases oil gas-powered vehicles. As a result, the move towards Electric Vehicles has gained a lot of popularity. In our research paper we touch upon the problems of demand supply imbalance of Electric Vehicles various states, and also the efficient allocation of charging Stations of EVs so as to obtain maximum utility. The first problem has been addressed using Transportation Problem where we have assumed demand and supply to be same so we can appropriately allot EVs to states with highest demand. The second problem in our paper has been approached by first why there is an insufficient supply of EV charging stations. Then, we have spoken about how to best increase it, without causing an unnatural spike in the cost of installation. This problem has been suggested to be solved using Linear Programming Problem. One of the biggest limitations faced by us was lack of data. We hope that in the future, when more and more people have adapted to EVs, more reliable data would be available for further analysis.

Keywords : Electric Vehicle, cost, demand, supply, charging, charging stations, fast charging.

I. INTRODUCTION

It is undisputable that the world is experiencing an environmental crisis. As concern for the environment increases, Electronic Vehicles (EV) gain traction. People have begun to understand the impact of gas-powered vehicles that emit a lot of smoke and their detrimental effects on our atmosphere. Along with environmental welfare, EVs also escort economic benefit. The electric vehicle revolution (EV) is accelerating,but can only go so far without the necessary infrastructure and technology. As thought moves from fossil fuels to the cheer, the visions of a brighter and optimistic world appear in sight. Research suggests, charge of electricity as fuel could go as low as Rs 1.1/km, assisting an electric vehicle owner to save up to Rs. 20,000 for every 5,000km traversed. The demand for electric vehicles is driven by hopes of fast-charging batteries facilitated by extended driving range. As an automobile industry, the fundamental challenge faced is the development of high quality batteries that are not only long-lasting and safe but can also store a great deal of energy. After a survey in the current ecosystem, lead-acid batteries and lithium ion batteries have come out winning. (India's automotive future looks electric)

The OR techniques used in our paper are Transportation Problem and Linear Programming Problem. Transportation Problem is a technique of Operations Research used to come up with a solution that provides us with minimum cost to transport commodities from various sources. The basis of TP lies in having equal demand and supply. (Salazar, 2019) Our second problem is suggested to be solved using Linear Programming Problem. LPP is a technique that considers certain linear relationships to arrive at optimal solution. Basically, an LPP typically has an objective function with multiple constraints.

Transportation Problem is the apt technique to solve the problem, as, we have assumed demand and supply to be equal in India due to the fact that EVs are a still growing sector in India. Thus, the utilisation of TP would help companies better match demand and supply in the country, so more and more people are encouraged to buy EVs. Linear Programming Problem is the best process to solve our second problem as it helps us understand how to best set up EV charging stations across various locations to get maximum utility. If the charging stations are not placed strategically and carefully, there may be either be overcrowding at charging stations is populated areas, or they would be almost empty as they were away from the population, or too many charging stations in one vicinity. Along with this, there are various constraints to be kept in mind. Like, electricity required for various chargers, cost incurred, and multiple other charging protocols and infrastructure requirement.

The cost of electric vehicle ownership is currently high when compared to vehicles with traditional drivetrains yet waiting to be offset when government incentives are leveraged. Manufacturers have predicted cost equivalence by 2025 and are working laboriously with the electric vehicle battery production supply chain to attempt reduction in costs and realization of overall efficiencies. The growth of electric vehicles (EVs) and hybrid electric vehicles (HEV) is the scale and for 2025, EVs will represent 30% expensive from all vehicle sales. Comparatively, in 2016, only less than 1 million vehicles or 1% of global car sales come

from electric vehicles (PEV). India's recently announced electric vehicle (EV) subsidies, together with high fuel prices, would be supportive factors for increased EV adoption between 2020 and 2023, resulting in a 26 percent average annual growth rate. Around 30% of new two-wheelers sold worldwide are electric, but new cars will only be able to do so by 2030. It will take another decade for India to obtain 30% electricity. By 2040, electric cars will outsell internal combustion engines with a market share of roughly 60%, while electric two-wheelers will have a market share of 77 percent. For FY2021, total EV sales are 2,38,120 units, down 19.41% from the previous year (FY2020: 2,95,497). With sales of 1,43,837 units (-5.37 percent) and 88,378 units (-5.37 percent), electric two- and three-wheelers, dubbed the "low-hanging fruit," were under pressure (-37.18 percent). Low-speed models accounted for the majority of e-two-wheeler demand (1,03,000 units), while high-speed models accounted for 40,836 units in the previous fiscal year. While the drop in electric three-wheeler numbers appears to be significant (almost 40% YoY), the SMEV data excludes vehicles that are not registered with the transportation authorities.

In general, the problems that have been addressed in the research papers we came across are charging points and infrastructure, extensive amount of time taken for charging, and the capacity of the vehicle after a given amount of charging. These are some of the more popular topics on which a considerable amount of work and research has already been done. Along with this, we would also be dealing with the cost minimizing aspect of it in our research paper. Further we have discussed some of the things we learnt while reding various other papers.

II. Literature Review

The research paper (Juan, Mendez, Faulin, de Armas, & Grasman, 2016) has tried to address similar issues like our research paper. They have focused more on building a transport network model for location of charging points. In particular, developing new optimization approaches for the Fleet Size and Mix Vehicle Routing. A lot of research papers deal with similar problems. We deal with coping up with the demand for such vehicles in our work. Not a lot of work is done along those lines and thus, we try to provide an optimal production supply solution for efficient allocation of such vehicles.

However, in (Brandst¨atter, et al., 2015) analysis has been done on Electric Car-Sharing System Design and Management where work has been done on optimization problems arising in sectors of design and management of car-sharing systems utilizing electric vehicles. For India, these problems are a little too far to discuss or worry about. As a result, this is not one of the problems we are going to be discussing in our paper.

Furthermore, (Sanguesa, Torres-Sanz, Garrido, Martinez, & Marquez-Barja, 2021) has discussed how the vast number of vehicles on-road have led to increased air pollution levels in urban environments. As a result, authorities in most developed countries are advocating for the switch to EVs to avoid concentration of various air pollutants along with other greenhouse gases. A lot of research papers that we came across during our research have discussed similar issues, and how a switch to electricity will help reduce that. However, not a lot of research papers spoke about the impact this would have on sources providing electricity. We will, in our research paper, talk about this issue, but do not delve too deep into that aspect of the topic.

We also came across certain research papers focusing on the high cost of production of electric vehicles. The research paper (Lee & Clark, 2018) highlighted one such problem. Electric vehicles being the new hot news globally and, as some governments consider “The need of the hour” came at the cost of higher raw materials initially. The duties and taxes of import and export of such materials was also high which directly resulted in higher selling cost. We in our research paper will take forecasted demand into account. The aforementioned research paper also talks about government subsidies to the manufacturers. Such support from the government for EV’s will only reduce the price, increasing the demand even more. Cell costs have dropped to $145 per kWh or less and are likely to continue to reduce as technology improves and large-scale production resumes. While cells are only one part of the installed battery cost, it has dropped from approximately $1,000 per kWh in 2010 to around $250-350 per kWh in 2018. The rising demand because of such factors coupled with some major factors is what we will deal with in our work, providing a solution to cope up with the demand more effectively.

They also talks how demand charges can dominate operating expenses for chargers on commercial energy tariffs. As a result, unless fast charging stations can reach sufficiently high usage rates, the total cost of power from fast charging stations is higher than slower home chargers. We in our research are going to focus on cutting costs for both. Simple home charging is competitive with today's more fuel-efficient gasoline cars, and it might be substantially less expensive if a time-of-use energy tariff is implemented, with reduced pricing during off-peak periods.

India is one of the leading countries for greenhouse gases emissions via the Automobile Industry. As a developing country, India has made strong commitments to containing pollution and reducing their carbon footprint. As per the results of the report (Khurana, Kumar, & Sindhpuria, 2019)**,** India is observed to have shallow adoption of EVs, but demand is expected to pick up sooner than later. Even though it may be expensive to first buy an EV, the maintenance costs are not as high in the long run. As a country focused heavily on self-image and how we perceive others, the social influence of owning an EV can be a major factor towards the country adopting EVs more and more. The Government of India has also made an announcement that all cars must be electric by 2030.

III. Research Objectives

Demand in various cities for electric vehicles after the charging setups will be very high. Given the current unaffordable prices for petrol and diesel, everyone is turning towards a cost saving alternative in the form of electric vehicles. Initially, production factories or setups will be available in only a handful of places however the demand will be widespread and might breach the rural market as well along with the urban market, sooner than later. Forecasted demand looks high and attractive and is geographically widespread. The forecasted demand is expected to be way higher than the forecasted supply in the near future. In such an instance,

attaining optimum efficiency in allocating the electric vehicles to the high demand cities is a task. We try to provide a solution deploying Operations Research models. We aim to create a demand and supply chain model for efficient allocation of electronic vehicles to the high demand forecasted cities. We will make use of "Transportation Problem" tool of Operations Research by using distance problems.

The advent of Electric Vehicles has set up a new trend which focuses on the shift from petrol or diesel based cars to cars using electricity. Even though this shift is major, the feasibility of owning an EV is not optimal, due to lesser number of charging stations. With the FAME II policy, India laid out its aim to become the electric vehicle hub of the world, by the year 2030. In addition to charging points, the lack of private parking spaces is also noted as a hindrance for electric vehicles adoption, and the lack of affordable renewable energy means charging EVs is putting a toll on the already stressed coal-powered electricity grid. Current estimates suggest that 80% of the charging occurs at personal spaces like vehicle owner's residence and in some instances, the workplace. According to auto giant Maruti Suzuki's research, 60% of Indian customers don't have their own parking space. "There is no way they can charge the vehicle, therefore they won't adopt it," said C V Raman, senior executive director (engineering) of Maruti Suzuki India. The lack of publicly available charging stations comes with what is referred to as range anxiety. There is no surety that a driver can top up in case the charge is running low. This is deeply linked to the lack of charging infrastructure in the country, and while conventional vehicles can be refuelled at petrol stations, such regularised infrastructure is not yet available for EVs. Rudratej Singh, president and CEO of BMW Group India, said that the infrastructure for electric vehicles is still ambiguous and uncertain, which would affect the price and acceptability of the vehicle among Indian consumers. Toyota too has recently halted the manufacturing of electric and hybrid cars for the Indian market, citing inadequate charging infrastructure. The cost of charging is high during the peak hours, which is from 4p.m. to 8 p.m. For EV vehicles it is feasible to charge these vehicles at night. In the absence of measures to shift individual charging loads away from peak hours, utilities would find themselves having to purchase greater peak capacity to meet EV demand and increase their local distribution capacity. With the increase in EV penetration there will be growing pressures to move to dynamic pricing to reflect actual rather than projected costs. With such a scenario in place having an optimum cost for charging these electronic vehicles is necessary. We try to provide a solution deploying Operations Research models. We aim to create a model that shows the minimum cost for charging electric vehicles. We will make use of the Linear Programming Problem tool of Operations Research.

IV. Research Methodology

In our research paper, as discussed above, we aim to solve the problem of optimally allocating supply of electric vehicles with cities with high demand. Along with this, we also try to provide solutions to solve the issue of minimum cost of charging along with strategic placement of charging infrastructure. All the data collected by us was done using secondary sources, by reading up on other research papers, articles from various sources and even a few reports, all of which have been cited. The data from demand has been taken from Vahaan Website, where authentic data is put after government approval. All of our data is secondary as EV is still a new concept, especially in a developing country like India. Hence, it was unable for us to get data directly from the source.

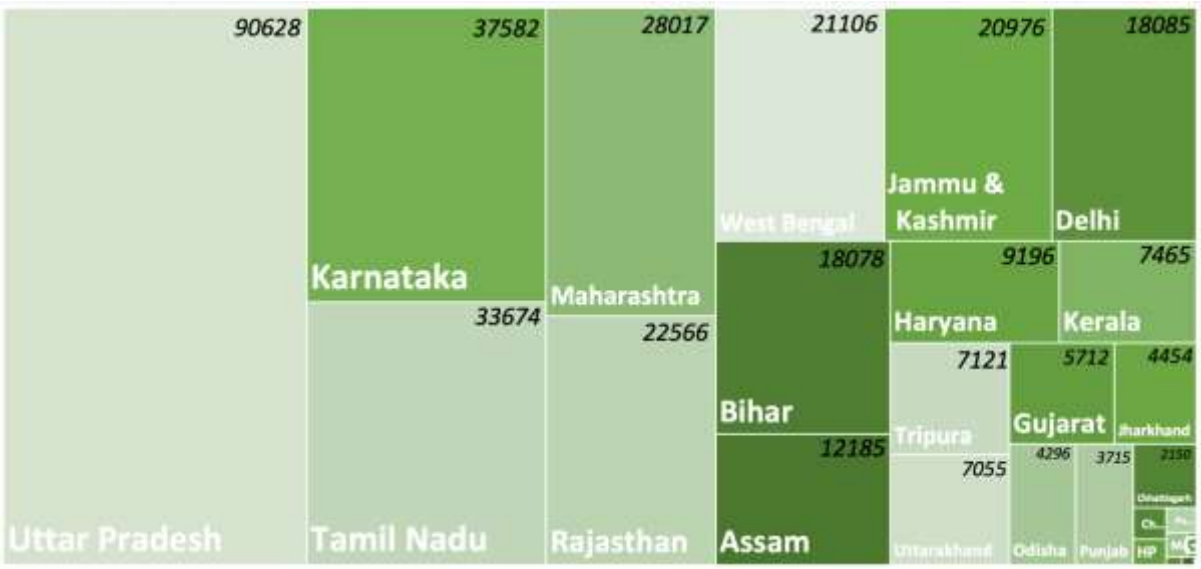
V. Analysis and Findings

The fresh wave of the FDI policy brought with it the boom in the electric vehicle industry in India. This boom has been assisted by an increase in new manufacturing hubs and an increased push to improve charging infrastructure stations. Federal subsidies and policies favouring deeper discounts for Indian-made electric two-wheelers as well as a boost for localized ACC battery storage production are other growth drivers for the Indian EV industry. The burden of oil imports, rising pollution, and as well as international commitments to combat global climate change are among key factors motivating India's recent policies to speed up the transition to e-mobility.

The demand for electric vehicles in India is going to increase a lot. Federal policymakers are developing a mobility option that is "Shared, Connected and Electric" and have projected an ambitious target of achieving 100% electrification by 2030. By proceeding with the move towards Electric Vehicles (EVs), a multitude of frontiers will be positively impacted across India. The country's clear-cut shortage of renewable energy resources and accessibility to skilled labour in the technology and manufacturing sectors are anticipated to benefit as well.

According to a study conducted by (CEEW The Council), the electric automobile sector in India is expected to develop into a $26 billion possibility by 2030, given the circumstances, that India continues to flourish unwaveringly towards this goal. The basic requirement for the same would be a $180 billion investment in required vehicle infrastructure, like production and charging stations. Another report by (Energy Storage Alliance in India) anticipates that the Indian EV market will grow at a CAGR of 36% by 2026, and projected growth for the EV battery market is at 30% in the same period. We expect the demand to be so high that an adequate and efficient production supply chain needs to be designed for the efficient allocation of EVs throughout India. We have the existing demand for Electric Vehicles across various states. So to help solve our problem, we have calculated the projected demand for Electric Vehicles, considering that the EV market will have a CAGR of 44% in the upcoming year. (Aggarwal, 2021)

Figure 1



Source: Authors' work from the data extracted from Vahan Dashboard

We are taking the case studies for the following companies: Mahindra Electric (all vehicles), MG Hector (4W), Ather (3W), Kinetic Green Energy (2W).

This is the data for the current production plants and their capacities as of 2021-22:

Figure 2

Company	City/State	Projected Supply	Reference
Mahindra Reva	Bengaluru	30,000 units	(Limited, 2021)
MG Hector	Gujarat	1200/2400/3600 units	(MG Motor India, n.d.)
Ather	Tamil Nadu	1,10,000 units	(R, 2021)
Kinetic Green Energy	Ahmednagar	30,000 units	(Karayamparambil & Bhaskar, 2021)

Source: Authors' work

Our proposed methodology first involves getting the projected state-wise/city-wise demand/sales for the selected companies for the upcoming years. These projections take into account a lot of things including existing demand, improving infrastructure, improving cost, and government incentives. Confidence among people for driving an electric vehicle and potential production centers throughout the country in the coming few years also play an important role.

Along with this, we will have the projected state-wise sales of our selected companies for the coming years. We can take the state-wise sales data for electric vehicles of 2020-21 given above as the base data for further accurate company-specific state-wise company-wise sales data projections.

From here, we then need to find the production centers/centers where electric vehicles are assembled in India for the selected companies for the upcoming years. The data for current production/assembly centers of electric vehicles for our selected companies are given above. We need to find if companies plan to expand their production centers into more different parts of the city over the years for the production of electric vehicles.

Once we identify our high-demand cities/states for our companies and our production/assembly centers we equate the projected demand and projected supply and create a distance problem for efficient allocation of vehicle units to where the demand is.

Such a production supply chain can prove extremely efficient for the companies and projected this beforehand will help the companies make better decisions.

They can take better decisions regarding starting a new production plant, efficiently allocating resources of the existing production plant, deciding capacity for the new production plant, plan their vehicle transport and delivery. This will help the companies plan their finances and networking beforehand keeping the entire proposed production/supply chain in mind.

Researchers and data scientists and analysts should further work on this problem and use the proposed methodology as this might prove extremely beneficial to the concerned parties. Having a state wise/city wise demand supply transportation model of competition companies can also help companies plan their own state wise/city wise target audience and improve their supply chain to capture a larger market share.

Our next Research Objective is about the optimum allocation of EV charging stations across the country to maximise charging of various Electric Vehicles.

India has facilitated the entry of EVs in the country by the announcement of their plans for the upcoming decade, where the emphasis has been laid on intense amounts of EV adoption by 2030. As we all know, pollution is at its peak in all major cities in India, making it that much more important for remedial solutions. Moreover, India forks out mountainous amounts for importing crude oil. A reduction in this can be practiced by the shift to EVs. As stated by the Society of Manufacturers of Electric Vehicles, there are roughly 1,800 charging stations in India for 16,200 electric cars. (Thornton, 2021) communicates that for India to accomplish its goal of 100% EVs by the year 2030, multiple factors like decreased cost of technology, government support, and

many more would be extremely pivotal. As observed by the global sales of EVs in 2020, there was an overall increase of 39% on a year-on-year basis, however, a decline of 14% was discerned in passenger cars.

The inauguration of India's largest public charging station for EVs was done in July 2021. Not only is this station the first of its kind, but it is also declared to be functional at all times with AC/DC chargers for all kinds of electric vehicles. A vehicle can take as little as 45bminutes to charge, but for vehicles assembled to be slowly charged, a parking bay has been built for overnight charging.

Why is there a lack of charging infrastructure for EVs?

Figure 3

Source: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

Challenges in setting up EV infrastructure: (Setia, 2020)

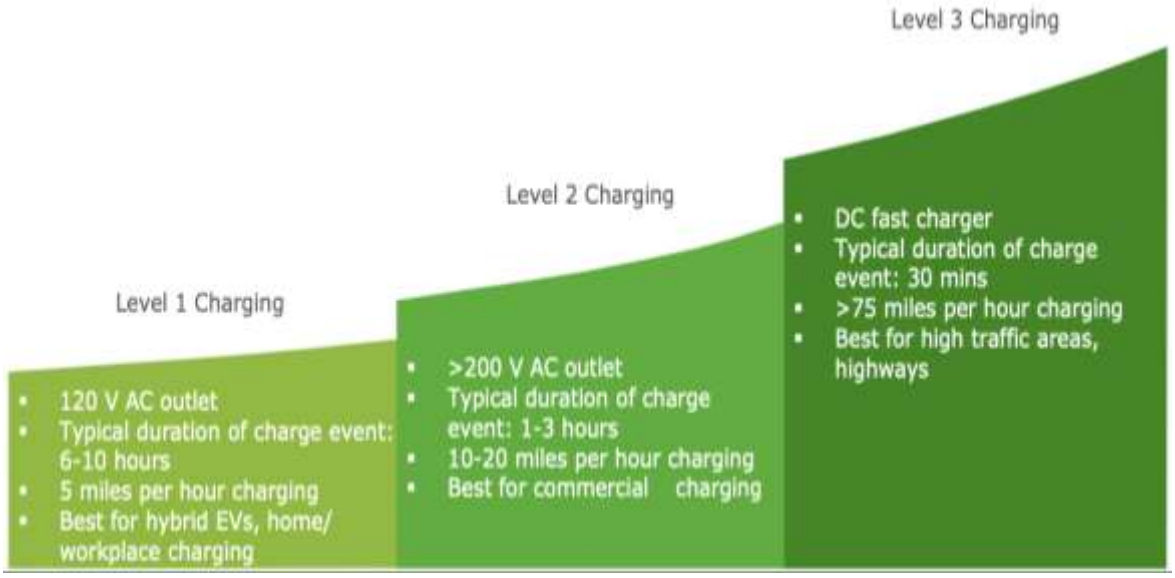
High Cost of Setting up the EV Charging Infrastructure: The set-up of an EV charging station can get quite expensive, and is highly dependent on the types of chargers being installed. Additionally, factors such as cost of land, cables, and other aide are crucial deciding factors. It is important to note that there is also a variable cost of electricity and power. The only way to counteract the high cost is to maximize the utilisation of these stations. To ensure this, the stations should be constructed at convenient locations, and DC charging should be preferred over AC charging.

Compliance with Multiple Charging Protocols: It should be warranted that all types of electric charging points are compatible at the station. This should include any possible mismatch in voltage, current, and frequency.

Safety Against Voltage Fluctuations: The erection of EV charging stations is a complex task. Only specialized technicians should be hired. This is of utmost importance as even the smallest of blunders can be extremely risky. For example, a sudden spike in voltage would lead to severe damage of components, driving up the cost of EV charging stations. Related measures to avoid such fallacies should be taken.

Hardware and Software Related Challenges: When conditions specified in the concord are fulfilled, hardware components like sensors and control pilots manage the charging connection of EVs. Nevertheless, the design of such components can be pretty taxing. Issues like heat dissipation, voltage measurement, and infinite more need to be tended to appropriately. When spoken about software issues, it is mandated that charging should start only when basic criterion concerning safety are met. The difficulty arises when the software must be programmed in a way to detect the protocol of the vehicle and charge the vehicle in its error-free way. The calibre of the electricity coming in from the grid has a huge impact in eradicating "charge anxiety".

Figure 4



Source: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

Cost of charging: According to BESCOM, the current charges are ₹60 per kW for slow charging and ₹190 per kW for fast charging. The rate charged per kWh unit is ₹5, notwithstanding the consumption pattern for electric vehicles. After careful consideration, the collective costs for a million EVs have come down to ₹75 Mn per day and ₹27.37 Bn per year. As an increase in electricity utilization is noted, the pressing requirement of green and clean electricity also gains traction. Reasonably, the only viable solution is the usage of renewable sources. Having said that, if this is not communicated in the near future, it will lead to widespread power shortage causing "energy anxiety". This, in a way, calls for setting up close to 50,000 kW solar power plants across India to sustain one million electric vehicles.

Financial Viability of EV Charging: Reduction in upfront set up charges of charging infrastructure takes the ledge off of requirement of government subsidies, enabling private organisations to participate as well. To ascertain the success of the young EV market, more light should be shined on the incrementation of accessible charging. Strategic distribution of several charging stations augmented by a few high-power stations will determine efficiency.

Targets for public charging infrastructure are generally based on considerations of accessibility or of EV charging demand. Targets can be broken down into two:

(a) Access-Based Targets aim to ensure minimal coverage across a city or region and are typically measured in terms of the "number of charging points/unit area." They are more appropriate in the early stages of EV adoption, due to low EV charging demand.

(b) Demand-Based Targets aim to provide sufficient public charging infrastructure for a growing number of EVs on the road. They are based on EV penetration rates and the number of electric kilometers driven. Demand-based targets are useful for a planned expansion of the public charging network, in line with projected EV growth.

The next section covers the process of EV charging demand assessment for target setting.
An EV charging demand assessment can feed into different aspects of charging infrastructure planning. It can be used as input data to set targets for the number of people. Additionally, it can also be used for location planning for public charging infrastructure and to analyse grid capacity and the need for enhancements. These are the steps involved in this assessment process:

Figure 5

Source: Authors' work from Singh, et al.

How to increase the number of charging infrastructure:

The evolution of low-cost charging technology for EVs will be a monumental turning point in India's journey to complete EV transition. The LAC offers an affordable, customised solution to adapt to the ever-changing and swiftly increasing charging demands. There is no need for expensive electrical infrastructure, and connections can be made using an omnipresent low-tension distribution network. This enables easy set-up of charging stations anywhere in the limits of the city, without worrying about power supply availability. Ultimately, the low cost of LAC devices sanctions the deployment of large-scale charging points without needing high investments. In simpler words, public EV charging does not need to be restricted to limited space and can easily be installed anywhere to create a cleverly strategized dense charging network that is not only accessible but also convenient to operate. Doing so reduces the burden of subsidies and land concessions on the government. This thus leads to a substantial slash on capital costs and boosts the business case for charging services. It is also noted that by following through with this, current and potential owners will be extremely beneficial as it will lead to the elimination of range anxiety and help welcome the faster shift to EVs. (Das & Kanuri, 2021)

A lot of specialists support the cause that there is a requirement of an unambiguous solution or a platform for users to be able to check the nearest charging stations and record other car-related data.

Here are some recommendations on how to best utilise electric mobility in India:

- Policies encouraging Distribution Utilities to facilitate the development of EV charging infrastructure should be formulated.
- Electricity Regulators should be designed and implementation of TOU tariffs should be put into place.
- Technical merits for charging equipment should be defined, designed, and approved.
- Financial Institutions should be motivated to help invest in the electric mobility sector.
- Current electric mobility schemes/policies should be updated and adjusted to this dynamic market and its expectations.

(Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ))

I. Limitations and Conclusions

While going deeper in the study of electric vehicles in India, one of the major and uncommon problems we came across was how the vehicle makers across country would deal with their supply policy in order to meet the anticipated demand and tried to create a transportation demand supply problem for them. We had mentioned in our literature review that forecasted demand looks high and attractive and is geographically widespread causing a potential demand supply imbalance and have justified it with reasons and data. Our research objective was aim to create a demand and supply chain model for efficient allocation of electronic vehicles to the high demand forecasted cities deploying operations research models. In conclusion, we used transportation problem to match our research objective. We tried to lay a proposed methodology of how to go about the problem after getting access to the data required and hope this study is carried forward and our proposed methodology is implemented since having a state wise / city wise demand supply transportation model of one's own and rival companies is extremely beneficial.

The automobile sector plays a huge role in increasing CO2 emissions in the environment. For a fact, a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year. And as no greenhouse gas emissions directly come from electric vehicles, they will play a key part in meeting India's goals regarding climate change. Crude oil prices have a direct relationship with domestic fuel prices. Because of regular ups and downs in fuel prices, running a vehicle is becoming very costly. As the number of conventional vehicles in India is increasing, electric vehicles offer the perfect solution to save money. In 2019-20, the sales of electric vehicles in India stood at 3,80,000. With this pace, the EV market is expected to grow at a CAGR of 44% between 2020-2027 and is expected to hit 6.34 million-unit annual sales by 2027. The EV industry is growing rapidly. The growth in the sector calls for an increase in demand. To maintain the steady demand in EV, the prices of the EV should be affordable. The prices of an EV can only be affordable when the cost of setting up the charging infrastructure for an EV is minimal. We can solve the problem of cost minimization of setting up an EV charging station by Linear Programming Problem. (The Startup Lab, n.d.)

One of the biggest limitations we faced was availability of quality data. Projected state-wise/city-wise demand/sales for the selected companies for the upcoming years and projected state-wise supply of our selected companies for the coming years was something we could neither find nor predict because a lot of factors had to be taken into considerations. The financial modelling required to get such data is of very advanced level and most probably available only with the respected companies. We have mentioned the current year data which can be taken as a base data in such future projections. However, with the help of advanced knowledge of financial modelling and data science, access to this data is possible. We recommend researchers in the future to get hands on the aforementioned data and try solving the transportation problem, either using our proposed methodology or making any necessary changes if required.

Just like the previous problem, our limitations in the second problem were all caused due to lack of appropriate data. We have tried to provide the solutions to the best of our ability, but our recommendation would be to do a more in depth analysis to find relevant data. After one has all the required data, constraints can be put in place to solve the problem using Linear Programming Problem.

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