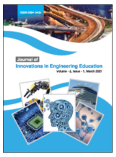

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# Deployment and charging station plan for public electric buses in Kathmandu valley using linear programming method and multi-criteria decision analysis

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Abstract

The government of Nepal is planning to develop electric bus (e-bus) fleet in Kathmandu valley with an aim to reduce the city pollution. The Sajha Yatayat, a governmental institution operating public buses in different routes of Kathmandu valley, is going to purchase e-bus for public services. The aim of this research is to develop models with which the number of buses can be minimized, and the best charging facility can be adopted by using Linear Programming and Multi-criteria Decision Analysis (MCDA) respectively. The six prominent routes of Sajha Yatayat were taken for models optimization. Many constraints affect the optimal number of buses that can be deployed in the routes. The data available from Sajha Yatayat and the specification of the e-bus were the basic input parameters for linear programming model. The technique for Order of Preference by Similarity to Ideal Solution(TOPSIS) method was used to choose model charging facility among different models. The optimization results showed that the number of e-buses required is 40; each route consisting of 6 or 8 e-buses. These e-buses must be charged overnight in a central charging facility over terminal charging or opportunity charging; this alternative got the greatest closeness from the ideal value in TOPSIS model.In this mode of charging facility the cost of operation can be minimal and the ease to maintain the fleet can be high. Furthermore, all of the e-buses will park overnight at on place where they are charged in two different time frame between 9 pm and 6 am. The electricity consumed per night is 11520 kWh which is supplied as 3-phase AC. The result also showed that the lifetime cost of e-bus is 1.7 times lesser than that of diesel bus in terms of social and economic cost. The study presents that acquiring and deploying e-bus is financially and technically feasible.



## 1. Introduction

Electric buses, also known as e-buses, are the motive vehicles used for transportation that run on electrical power instead of conventional diesel fuel. The introduction of e-bus fleet in Nepal is imminent if we are to keep up with the world trend. In 2011, the contribution of electrical vehicle in the world was as small as 0.1%, while in 2020 ithas been increased to 3.2% [1]. On the other hand, the total energy consumption by diesel bus was 101.5 TJ in 2017 alone [2]. Considering those thing in mind, the government of Nepal developedElectric Mobility Planin 2018 in association with the Global Green Growth Institute with an eager aim to increase the number electric vehicles including e-bus to 20% by 2020 [3].

SajhaYatayat is one of the leading transportation facility providers in Nepal that operates public buses mainly within Kathmandu valley. It currently has 71 public diesel buses of short and long routes. The government of Nepal has been working closely with SajhaYatayat in order to achieve the increment of electric buses' fleet in Kathmandu valley. Now, this institution is planning to procure 40 electric buses in near future. However, the planning of electric bus fleet and developing their charging station is new practice for Nepal in the history of public transportation. Although, the operation of electric buses becomes imminent, there lies a huge

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Table 1: Routes adopted for e-bus

| | Terminal A | Terminal B | No. of Stops | Distance Between Terminals |
|---|---|---|---|---|
| Route 1 | Lagankhel | NayaBuspark | 16 | 14.0 km |
| Route 2 | Lagankhel | Budanilkantha | 20 | 16.3 km |
| Route 3 | Godawari | Ratnapark | 16 | 14.2 km |
| Route 4 | Lamatar | Ratnapark | 19 | 14.4 km |
| Route 5 | Thannkot | Lagankhel | 20 | 18.2 km |
| Route 6 | Bhaisipati | Ratnapark | 17 | 14.4 km |

challenge in planning for their execution. First challenge would be to select how to run these new electric buses among the existing diesel buses. Now, the two major challenges are on which routes must these electric buses run and how these electric buses should replace the diesel buses. In addition, there are a number of factors that need to be considered and planned before the electric buses can be set to start on the road.

### 1.1. Routes

The number of buses that will run in the selected routes should be planned for the optimum use of them. There are certain routes that are busier in comparison to the other routes. For example, SajhaYatayat has categorized their routes within Kathmandu valley into two different types based on the number of passengers:

- Urban routes
- Sub-urban routes

The urban routes have more number of buses than the sub-urban routes. The time period between which the two consecutive buses begin their journey, which we call headway, is also more compact in the urban routes than in the sub-urban routes. The adopted routes are shown in Table 1.

### 1.2. Charging facility

The requirement and construction of charging facility is one of the most distinct aspect of the electric buses. Unlike diesel buses, electric buses cannot be refueled at any time within a short period. The charging period can take from 2 hours to 6 hours based on the battery capacity used by the bus and the charger capacity. The charging facility includes:

- Land area required to park the buses and the chargers
- Civil infrastructure required to place the charger and the electricity outlet
- Manpower to look after the maintenance of the buses

### 1.3. Electricity

The battery of the existing electric bus can range anywhere from 50kW to 500 kW. If we look at the capacity of the charger, it can be the range of 20 kW to 150 kW. So, if a battery is charged for 4 or 5 hours, it will consume 80 kWh to 750 kWh. This is a huge amount of electricity that the national electricity authority must allocate for the buses.

One of the major aspects that needs a serious consideration in a country like Nepal is the total electricity supply that can be available per day at different time of a year.

### 1.4. Overall operation cost

The operation and maintenance of electric bus incurs many costs over its lifetime. But one of the best and teasing factors is that the maintenance cost is very little in comparison to that of diesel bus. The electric motor, the controller and the charger do not require as frequent maintenance as the IC engine, transmission box and the clutch system in a diesel bus require.

The operation cost of electric bus breaks even with that of diesel bus in 10.7 years.On top of that, the price of e-bus is expected to drop gradually over the years which mean the breakeven point of total cost of two different buses can be achieved in the period of less than 10 years [4].

## 2. Methods

### 2.1. Route

Since the study is based upon Sajha Yatayat, the 6 most unchanging routes are selected based on the factors like population density, availability of educational and working institutes, connectivity between majors junctions and feasibility of running electric buses in those routes. The routes distance range from 14 km to 18 km and have several stops.

### 2.2. Electric bus

The selection of e-bus is one of the most crucial parts in this study. Different e-buses offer different motor capacity, energy storage capacity and mileage per full charge in battery. Since all the financial activities of

Table 2: Mode transition

| SN | Parameters | BYD K9 | Tata Starbus | Olectra C9 | Volvo 7900 | Unit |
|---|---|---|---|---|---|---|
| 1 | Country of origin | China | India | China-India | Sweden | |
| 2 | Top Speed | 62.5 | 75 | 70 | 50 | kmph |
| 3 | Max Gradability | 17 | 17 | 17 | N/A | % |
| 4 | Motor Type | AC Synchronous | AC Asynchronous | AC Synchronous | AC Synchronous | |
| 5 | Max Power | 300 | 245 | 360 | 200 | kW |
| 6 | Max Toque | 1100 | 400 | 800 | 425 | Nm |
| 7 | Battery Type | Lithium-Iron Phosphate | Lithium ion | Lithium-Iron Phosphate | Lithium ion | |
| 8 | Battery Capacity | 324 | 186 | 360 | 330 | kWh |
| 9 | Charging Capacity | 80 (AC) | 200 (DC) | 80 (AC) | 150 (DC) / 11 (AC) | kW |
| 10 | Charging Time | Up to 4 | Up to 4 | Up to 5 | Up to 5 | hrs |
| 11 | Pantograph charging | Yes | Yes | Yes | Yes | |
| 12 | Mileage | 250 | 150 | 300 | 200 | km |

Sajha Yatayat falls under *Sahakari Ain* of Nepal Government, the procurement of e-buses would be in the expense of government and would go through bidding process. Although any bus could be procured by this process, e-buses from different companies were taken in consideration for this study and a comparison was made between those buses considering the important parameters of those buses. After this comparison between four different e-bus models of 12*2.5*3.4 (m*m*m) as shown in Table 2 was made, this study selected one model on the basis of which all the calculations and optimization would be made.

From the technical comparison made between the e-buses of different companies, it isconcluded that Olectra C9 bus offers the best battery capacity i.e. of 360 kWh, gives best power and runs for the longest mileage i.e. for 300 km. therefore the whole calculation was done for Olectra C9 bus and its specifications.

## 2.3. Charger

The charging facility is another important device that charges the battery of e-bus. Different e-buses offer their own chargers that match their specification and requirements. For the purpose of the study, Olectra C9's own charger is taken for reference. It runs on 3 phase AC and has the capacity of 80 kW which means it can charge a battery from 0% to 100% state of charge (SOC) within 4 to 5 hours.

## 2.4. Battery

The battery is the energy storage device for electric bus. The battery used in Olectra C9 is a series of Lithium-Iron Phosphate (LiPO4) cells having total energy storage capacity of 360 kWh.The maximum desired SOC after charging the battery is 100% and keeping the health of the battery in mind, the minimum desired SOC after discharging can be no less than 20% [5]. The charging method used in charging these batteries is Constant Current – Constant Voltage method, which means first the battery, is quickly charged by supplying constant current, after that it is slowly charged by supplying constant voltage as shown in Figure 1.

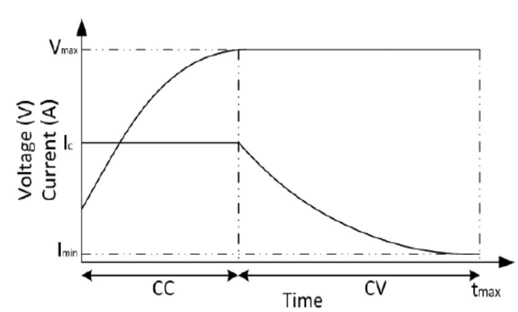


Figure 1: CC-CV curve for charger

## 2.5. Problem statement

The government of Nepal has developed action plans to develop electric mobility in the Kathmandu valley [3]. Under the same action plans, the government started making the prefeasibility study in co-operation with GGGI and SajhaYatayat [6]. That prefeasibility study takes aimed to find out what kind of electric buses would best suit the routes that SajhaYatayat was using in 2017. The study tried to find out the cost of replacing diesel buses by electric buses. While these studies developed pre-feasibility study and paved a way for actual deployment of electric buses, the study for optimization of routes and finding of the best method of charging station was not made. To formulate the model of minimization of e-bus in routes, the theory of vehicle scheduling problem were approached where minimization model for single deport is formulated as a problem for which polynomial time algorithms are known [7]. In minimum decomposition model, each trip is represented by an arrival node and a departure node. This minimization model minimizes the product of operational cost and the number of buses in between each arrival and departure node. The objective function is then subjected such that the number of buses in each trip and in each arrival and in departure is equal to 1.

However, while these models try to minimize the total number of buses deployed in a day, they provide solution without respecting either the minimum number of e-bus or operation cost. Also, although it is not required, no upper bound for the fleet size can be set in this model.

Furthermore, the formulation of model for selection of charging location must consider different criterions that would be needed to build the infrastructure of the charging facility. Some elements that need to consider are:

- Where to charge i.e., at the nodes and/ or in between route
- When to charge i.e., overnight and/or during operating hours
- How to charge i.e., identifying type(s) of charging technology to be adopted

These three elements ensure that charging the electric bus fleet helps in achieving the regular bus service on the bus route in consideration. The identified charging possibilities become the basis selection of best-fit charging technology among the alternatives provided, followed by analyses of different cases to devise interrelations between the operation parameters of an e-bus fleet which would guide the planning of establishment of charging infrastructure for an e-bus fleet [8]. While the previous literature provide a solid base for this study, the requirements and parameters to be considered for the charging station selection within Kathmandu valley.

Therefore, this study aims to adopt the routes to be used by e-buses, the number of which would be minimized using Linear Programming method. For these minimized number of e-buses, we would require an optimal method of charging facility. This optimal method or the best-fit of charging method would be optimized using Multi-criteria Decision Analysis. Finally, an economic comparison between existing diesel bus of Sajha Yatayat and the adopted e-bus would be made to see if the deployment of e-bus would be cost-effective over the years of its operation.

## 3. Optimization model

### 3.1. Assumptions and considerations

The vehicle scheduling and charging station planning of public e-buses has a broad scope. The overall planning would start from the mapping of population density within different areas of the Kathmandu valley. This would directly influence the need of the number of public e-buses in those areas. For example, the busy areas like Koteshwor, Lagankhel, Tripureshwor, Kalanki, and Naya Bus Park would need a greater number of e-buses while the outskirts of the valley may need comparatively less number of e-buses. The optimization needs to consider many technical and non-technical aspects like the mileage of the e-bus used, the distance of the routes, availability of proper charging location and availability of electricity and so on. All these factors would need a large data collection from different sectors, and it also would be time consuming. So, certain assumptions and thoughts were made to make the calculation linear, without missing to consider any necessary and sufficient conditions. Assumptions and limitations of this study are:

i The six routes selection in this research will be based on the routes opted by SajhaYatayat.

ii The average speed of all e-buses throughout all routes will be assumed to be same at all the time.

iii The density of people, thus the need for the e-buses will be assumed to be same at all the time.

iv The traffic density will be assumed to be same at all the time.

v The headway, time between the departures of two consecutive bus in the morning, is the average value of all headways used by the six routes. This study will consider the headway of 20 minutes, based on the study made within Sajha Yatayat.

vi The number of e-buses starting at each time-node will always be equal to 1.

vii Each e-bus will travel to from one terminal to the other terminal of the route and wait for 20 minutes and return to the first terminal. So the layover time will be 20 minutes in this study.

viii The time-period in a day when the e-buses will run will be assumed to be from 6 am till 8 pm or 9 pm. This means the last bus will stop at its terminal before 8 pm or 9 pm.

ix For the safety purpose, each e-bus will not start from the terminal if its SOC would run below 20% [9, 10].

### 3.2. Optimization of number of buses

The optimization of bus fleet is one of the important aspects since the deployment of unnecessary e-bus is not desirable. If the polynomial time algorithm is known, the product of cost and the number of buses can be minimized by fixating the number of buses in each route [7, 11]. The formulation of LP will be first started from the division of the day into different time-nodes. As shown the Figure 2, each time-node will be the starting point for e-buses from each terminal. The calculation of time to travel from one terminal at one time-node to another terminal at another time-node will be made by the time-distance formula given in Equation 1.

$$\text{TRROT} = \frac{\text{DBTT}}{\text{SOB}} \tag{1}$$

Where,

TRROT : Time Required to Reach the Other Terminal

DBTT : Distance Between Two Terminals

SOB : Speed of the e-Bus

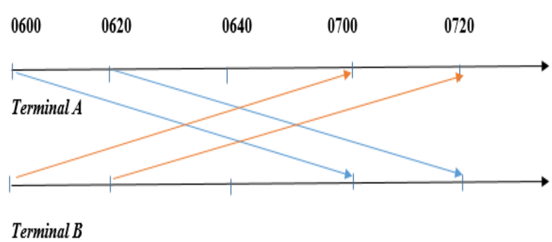


Figure 2: Travelling pattern of e-bus in different time-nodes

The thoughts involved in the formulation of LP are listed as below:

i The minimization of number of buses will be made for a day between two terminals, Terminal A and Terminal B in each of the six routes.

ii The route of each bus will be further broken down into different time frame – with 20 minutes of headway and 20 minutes of layover time between each time-node.

iii The number of bus starting from any given time-node must be 1.

iv The total amount of time spent by an e-bus (Ti or Tj) when it travels between the terminals also takes the layover time in account.

v If the solution is in fraction, the number will be rounded up or down, thus giving the exact number of bus that would start from one terminal.

vi Since the bus starting pattern would be exactly same in the other terminal of each route, the number of bus that would start from the second terminal of each route is equal to the number of bus starting from the first terminal.

vii If the buses should start from only one terminal in the morning, the time-node covered by the number of new buses starting in the morning would exactly double. Thus, this case will not have any effect on our formulation.

The formulation of Linear Programming is given in Equation 2.

$$\begin{aligned} &\text{Minimize} \quad : \sum_{i=1}^{i=6} x_i \\ &\text{Subjected to:} \\ &x_i, h_i \geqslant T_i \\ &x_i \geqslant 0 \end{aligned} \tag{2}$$

Where,

$x_i$ : The number of buses in each route

$h_i$ : Headway between buses in each route

$T_i$ : Total time spent when the first bus reaches the other terminal, also the time between which the minimized number of bus take off from the terminals.

The operation of this linear programming is made in MS Excel using Solver method. The solution obtained in the Solver is shown in Table 3.

The Table 3 and the result implies that in each route the minimized numbers of vehicles are either 3 or 4, which are the rounded numbers of the variables assigned to each route. These value are the direct effects of the route distances. The minimized objective function is rounded down to 20 for each terminals. Since the same number of e-bus start from the other terminal in each route, the total number of e-bus required in each routes becomes twice the value i.e. 6 or 8. Thus,from above, it illustrates that the optimum number of buses required is 40.

### 3.3. Selection of charging facility

The selection of the charging facility is as important as the optimization of the number of buses. The charging facility is a place where the electric buses are parked and charged duly. This facility must also contain the maintenance facility along with a practical mode of supervision. The execution of deployment of the electric buses also must be possible with highest ease. So the approach for

Table 3: Different parameters for battery sizing

| | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 | Total E-bus Required |
|---|---|---|---|---|---|---|---|
| No. of E-bus | 3.480 | 3.956 | 3.504 | 4.184 | 3.578 | | |
| Terminal A | 3 | 4 | 3 | 3 | 4 | 3 | 20 |
| Terminal B | 3 | 4 | 3 | 3 | 4 | 3 | 20 |
| Total E-bus Required | | | | | | | 40 |
| Headway | 20 | 20 | 20 | 20 | 20 | 20 | |
| Time-span | 69.6 | 79.12 | 70.08 | 73.56 | 83.68 | 71.56 | |
| Distance | 14 | 16.3 | 14.2 | 14.4 | 18.2 | 14.1 | |
| Speed | 25 | 25 | 25 | 25 | 25 | 25 | |
| Stop Time | 16 | 20 | 16 | 19 | 20 | 17 | |
| Layover | 20 | 20 | 20 | 20 | 20 | 20 | |
| Total Time | 69.9 | 79.12 | 70.08 | 73.56 | 83.68 | 71.56 | |
| Objective Function 22.38 | | | | | | | |

the selection of the mode of charging facility must start with the physical viability of the mode. The analytical calculation for the viability of execution of deployment should then be approached, finally making technical and economical comparisons between the different modes of the charging facility. Charging technologies currently deployed worldwide for charging e-buses are diverse in their method of electricity transfer, power output levels, control and communication capabilities, etc. The lack of international standards for these charging technologies makes it difficult to compare the different charging technologies available in the market in a consistent way, so a self-development of an analytical approach is necessary [11, 12].

From our previous optimization, we were handed with 40 electric buses that would run in 6 different routes that start from different corners of Kathmandu valley. The selection of the location for charging facility would be another crucial matter because the facility should contain the necessary amount of chargers, equipment and manpower. The buses should come to the charging location before the SOC of their battery reaches down to 20%, so the distance and time covered between the charging location and the two terminals of the routes must be considered too.Based upon the consideration of feasibility, the charging station location could be selected: i) at only one terminal of the routes; ii) at both terminal on the routes; iii) between the different locations of the routes; iv) at a centralized station at some distance from the terminal of the routes [13, 14].

However, the facilitation of charging stations in between the routes would not be necessary as the total distance to be covered is very low. So we have the option of either charging at each terminal of the routes or a centralized charging. This study will take opportunity charging and battery swapping in consideration too. Opportunity charging is a method where it provides ultra-fast charging rates. Opportunity charging can be fulfilled by DC pantographs and inductive charging. It is suitable if the need for charging the e-bus is very crucial. An opportunity charger of 150 kW and layover time of 20 minutes is considered for this study.

Charging rate of opportunity charging = charger capacity × layover time

Discharge per day = discharge rate × average number of trips × average distance of a route

However, it adversely affects the battery cycle life and increases the load on the grid significantly [5, 9, 10]. On the other hand, battery swapping is a method where the drained out battery is replaced by a fully charged battery. In this method, the batteries are charged externally. However, it is not always financially viable since the number is battery required for one bus is doubled. For our study, battery swapping and opportunity charging both at the same time is not considered as this will only add redundancy.

Now, if we consider the two location of charging facility and three method of battery charging, we can come up with six alternatives for the mode of charging facility. The thus formed different alternatives available for charging the buses and for selection of the charging facility/facilities are:

i Overnight terminal charging

ii Overnight central charging

iii Overnight terminal charging with opportunity charging

Table 4: Different parameters for battery sizing

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not Favorable at All | Below Satisfactory | Satisfactory | Above Satisfactory | Excellent |

iv Overnight central charging with opportunity charging

v Overnight terminal charging with battery swapping

vi Overnight central charging with battery swapping

The selection of best charging facility will be given by MCDA by taking various variables in consideration. The criterions/parameters used for the comparison between the six modes of charging facilities are based upon the physical, technical, financial and analytical approach like mentioned above. The parameters are that are considered are both quantitative and qualitative; they are also both beneficial, meaning the more the better, and non-beneficial, meaning the less the better. The quantitative non-beneficial parameters are:

i Charging period (in hours)

ii Number of chargers required

iii Area occupation

iv Electricity consumption throughout day (in kWh)

v Capital cost of charger and/or battery (in Rupees)

The qualitative and beneficial parameters are:

i Viability of electricity and effect of charger on the battery

ii Ease of rendering ancillary infrastructure

iii Ease of rendering manpower and maintenance

iv Effectiveness to maintain headway

v Ease of supervision and co-ordination

Within MCDA, the crossover of each mode of charging facility and the parameters used for the evaluation creates 60 boxes where 60 values are assigned. The values are assigned in the range of 0 to 5 where the range means different level of importance [15] as shown in Table 4.

Justification for the value can be explained in two different ways since there are both subjective and objective values assigned for each parameter. For objective criterion, the real values obtained from calculation are used, and for subjective criterion, an attempt is made to quantify the subjectivity by analyzing the different parameters within the subjective criterions.

### *3.3.1. Number of chargers*

The number of charger directly affects the economy of the charging facility. The less is the charger used, the more desirable it is. The number of charger depends upon the location of the charging facility and the remaining SOC of battery by the end of each day. If the e-bus is charged overnight in each terminal:

Number of available charging period = total time available to charge / time required to charge a bus full

Number of chargers required in each terminal for overnight terminal charging = number of buses to be charged / number of available charging period

Since the battery swapping method is considered without any opportunity charging, the number of chargers required would be similar to above.

Again, for overnight terminal charging with opportunity charging, the fast chargers can charge the buses in the night too. Again, for overnight central charging with opportunity charging, regular chargers along with fast chargers might be required are required. But, since the opportunity charging can charge the bus to 100% SOC during its operation, the central charger should only account for the when opportunity chargers are not used.

### *3.3.2. Charging period*

The charging period for different modes of charging is different. The overnight charging is done between 9 pm and 6 am only, thus we have 9 hours of charging period. The same goes for battery swapping method as both opportunity charging and battery swapping method is not considered. If opportunity charging is considered, since each terminal has exactly one bus waiting there for 20 minutes, the 150 kW chargers are in constant operation. So, the full operation of the fast chargers will eliminate the requirement of night chargers, if the adversity of fast charging is not considered.

### *3.3.3. Area occupation and its viability*

We already know what quantities of chargers are required in different modes of charging facility. While total area required by the total 40 buses will be same, the distribution would be different.

Total area required = number of e-buses × area of one e-bus + number of chargers × area of one charger

The central charging will need the total area in one location. Sajha Yatayat already has 12210 sq. meter land is Pulchowk, Lalitpur. They are also in talk with the government to provide additional land to facilitate the charging station. In any case, the land acquisition will be fairly easy if one chunk of land is needed. If Sajha Yatayat needs lands in 12 different place, it would not be very feasible to acquire the land, given that some terminal are usually already packed small lands.

### 3.3.4. Electricity consumption

The electric buses will consume electricity from 3phase AC or DC fast chargers. We already know that overnight chargers can operate in 2 different halves between 9 pm and 6 am. Let's check the calculations.

Total electricity consumption overnight = charging capacity of a charger × total number of e-buses

### 3.3.5. Viability of electricity and effect on batteries

For overnight charging, 11520 kWh charge is feasible once SajhaYatayat completes the procedure of getting 3-phase electricity from NEA. However, opportunity charging consume high amount of electricity during the 14 hours of their operation.

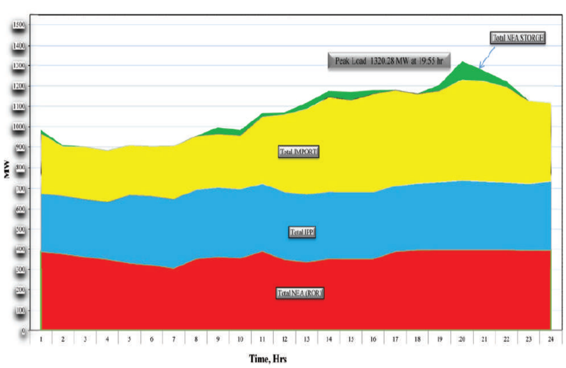


Figure 3: Load curve during dry season [16]

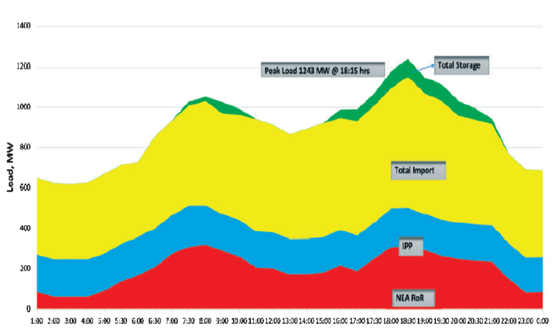


Figure 4: Load curve during wet season [16]

Fast charging also has adverse effect and consumes electricity during peak hours. As shown in the load curve in Figure 3 and 4, electricity consumption increases during the evening time. So, this qualitative aspect is given value of 5 for overnight charging, while the mode containing opportunity charging is assigned the value of 2 as it is not highly recommended.

### 3.3.6. Capital cost of chargers and extra batteries

More is the number of e-bus used, more is the number of chargers required. Thus the cost of charger, which is a non-desirable parameter, tends to be minimal for the best method of charging facility. Battery swapping method needs an extra battery pack for each e-bus. Thus the capital cost is very high for this method.

### 3.3.7. Ease of rendering civil and ancillary infrastructure

The charging infrastructure needs a lot of supporting infrastructures like the wall for holding the charger, the equipment for supplying electricity like the transformers, electricity grid, cables and control stations, and also the places where the employees of the charging facility can stay. All these infrastructure need finance and policy making too. Now if the charging facility is central, the cost can be saved in making the civil infrastructure and in supplying the electricity. So, if the values of 1 or 0 are assigned to each the above qualities, as shown in Table 5, we can provide quantification to the qualitative values of different charging modes [17, 18]. The value assigned for superiority is compared between terminal charging and central charging; value of 1 will be assigned to whichever has the win over the two modes of charging – be it overnight charging or fast charging.

### 3.3.8. Ease of rendering manpower and maintenance

Another important aspect to be considered while planning for a mode of charging facility is how easy it is to provide manpower in that mode and how easy it is for the buses to be maintained if they need periodic, preventive or reactive maintenance. Here, the same approach of assigning values to qualitative aspects is made with 5 criteria in mind. The assigning of values to these 5 criteria is shown in Table 6. It is assumed that a smaller number if manpower and maintenance tools can be used if it is to be done in one place rather than several places.

### 3.3.9. Effectiveness to maintain headway

The buses start their journey each morning, so they need to be ready from 6 am in each terminals of each routes. For the central charging station, the location cannot be selected near to all the terminals. So, the location can

Table 5: Quantification of each of rendering ancillary and civil infrastructure.

| Parameters | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Can civil infrastructure be built? | 1 | 1 | 1 | 1 | 1 | 1 |
| Is feasibility of civil infrastructure superior? | 0 | 1 | 0 | 1 | 0 | 1 |
| Can electricity infrastructure be provided? | 1 | 1 | 1 | 1 | 1 | 1 |
| Is feasibility of electricity infrastructure superior? | 0 | 1 | 0 | 0 | 0 | 1 |
| Is cost of civil infrastructure superior? | 0 | 1 | 0 | 1 | 0 | 1 |
| Sum | 2 | 5 | 2 | 4 | 2 | 5 |

Table 6: Quantification of ease of rendering manpower and maintenance.

| Parameters | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Can manpower be supplied? | 1 | 1 | 1 | 1 | 1 | 1 |
| Is providing manpower superior? | 0 | 1 | 0 | 1 | 0 | 1 |
| Can maintenance be done? | 1 | 1 | 1 | 1 | 1 | 1 |
| Is maintenance superior? | 0 | 1 | 0 | 1 | 0 | 1 |
| Is cost of manpower and maintenance superior? | 0 | 1 | 0 | 1 | 0 | 1 |
| Sum | 2 | 5 | 2 | 5 | 2 | 5 |

be at any distance ranging from few kilometers to the distance equal to the average route distance which is 15 kilometers. While for the terminal charging, the buses are parked from right where they can start their journey. This effectiveness is also a qualitative criterion, so differ- ent aspects within the effectiveness to maintain headway are selected. Here, as shown in Table 7, desirable qualitative aspects will be assigned the value of 1 while the undesirable aspect 0.

### *3.3.10. Ease of supervision and co-ordination*

The charging station for the facility is an operation that will continue almost daily for a long time. They will need supervision to maintain an effective operation at any given time. There is a need of co-ordination between the transportation company, the policy makers, the employees, and the different operators. The distributed nature of the terminal charging will surely lack behind in maintain the effectiveness in supervision and co-ordination. Different values must be assigned of these qualitative aspects are to quantitatively justified. This study have selected values from 1 to 5 in order to make the MCDA calculation. Since the terminal charging has more challenges in supervision, value 3 is assigned while the central charging is assigned the value of 5.

Now that we have all the necessary justification for the values that we have used in the calculation, we can move on to making the optimization to select the most feasible method of mode of charging the buses. TOPSIS method is used for our calculation. TOPSIS method is best suited for calculating the ranks among the 6 available charging modes. TOPSIS method makes series of calculations where it finds a performance score for each alternatives. Whichever alternative has the highest performance score can be inferred as the optimal mode of charging facility.

The TOPSIS process is carried out as follows:

**Step 1:**

As shown in Table 8, we create an evaluation matrix consisting of 6 alternatives and 10 criteria, with the intersection of each alternative and criteria given as $x_{ij}$ we therefore have a matrix $(x_{ij})_m\ x_n$.This evaluation matrix is already mentioned above with justification for each $x_{ij}$.

Where,

A : Overnight terminal charging

B : Overnight central charging

C : Overnight terminal charging with opportunity charging

D : Overnight central charging with opportunity charging

E : Overnight terminal charging with battery swapping

F : Overnight central charging with battery swapping

1 : Number of chargers required

2 : Charging period (in hours)

3 : Area occupation and its viability

4 : Electricity consumption throughout day (in kWh)

Table 7: Quantification of ease of maintaining headway.

| Parameters | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Should the bus travel a certain distance to reach terminal? | 1 | 0 | 1 | 0 | 1 | 0 |
| Does the distance to the terminal effect the mileage? | 1 | 1 | 1 | 1 | 1 | 1 |
| Does the distance to the terminal effect passengers? | 1 | 1 | 1 | 1 | 1 | 1 |
| Does the distance to the terminal effect the SOC of battery? | 1 | 0 | 1 | 0 | 1 | 0 |
| Is effectiveness superior? | 1 | 0 | 1 | 0 | 1 | 0 |
| Sum | 5 | 2 | 5 | 2 | 5 | 2 |

Table 8: Evaluation matrix for TOPSIS method.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | 24 | 20 | 12 | 12 | 24 | 20 |
| 2 | 9 | 9 | 14 | 14 | 9 | 9 |
| 3 | 66.24 | 55.2 | 33.12 | 33.12 | 66.24 | 55.2 |
| 4 | 12.096 | 11.52 | 12 | 12 | 12.096 | 11.52 |
| 5 | 72 | 60 | 36 | 36 | 2399 | 2387 |
| 6 | 5 | 5 | 2 | 2 | 5 | 5 |
| 7 | 2 | 5 | 2 | 4 | 2 | 5 |
| 8 | 2 | 5 | 2 | 5 | 2 | 5 |
| 9 | 5 | 2 | 5 | 2 | 5 | 2 |
| 10 | 3 | 5 | 3 | 5 | 3 | 5 |

5 : Viability of electricity and effect of charger on the battery

6 : Capital cost of charger and/or battery (in Rupees)

7 : Ease of rendering ancillary infrastructure

8 : Ease of rendering manpower and maintenance

9 : Effectiveness to maintain headway

10 : Ease of supervision and co-ordination

**Step 2:**

Calculate $(\sum(x_{i,j})^2)^{\frac{1}{2}}$ for each row and divide each $x_{i,j}$ to get $r_{i,j}$, where $r_{i,j}$ is the coefficient for normalized matrix. These calculations are presented in Table 9 and 10.

**Step 3:**

Here the weight is assigned by entropy method since each parameters have their own objectivity and a hierarchy among them cannot be created. According to [19], the entropy weight method which is also called the objective method of assigning weight is always effective and reliable. The entropy value ($e_j$) is first computed by the formula in Equation 3 and is presented in Table 11.

$$\begin{aligned} e_j &= -h\sum_{i=1}^{m} r_{i,j}\times ln(r_{ij});\ j=1,2,3,...,10 \\ d_j &= 1-e_j \\ h &= \frac{1}{ln(m)} = \frac{1}{ln(6)} = \frac{1}{ln(1.7917)} = 0.558 \end{aligned} \tag{3}$$

Where,

$d_j$ : degree of diversification

h : coefficient of entropy

**Step 3.1:** So, we first create a matrix for product of normalized matrix and natural log of the normalized matrix ($r_{ij} \times \ln(r_{ij})$).

**Step 3.2:** The sum of the product of normalized matrix and natural log of the normalized matrix is computed.

**Step 3.3:** The sum of the product is then multiplied by negative value of h which is -0.558. This gives us the entropy value ($e_j$).

**Step 3.4:** For each entropy value, a degree of diversification is computed by differencing 1 from the entropy value.

**Step 3.5:** The weight for each parameter is computed by the formula given in Equation 4

$$W_j = \frac{1-e_j}{\sum_{i=1}^{m}(1-e_j)} \tag{4}$$

Table 9: Square root of sum of squares of coefficients.

| | A | B | C | D | E | F | $\sum(x_{i,j})^2$ | $(\sum(x_{i,j})^2)^{\frac{1}{2}}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 24 | 20 | 12 | 12 | 24 | 20 | 2240 | 47.3286 |
| 2 | 9 | 9 | 14 | 14 | 9 | 9 | 716 | 26.7582 |
| 3 | 66.24 | 55.2 | 33.12 | 33.12 | 66.24 | 55.2 | 17063.424 | 130.627 |
| 4 | 12.096 | 11.52 | 12 | 12 | 12.096 | 11.52 | 846.047 | 29.0869 |
| 5 | 72 | 60 | 36 | 72 | 2399 | 2387 | 11468234 | 3386.478 |
| 6 | 5 | 5 | 2 | 2 | 5 | 5 | 108 | 10.3923 |
| 7 | 2 | 5 | 2 | 4 | 2 | 5 | 78 | 8.8318 |
| 8 | 2 | 5 | 2 | 5 | 2 | 5 | 87 | 9.3274 |
| 9 | 5 | 2 | 5 | 2 | 5 | 2 | 87 | 9.3274 |
| 10 | 3 | 5 | 3 | 5 | 3 | 5 | 102 | 10.0995 |

Table 10: Evaluation matrix for TOPSIS method.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | 0.5071 | 0.4226 | 0.2535 | 0.2535 | 0.5071 | 0.4226 |
| 2 | 0.3363 | 0.3363 | 0.5232 | 0.5232 | 0.3363 | 0.3363 |
| 3 | 0.5071 | 0.4226 | 0.2535 | 0.2535 | 0.5071 | 0.4226 |
| 4 | 0.4159 | 0.3961 | 0.4126 | 0.4126 | 0.4159 | 0.3961 |
| 5 | 0.0213 | 0.0177 | 0.0106 | 0.0213 | 0.7084 | 0.7049 |
| 6 | 0.4811 | 0.4811 | 0.1925 | 0.1925 | 0.4811 | 0.4811 |
| 7 | 0.2265 | 0.5661 | 0.2265 | 0.4529 | 0.2265 | 0.5661 |
| 8 | 0.2144 | 0.5361 | 0.2144 | 0.5361 | 0.2144 | 0.5361 |
| 9 | 0.5361 | 0.2144 | 0.5361 | 0.2144 | 0.5361 | 0.2144 |
| 10 | 0.2970 | 0.4951 | 0.2970 | 0.4951 | 0.2970 | 0.4951 |

**Step 4:**

Multiply each row by assigned weight ($w_i$) to get $v_{ij}$, where $v_{ij}$ is the weighted normalized matrix. This, along with the result of the remaining calculation is shown in Table 12.

**Step 5:**

Determine positive ideal solution $Z^+$ which is the highest value from each column if more value is favorable and the lowest value if less value is favorable. At the same time, determine negative ideal solution $Z^-$ which is the lowest value each column of more value is favorable and the highest value if less value is favorable.

**Step 6:**

Determine separation values from each column: first $S^+$ which is the separation from $Z^+$ and then $S^-$ which is the separation from $Z^-$.

$$\begin{aligned} S^+ &= \left[\sum(v_j - Z^+)^2)\right]^{\frac{1}{2}} \\ S^- &= \left[\sum(v_j - Z^-)^2)\right]^{\frac{1}{2}} \end{aligned} \tag{5}$$

**Step 7:**

Calculate the relative closeness ($C^+$) to the ideal solution.

$$C^+ = \frac{S^-}{S^+ + S^-} \tag{6}$$

**Step 8:**

Rank the preference order based on the value of $C^+$. The calculations are made on Microsoft Excel using the same steps and the results are presented in Table 12.

Thus, we can see from the rank that overnight central charging without installing opportunity charging or battery swapping is the most suitable mode of charging the buses and preparing the charging facility; it gets the performance score of 0.890.

## 4. Results and discussion

### 4.1. Minimization of number of e-bus

The deployment of e-bus in each route was the foremost aim of this study. The optimization model for the minimization of the number of e-bus in each routes was the successor to the primary aim of e-bus deployment in Kathmandu valley. For this study, SajhaYatayat was the basis of the data collection; six different routes were

Table 11: Evaluation matrix for TOPSIS method.

| | A | B | C | D | E | F | Sum | $e_j$ | $d_j$ | $w_j$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -0.344 | -0.3640 | -0.3479 | -0.3479 | -0.3443 | -0.3640 | -2.1125 | 1.178 | 0.178 | 0.088 |
| 2 | -03665 | -0.3665 | -0.3389 | -0.3389 | -0.3665 | -0.3665 | -2.1438 | 1.196 | 0.196 | 0.097 |
| 3 | -0.344 | -0.3640 | -0.3479 | -0.3479 | -0.3443 | -0.3640 | -2.1125 | 1.178 | 0.178 | 0.088 |
| 4 | -0.364 | -0.3668 | -0.3653 | -0.3653 | -0.3649 | -0.3668 | -2.1940 | 1.224 | 0.224 | 0.111 |
| 5 | -0.081 | -0.0715 | -0.0483 | -0.0819 | -0.2442 | -0.2465 | -0.7743 | 0.432 | 0.568 | 0.281 |
| 6 | -0.352 | -0.3520 | -0.3171 | -0.3171 | -0.3520 | -0.3520 | -2.0423 | 1.139 | 0.139 | 0.069 |
| 7 | -0.336 | -0.3221 | -0.3363 | -0.3587 | -0.3363 | -0.3221 | -2.0119 | 1.122 | 0.122 | 0.060 |
| 8 | -0.330 | -0.3342 | -0.3302 | -0.3342 | -0.3302 | -0.3342 | -1.9932 | 1.112 | 0.112 | 0.055 |
| 9 | -0.334 | -0.3302 | -0.3342 | -0.3302 | -0.3342 | -0.3302 | -1.9932 | 1.112 | 0.112 | 0.055 |
| 10 | -0.360 | -0.3481 | -0.3606 | -0.3481 | -0.3606 | -0.3481 | -2.1259 | 1.186 | 0.186 | 0.092 |
| Sum | | | | | | | | | 2.019 | 1 |

Table 12: Calculation of performance score and ranks

| | A | B | C | D | E | F | $Z^+$ | $Z^-$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.045 | 0.037 | 0.022 | 0.022 | 0.045 | 0.037 | 0.02245 | 0.04491 |
| 2 | 0.033 | 0.033 | 0.051 | 0.051 | 0.033 | 0.033 | 0.03269 | 0.05085 |
| 3 | 0.045 | 0.037 | 0.022 | 0.022 | 0.045 | 0.037 | 0.04491 | 0.02245 |
| 4 | 0.046 | 0.044 | 0.046 | 0.046 | 0.046 | 0.044 | 0.04399 | 0.04618 |
| 5 | 0.006 | 0.005 | 0.003 | 0.006 | 0.199 | 0.198 | 0.00299 | 0.19929 |
| 6 | 0.033 | 0.033 | 0.013 | 0.013 | 0.033 | 0.033 | 0.03327 | 0.01331 |
| 7 | 0.014 | 0.034 | 0.014 | 0.028 | 0.014 | 0.034 | 0.03439 | 0.01376 |
| 8 | 0.012 | 0.030 | 0.012 | 0.030 | 0.012 | 0.030 | 0.02980 | 0.01192 |
| 9 | 0.030 | 0.012 | 0.030 | 0.012 | 0.030 | 0.012 | 0.02980 | 0.01192 |
| 10 | 0.027 | 0.046 | 0.027 | 0.046 | 0.027 | 0.046 | 0.04567 | 0.02740 |
| S+ | 0.040 | 0.025 | 0.048 | 0.040 | 0.200 | 0.197 | | |
| S- | 0.197 | 0.200 | 0.198 | 0.197 | 0.039 | 0.046 | | |
| S+ + S- | 0.237 | 0.224 | 0.246 | 0.237 | 0.240 | 0.243 | | |
| C+ | 0.832 | 0.890 | 0.805 | 0.831 | 0.164 | 0.189 | | |
| Rank | 2 | 1 | 4 | 3 | 6 | 5 | | |

selected on which the e-bus fleet was to be deployed. Each of the six routes had different distances between their terminal that ranged from 14 km to 18.2 km; the number of stops in these routes ranged from 16 to 20 where the e-buses would stop for no more than 1 minute. However, the average speed of 25 kmph was taken in consideration based upon the different trails previously made by SajhaYatayat themselves. In addition to these data, few assumptions were made for this study as this optimization model works linearly and cannot take in account different changing parameters. The traffic density was considered same throughout the day. The need of number of e-bus was considered same throughout the day.

The optimization model used for the minimization of number of e-bus was Linear Programming. Excel Solver was used to solve the linear programming. The objective function was the sum of number of buses that would start from one terminal of each route which was subjected to the constraint that the time between which the first bus that started from one terminal reaches the other terminal should be the time when the minimized number of buses (Figure 3 illustrates the minimized number of buses for each terminal), start from the first terminal by maintaining the headway of 20 minutes. However, this headway can be flexible as the total time might not be in the multiple of 20. In such case, the effective headway is changed.

The number of e-buses that would start from the two terminals of the six routes is shown in Table 13 and Figure 5.

Table 14 will illustrate the time between which the buses can run. The last hour when the diesel bus currently stopped for existing diesel bus is 9:00; the model used the acceptable least SOC as 20%. This showed if the model was in par with the current scenario, along with the SOC remaining by the end of the day.

## 4.2. Optimization of charging facility

The selection of a type of charging facility is one of the most important tasks if the planning for deployment of e-bus is to be made. The charging facility offers

Table 13: Number of e-bus for each route

| | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 |
|---|---|---|---|---|---|---|
| Distance | 14 | 16.3 | 14.2 | 14.4 | 18.2 | 14.4 |
| Terminal A | 3 | 4 | 3 | 3 | 4 | 3 |
| Terminal B | 3 | 4 | 3 | 3 | 4 | 3 |
| Total E-bus | 6 | 8 | 6 | 6 | 8 | 6 |

Table 14: Table illustrating the running time and SOC by the end of the day

| Parameters | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 |
|---|---|---|---|---|---|---|
| Starting time (for the first bus) | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| Distance available per day | 210 | 210 | 210 | 210 | 210 | 210 |
| Running hours | 17.7 | 17.29 | 17.57 | 18.18 | 16.39 | 17.69 |
| Can the bus run up to 9 pm? | Yes | Yes | Yes | Yes | Yes | Yes |
| Least SOC up to 9 pm | 25% | 25% | 25% | 25% | 25% | 25% |

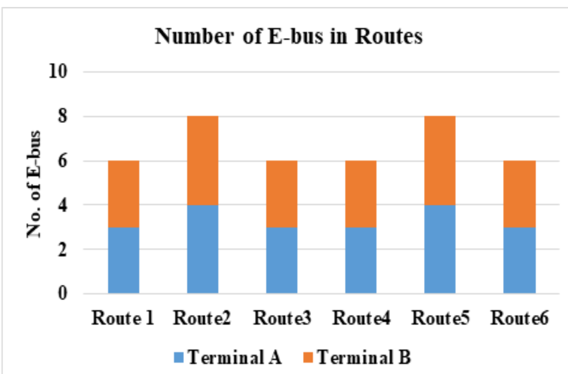


Figure 5: Number of e-bus in 6 Routes

primary function of charging the e-buses. However, the recharging of batteries of those e-buses is far more time consuming than refueling of diesel buses. Olectra C9 which has the battery capacity of 360 kWh can be charged by its charger of 80 kW in 4.5 hours. This time consumed to charger one bus alone is not a small period. Moreover, when there are 40 e-buses to be charged every day, the necessity for the development of a model of charging facility and charging method was felt necessary.

The optimization of the best charging facility is made through multi-criteria decision analysis using TOPSIS method. The alternatives of the charging facility are overnight terminal charging, overnight central charging, daytime opportunity charging and battery swapping. 6 different alternatives of the charging facility, which are mentioned as letters A – F, were formulated based on the comparison between 10 different quantitative and qualitative alternatives. Where,

A : Overnight terminal charging

B : Overnight central charging

C : Overnight terminal charging with opportunity charging

D : Overnight central charging with opportunity charging

E : Overnight terminal charging with battery swapping

F : Overnight central charging with battery swapping

In Table 15, we can see that the alternative B, which is 'Overnight Central Charging Facility' has the highest relative closeness ($C^+$) value from the ideal value.

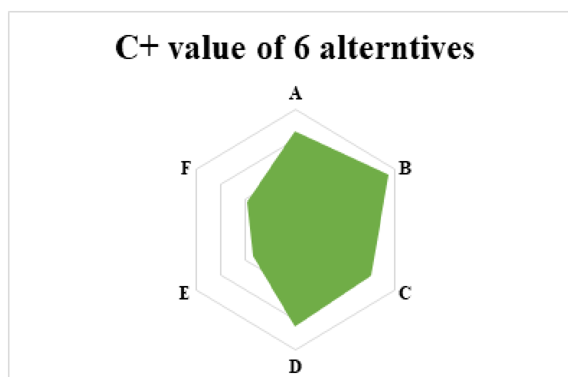


Figure 6: Relative closeness of 6 alternatives of charging facility

This spider plot of Figure 6 depicts $C^+$ values of all 6 alternatives. This C+ values ranges from 0 to 1. The center of the plot is the value of 0 and that means it is the negative ideal value; the farther an alternative is better it is. The outermost part of the plot has the value of 1 which is the ideal value; the closer an alternative is, better it is. We can observe in the spider plot that alternative B is the closest to the ideal value, thus the alternative B which is 'Overnight Central Charging

Table 15: Relative closeness value and ranking of 6 charging facility methods

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| C+ | 0.832 | 0.890 | 0.805 | 0.831 | 0.164 | 0.189 |
| Rank | 2 | 1 | 4 | 3 | 6 | 5 |

Table 16: Technical specifications of overnight central charging facility

| S.N. | Parameter | Magnitude |
|---|---|---|
| 1 | Minimum area required (sq. meter) | 1265 |
| 2 | Number of e-bus | 40 |
| 3 | Effective number of chargers | 0.5 |
| 4 | Number of chargers required | 20 |
| 5 | Electricity consumption per day (kWh) | 11520 |
| 6 | Charging period | 9 pm - 6 am |
| 7 | Charging method | 3-phase AC charging |
| 8 | Charging pattern | Overnight in two different halves |

Facility' is the best fit among others. This can be also visualized in Table 15 where the respective $C^+$ values are given for each alternative.

The sensitivity analysis was made by changing the weight of the parameters, but 'Overnight Central Charging Facility' had the highest $C^+$ value in each of the different case. This strongly infers that Overnight Central Charging Facility is the best fit for charging 40 e-buses. Furthermore, different parameters that were considered while making the TOPSIS analysis reflected the physical requirements of the charging facilities. The physical parameters of 'Overnight Central Charging Facility' is given below: Furthermore, Table 16 presents the area required to accompany the 40 e-buses and 20 chargers which comes to 1265 sq. meter, the electricity consumed per day which comes to 11520 kWh. The e-buses would be charged by 3-phase AC in two different period each night.

## 4.3. Cost comparison

The operation of the electrical vehicle can be feasible but it is also important for any study to find the economic feasibility of any project. First the benefit of a project must be at least match the expenditure. In a project like one in this study, the project replacing the previous one must more economic or social benefits. To check if the project that this study advocates, the comparison between the operational cost of both existing diesel vehicles and that of the incoming electric vehicles is made.The fuel cost for and maintenance cost is extracted from SajhaYatayat [20]. The environment cost is calculated based on the cost of pollutant on the study made in European cities [21]. All the cost are in Nepalese rupees (Nrs). The yearly growth in the expenses is assumed to be 5% per annum and the discount rate is taken as 12% per annum [22].

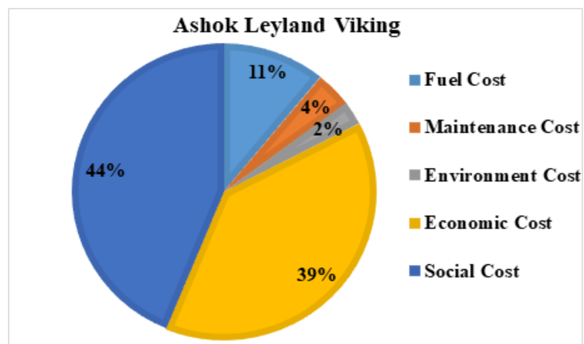


Figure 7: Operation cost for diesel bus

As illustrated in Figure 7 and 8, the observable operation cost of diesel bus comes primarily from fuel and maintenance. However, the diesel buses are huge contributors of pollution that has health effect on citizens of the city. On top of that, diesel buses guzzle up budget in terms of economic and social cost.

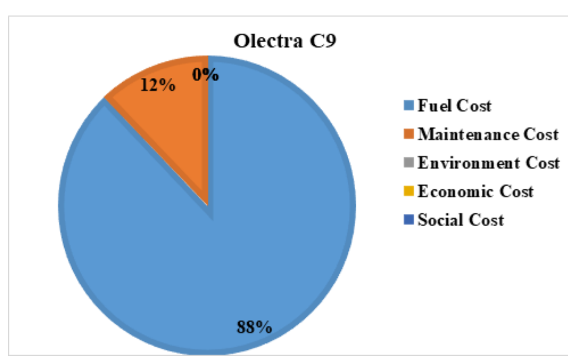


Figure 8: Operation costs for e-bus.

In contrary to the diesel buses, electric buses are pollution free. So, the environment cost, economic cost

Table 17: Overall cost comparison between diesel bus and electric bus.

| SN | Category | Ashok Leyland Viking | Olectra C9 |
|---|---|---|---|
| 1 | Acquisition cost | 3055972.00 | 36150000 |
| 2 | Fuel cost | 2913750 | 6122448 |
| 3 | Maintenance cost | 1046346.09 | 842418.99 |
| 4 | Environment cost | 693108.7 | 0 |
| 5 | Economic cost | 10393303 | 0 |
| 6 | Social cost | 11723683 | 0 |
| 7 | Total cost | 29826162.79 | 43114866.99 |
| 8 | Total distance run | 78750 | 78750 |
| 9 | Total cost without acquisition cost | 26770190.79 | 6964866.988 |
| 10 | CVFA (I = 5, t = 12) | 15.917 | 15.917 |
| 11 | Cost over the total age | 426101126.7 | 110859787.8 |
| 12 | PVF(I = 12, t = 12) | 0.257 | 0.257 |
| 13 | NPV of cost | 109507989.6 | 28490965.48 |
| 14 | NPV with acquisition cost | 112563961.57 | 64640965.48 |
| 15 | Cost per km | 1429.38 | 820.84 |

and social cost of electric buses are negligible. The operation cost of an electric bus comes from fuel which is electricity and from maintenance only.

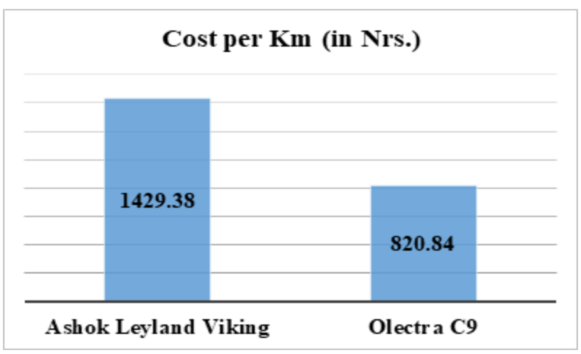


Figure 9: Cost per kilometer comparison between diesel bus and e-bus.

After the calculation made with the figures mentioned in Table 17 , it has been found that over the life of 12 years, electric buses are 1.7 times cheaper than the diesel buses. We can see in Figure 9 that while one diesel bus costs rupees 1429.38 per kilometer, one electric bus only costs rupees 820.84 per kilometer. This suggests that deploying electric bus over diesel bus is economically profitable.

## 5. Conclusion

The Linear Programming Method and MCDAmodels were adopted for optimizing the number of buses running in the routes and for optimizing the mode of charging facility. Different trials were made for minimizing the number of buses and different parameters were analyzed to get the optimum mode of charging facility. The results were discussed and compared with the data from existing models and with actual scenarios of diesel buses. Following conclusions were extracted from the study:

- The number of buses deploying in the routes can be minimized by taking the available time and distance of the routes in account.
- The Olectra C9's battery capacity was feasible for the services.
- The charging facility must be centrally located so that the operation cost is minimized and the supervision is made possible.
- Electric bus is economically feasible over existing diesel bus if the lifetime operation is considered.

## 6. Acknowledgement

The authors would like to sincerely thank Sajha Yatayat for their co-ordination by providing important information and data to make this study possible.

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