ADVANCING PUBLIC TRANSPORT

KNOWLEDGE BRIEF

# PLANNING FOR ELECTRIFICATION OF RURAL AND INTERCITY BUSES

## STRATEGIES FOR ROUTE, DEPOT AND CHARGING LOCATION SELECTION

OCTOBER | 2022

## INTRODUCTION

*Electric bus (e-bus) adoption efforts in the India bus sector, like in many other places globally, have predominantly focused on urban bus services, given their lower daily-kilometre (km) characteristic compared to rural and intercity buses, making it relatively easier to overcome the range constraints of e-buses. However, the bus landscape in India is dominated by rural and intercity buses, which account for 70% of the Nation's entire bus fleet[1], with about 1,02,541 out of 1,46,559 public buses operated by State Transport Undertakings (STUs) operating in the rural and intercity market at the end of March 2022, while the remaining 44,018 buses are in urban areas[2]. India has about 2,000 operational e-buses by the end of June 2022 while about 7,000 more buses are contracted to be deployed by 2023. Government of India (GoI) has recently announced a National Electric Bus Program (NEBP) which aims to deploy an additional 50,000 new e-buses in the near future of which rural and intercity buses are expected to form a significant share.*


AC Sleeper intercity bus service: Ambari

The key constraints (operational requirements) to be addressed in replacing conventional internal combustion engine (ICE) buses powered by diesel or compressed natural gas (CNG) with e-buses include the limited range (km run on a single charge) of e-buses compared to ICE buses and the time needed to charge e-buses, which is significantly longer than the time needed to refuel ICE buses. Rural buses provide connectivity from villages to the nearest urban centres, markets and services while intercity buses provide connectivity between cities and typically operate more km per day compared to rural buses as they operate on highways. Hence, rural and intercity bus services require buses to have longer range than urban busess, thereby adding to the battery requirements and e-bus cost. E-buses' range constraints can necessitate the use of additional buses to provide the ICE-equivalent number of trips[4]. However, the higher daily-km operated by these buses also translates into additional cost savings thanks to e-buses' intrinsic higher energy efficiency. Intercity and rural bus fleet operators need to balance e-buses' range constraints and their higher initial capital cost with their cost savings potential to identify their strategy to move towards e-buses.

This knowledge brief outlines a practical strategy for depot, route, and charging location selection for electrification of long-range buses. The strategy proposes a structured approach to e-bus deployment that can provide inputs for on-ground implementation after adapting the analysis and outputs to the specific operational requirements and technologies available at the time of implementation.


*Intercity Non AC bus service: Suvarna Karnataka Sarige*

## IMPORTANCE OF REPLACEMENT RATIO (RR) IN ELECTRIFICATION OF INTERCITY AND RURAL BUSES

The replacement ratio is defined in this study as the number of e-buses needed to provide an exisiting ICE bus-equivalent service. Prioritisation of routes and depots that offer the lowest RR will minimise the total cost of ownership (TCO) of transitioning towards e-buses[4]. Longer single-charge ranges typically reduce the RR. At the same time, long-range buses require provision of en route opportunity charging to increase their daily operational range. Hence, appropriate placement of opportunity charging stations is also a crucial part of bus operators' strategy for electrification of long-range buses.


*Non AC super deluxe buses (Rajahamsa)*

## THE CASE STUDY AND ITS BROADER APPLICABILITY

This knowledge brief covers a case of intercity and rural bus services in Karnataka, India. An overview of intercity and rural public transport bus operations in Karnataka is given, followed by a detailed analysis of the operations of Kalyana Karnataka Road Transport Corporation (KKRTC), one of the three regional public bus service providers in the state, based on which potential depots, routes, and charging locations are identified.

The approach proposed here is operator agnostic and can be adopted by long-range bus fleet operators in other contexts. While the analysis focuses on public bus services, private intercity buses are likely to follow similar origin-destination (OD) patterns and hence have similar operational requirements. Therefore, the proposed approach can also be used by private bus operators to identify the intercity routes and charging locations to be developed. However, Indian private bus operators operate as small fleets on their own preferred routes, necessitating an aggregated analysis across several operators to prioritise routes for e-buses. implementation.

## APPROACH FOR DEPOT, ROUTE AND CHARGING INFRASTRUCTURE LOCATION SELECTION

Bus agencies deploying e-buses on rural and intercity routes which currently operate ICE buses need to balance the cost savings offered by long-range buses with their constraints, such as range and charging time limitations, to minimise the costs incurred and maximise the benefits accrued from the e-buses. Advanced methods for such prioritisation of depots and routes recommend TCO and energy efficiency modelling of different routes based on their operational characteristics such as length, the speed profile, altitude, temparature and load carried, amongst other factors[4]. However, the limited data available with Indian bus agencies, as well as limitations in technical capabilities to carry out such modelling, render such an analysis unviable at a large scale. Instead, a simplified approach using available datasets with Indian bus agencies is proposed in this knowledge brief.

### APPROACH FOR DEPOT AND ROUTE PRIORITISATION

1. Service type selection
2. Bus and charger technology identification
3. Depot selection for overnight charging
4. Location selection for opportunity charging using spatial analytics
5. Selection of routes and schedules

It is recommended to take a phase-wise and iterative approach to selecting the depots and routes for initial e-bus deployment, after evaluation of operational feasibility. With technological evolution and declining battery prices, even the routes that are infeasible today are likely to become feasible in the future. The following step-wise approach for depot and route prioritisation when planning for initial e-bus deployment is proposed:

- Service type selection: Indian intercity and rural public bus agencies offer a wide range of bus services, including low-cost rural services (typically called as 'ordinary' service), 'express' buses which offer intercity services connecting the district headquarters to other urban and high demand tourist centres and air-conditioned (AC) services for long-distance passengers (typically called as 'premium services'). Each service type has distinct operational requirements and clientele. Therefore, identifying the priority order of service types to be electrified helps determine the appropriate technical and functional specifications for the buses, as well as their operational economics. Hence, service type selection is the first step in depot and route planning approach.
- Bus and charger technology identification: The RR associated with e-buses in a given context is a crucial factor in determining the e-bus TCO. Hence, bus technology specifications such as battery type and size, energy consumption and single-charge range, along with charger technology specifications such as capacity and charging speed, need to be identified according to the service type selected[5]. Investigating and matching the e-bus and charger technology needs with available market offer (=industry market places) is cost-efficient, as there is limited additional investment required by the original equipment manufacturers (OEMs) to develop the vehicles, and there is already a well-established supply chain. Thus, we recommend a testing phase to trial the suitability of available vehicle models that match the operational requirements of bus agencies before specifying requirements.
- Depot selection for overnight charging: The majority of intercity and rural buses are parked at their depots overnight, while a few long-distance services offer overnight services but are stationed at the depots for a few hours between trips during the day. Hence, the identification of depots with adequate grid connectivity to enable the implementation of charging infrastructure at the depots is a key determinant of e-bus feasibility. This requires matching the bus and depot network data with data on access to the grid, power infrastructure like substations and high-tension lines. Since such data may not be readily available, the type of location can be used as a proxy to determine the availability of power infrastructure; for example, in high public transport demand nodes, the current development patterns and their energy consumption patterns are assumed to have enabled sufficient existing power infrastructure to meet the energy needs of the proposed e-buses. Therefore, the top 20 OD nodes within the overall bus network OD matrix are selected for further analysis, under the assumption that they will have adequate grid connectivity. However, since this is only a proxy indicator, the actual number of locations with adequate power infrastructure and specific locations for charging and their costs need to be worked out at the time of implementation.

- **Location selection for opportunity charging using spatial analytics:** Long-range buses typically require opportunity charging during the day to enhance their state of charge (SoC) and thereby extend the range they can deliver within the day. This would reduce the e-bus battery size requirements and its RR. Opportunity charging can be taken up at depots that have been proposed for charging infrastructure deployment, as well as other locations such as bus stations with several routes passing through them, which will enable to access to charging infrastructure for more buses. Many Indian bus agencies do not have a spatial map of their network and services, which makes identification of such locations difficult. Recent developments in geospatial analytics have enabled the use of routing algorithms to create maps based on the order of stops within a route. The entire bus route network can be built using these methods, and analysing the network using Geographic Information System (GIS) software can help identify locations for opportunity charging.
- **Selection of routes and schedules:** The routes and their service schedules operating from the selected depots for overnight charging and passing through the locations proposed for opportunity charging are recommended to be selected for e-bus deployment. Despite the availability of charging infrastructure, the current time available between successive trips may not allow for overnight nor for opportunity charging. In such cases, existing bus service schedules need to be modified to incorporate technological constraints without significantly impacting operational requirements. Therefore, we recommend identifying opportunity charging locations based on the current services and incorporating additional charging time into their schedules as needed. At the same time additional charging times within the schedules should carefully evaluate passenger preference and ensure minimum inconvenience caused through additional wait times.

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# KARNATAKA CASE STUDY

## BUS SERVICES IN KARNATAKA

Karnataka State is spread across approx. 0.192 million sq. km[6] and has with a population upwards of 67.5 million inhabitants[7] a population density of about 350 inhabitants per sq. km. Buses are the mainstay of public transport in Karnataka across urban, rural, and intercity travel. Public bus services are provided by the four government-owned road transport corporations (RTCs): the Karnataka State Road Transport Corporation (KSRTC), Bengaluru Metropolitan Transport Corporation (BMTC), North Western Karnataka State Road Transport Corporation (NWKRTC), and Kalyana Karnataka State Road Transport Corporation (KKRTC) (previously known as North Eastern Karnataka State Road Transport Corporation (NEKRTC)). Even though Karnataka has private bus services, their operations are restricted to long-distance premium services and areas with limited public bus connectivity. While BMTC provides urban bus services in the Bengaluru metropolitan region, the remaining three corporations provide regional services in rural and intercity routes. Even though they operate as individual corporations, they have significant integration at the policy and governance levels under the Government of Karnataka (GoK). The three corporations besides BMTC undertake aggregated procurement of buses and spares, have a common pool of staff and interlocking boards, with the managing directors of all the corporations being on the boards of each corporation, and have common procedures for all activities. Hence, a detailed analysis of one of these corporations is representative of all three of them.

Table 1 provides a summary of the three regional corporations in Karnataka in 2019-20, before the coronavirus (COVID-19) pandemic. The overall fleet sizes have decreased since then due to lack of fleet replacement and augmentation because of the financial constraints caused due to the decreased demand and associated revenue since the pandemic. This is reflected in the high percentage of buses which have crossed their retirement age but continue to operate due to lack of adequate fleet replacement and augmentation. Together, these three corporations held 17,267 buses, making Karnataka a state with one of the largest non-urban public transport fleets. These buses had an average of 16,388 schedules[8] across various types of services, such as ordinary, express, and sleeper coaches (AC and non-AC). Their daily ridership of 6.51 million and staff strength of 81,918 shows their importance to both the users and employees of these organisations.

The e-bus deployment efforts in these corporations have been limited thus far, with KSRTC[9] contracting 50 e-buses through the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles II (FAME II) scheme, which are yet to be deployed. At the same time, KKRTC has announced its intention to procure another 50 e-buses[10]. A strategic roadmap for electrification has not yet been prepared for any of these corporations. Therefore, the analysis presented in the paper can help the corporations prioritise routes and depots for their upcoming rounds of procurement.

| KEY PERFORMANCE INDICATORS | KSRTC | NWKRTC | KKRTC |
|---|---|---|---|
| Fleet size (annual average) | 8,709 | 5,080 | 4,729 |
| Number of schedules (annual average) | 8,172 | 4,661 | 4,456 |
| Percentage buses past their retirement age | 44% | 45% | 30% |
| Number of administrative divisions | 17 | 8 | 9 |
| Number of depots | 83 | 51 | 52 |
| Number of bus stations | 166 | 177 | 154 |
| Fleet utilisation (daily % buses on-road) | 90.5 | 90.3 | 85.4 |
| Vehicle utilisation (km/bus/day) | 365 | 346 | 343 |
| Staff on-rolls | 38,368 | 23,174 | 20,376 |
| Daily ridership (millions) | 3.00 | 2.15 | 1.36 |

*Table 1: KSRTC, NWKRTC, & KKRTC indicators (FY 2019-20)*

## KKRTC OPERATIONS OVERVIEW

The three corporations adopt similar planning, procurement and operations practices. Hence, KKRTC was selected as the representative case study to demonstrate the approach for route and depot selection analysis for the rest of Karnataka as well as other Indian states. The analysis used detailed service schedule and operational performance data provided by KKRTC for the month of November 2021, i.e. the period by when operations stabilised after the first two waves of the COVID-19 pandemic. Even though there were subsequent waves of the pandemic, they did not significantly affect bus operations, and, hence, the data used for this analysis reflects any post-pandemic changes. The data covered operations for all nine divisions of KKRTC, including trip-wise service schedule data and service type-wise operational and financial performance data. The service schedule data included items such as depot number, service type, schedule number, trip number, trip-wise origin and destination, trip-wise departure and arrival times, and trip-wise and daily distance covered for the schedule in a day. The operational performance data included service type-wise daily-km operated, along with costs and revenue per km of operation. KKRTC provided data in its current form, which is compiled based on its operational requirements. This data was converted into a consolidated database across the entire network covering the trip-wise service schedule data, as well as service type-wise cost and revenue performance data for further analysis.

## KKRTC DEPOT AND ROUTE SELECTION

The application of the step-wise approach explained in the previous section to the KKRTC case is presented below:

### STEP 1: SERVICE TYPE SELECTION

Table 2 presents the corporation level summary of KKRTC's operations and financial performance for the 2019-20 fiscal year (pre-COVID-19). Ordinary and express services constitute 89% of all schedules and 91% of the total effective-km (service-km available to users) operated. The financial performance analysis shows that express services contribute 62% of the farebox revenue and 56% of the total cost of operations. Given the crucial value contribution of express services as business drivers, they have been identified as the primary target for introduction of e-buses, in order to deliver the new services to a majority of users and provide energy cost savings on the service type with the majority share of costs.

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| SERVICE TYPE | SHARE OF SCHEDULES | | EFFECTIVE KM | | FAREBOX REVENUE | | COST OF OPERATIONS | |
|---|---|---|---|---|---|---|---|---|
| | NO. | % | LAKH-KM | % | RS. LAKHS | % | RS. LAKHS | % |
| ORDINARY | 1,916 | 43% | 1,769 | 36% | 415 | 29% | 644 | 35% |
| EXPRESS | 2,029 | 46% | 2,729 | 55% | 886 | 62% | 1,039 | 56% |
| RAJHAMSA/SUHAS | 49 | 1% | 75 | 2% | 23 | 2% | 29 | 2% |
| AC SLEEPER | 19 | 0.4% | 26 | 1% | 9 | 1% | 10 | 1% |
| NON-AC SLEEPER | 98 | 2% | 147 | 3% | 51 | 4% | 55 | 3% |
| CITY SERVICES | 345 | 8% | 184 | 4% | 45 | 3% | 84 | 5% |
| TOTAL | 4,456 | 100% | 4,930 | 100% | 1,428 | 100% | 1,861 | 100% |
| SHARE OF AC SERVICES | - | 0% | - | 1% | - | 1% | - | 1% |
| SHARE OF NON-AC SERVICES | - | 100% | - | 99% | - | 99% | - | 99% |

*Table 2: KKRTC service type-wise operational and financial performance (FY 2019-20)*

## STEP 2: BUS AND CHARGER TECHNOLOGY IDENTIFICATION

The e-bus and charger technologies currently available on the Indian market have been used to analyse their suitability to meet KKRTC requirements. Table 3 provides a summary of the three anonymised e-bus types used, which are based on e-bus models being operated in Indian cities. The charger specification is considered as a constant across the three bus models to meet the operational needs with limited charging time available in rural and intercity operations. A combined charging system (CCS) 2.0 standard direct current (DC) charger with a capacity of 240 kilowatts (kW) is assumed to be deployed. The charging speed (charge per min) currently offered by such chargers is used for the operational feasibility analysis.

| BUS TYPE | BATTERY SIZE (KWH) | CHARGER CAPACITY (KW) | CHARGE PER MINUTE (KWH/MIN) |
|---|---|---|---|
| Bus 1 | 250 | 240 | 2.56 |
| Bus 2 | 320 | 240 | 2.56 |
| Bus 3 | 395 | 240 | 2.56 |

*Table 3: Bus and charger models analysed for KKRTC operations*

## STEP 3: DEPOT SELECTION FOR OVERNIGHT CHARGING

The top 20 OD nodes within the overall bus network were identified with the majority of trips terminating in them, under the assumption that they would have adequate power connectivity. These locations have relatively high demand for bus services within the KKRTC network and hence are assumed to be in areas with significant residential or commercial activity, thereby indicating the high likelihood of their access to high-tension power infrastructure. The specific locations and their costs should be determined and further fine-tuned at the time of implementation.

| | |
|---|---|
| Kalburgi | Sindhnur |
| Ballari | B.Kalyan |
| Vijayapura | Gangavathi |
| Raichur | Sindagi |
| Bidar | Muddebihal |
| Hospet | Aland |
| Koppal | Indi |
| Bhalki | Shahapur |
| Humnabad | Lingsugur |
| Yadgiri | Kushtagi |

*Table 4: Top 20 origins and destinations for KKRTC buses*

## STEP 4: LOCATION SELECTION FOR OPPORTUNITY CHARGING

This analysis uses a rule-based methodology to identify suitable locations for installing charging stations. The Excel-based schedules of each KKRTC depot were aggregated into a large database, and the latitude and longitude values of the origin, destination, and intermediate points were derived using Open Street Maps Application Program Interfaces (APIs). Online routing algorithms were applied on this spatial database to extract paths between origins and destinations via the intermediate points. The routes on each road were added to calculate the total volume of buses on each road. All roads with more than 100 routes[11] passing through them were selected, and their route-termination nodes within 1 km of the roads were identified as potential opportunity charging nodes. It should be noted that this estimation assumes that charging stations are required at locations where there are at least 100 routes passing through a location, and therefore the actual number of charging stations needed may change contextually based on the threshold adopted. Graphs of the route overlap and charging location identification analysis results are shown in Figure 2. Seventy-three locations were identified for potential charging stations. These locations primarily cluster around hubs, i.e. the main depots from where the routes are operating, in relatively larger urban agglomerations in the region. These locations are shown in Figure 3. While this analysis generated indicative locations of the charging stations; the exact locations need to be identified based on detailed on-ground surveys covering proximity to the power grid, land availability, bus operations feasibility, etc.

| Depot | Schedule No | Trip number | Route | | Dist. in Kms | Timings | | Type of Service | Total km | Important Enroute places | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | From | To | | Dept. | Arrl. | | | | | | | |
| KALABURGI-1 | 3 | 1 | KALABURGI | BIDAR | 118 | 0800 | 1020 | Express | 472 | Humnabad Non Stop | | | | |
| | | 2 | BIDAR | KALABURGI | 118 | 1100 | 1320 | Express | | Humnabad Non Stop | | | | |
| | | 3 | KALABURGI | BIDAR | 118 | 1400 | 1620 | Express | | Humnabad Non Stop | | | | |
| | | 4 | BIDAR | KALABURGI | 118 | 1700 | 1920 | Express | | Humnabad Non Stop | | | | |
| KALABURGI-1 | 4 | 1 | KALABURGI | PANAJI | 510 | 1415 | 0515 | Express | 510 | Afzalpur | Sindagi | Vijayapur | Mapsalan | Lokapur |
| KALABURGI-1 | 5 | 2 | PANAJI | KALABURGI | 510 | 1745 | 0845 | Express | 510 | Mapsa | Kanakumt | Belagavi | Yaragatti | Lokapur |
| KALABURGI-1 | 8 | 1 | KALABURGI | BOREVELY | 558 | 2000 | 0620 | NON /A/C | 558 | Aland | Solapur | Temburni | PuneE(Sw | Lonavala |
| KALABURGI-1 | 9 | 1 | BOREVELY | KALABURGI | 558 | 1630 | 0305 | NON /A/C | 558 | Kurla | PuneE(SW | Modalimb | Solapur | AKALKOT |
| KALABURGI-1 | 10 | 1 | KALABURGI | CHINCHOLI | 81 | 0900 | 1120 | Ordinary | 324 | Sannur | Kalagi | Sulepet | | |
| | | 2 | CHINCHOLI | KALABURGI | 81 | 1145 | 1405 | Ordinary | | Sulepet | Kalagi | Sannur | | |
| | | 3 | KALABURGI | CHINCHOLI | 81 | 1445 | 1705 | Ordinary | | Sannur | Kalagi | Sulepet | | |
| | | 4 | CHINCHOLI | KALABURGI | 81 | 1730 | 1950 | Ordinary | | Sulepet | Kalagi | Sannur | | |
| KALABURGI-1 | 11 | 1 | KALABURGI | SEDAM | 58 | 0700 | 0825 | Express | 348 | Sannur | Tegli | | | |
| | | 2 | SEDAM | KALABURGI | 58 | 0845 | 1010 | Express | | Malakhed | Madbul | | | |
| | | 3 | KALABURGI | SEDAM | 58 | 1045 | 1210 | Express | | Sannur | Tegli | | | |
| | | 4 | SEDAM | KALABURGI | 58 | 1230 | 1355 | Express | | Malakhed | Madbul | | | |
| | | 5 | KALABURGI | SEDAM | 58 | 1430 | 1600 | Express | | Sannur | Tegli | | | |
| | | 6 | SEDAM | KALABURGI | 58 | 1630 | 1755 | Express | | Malakhed | Madbul | | | |
| KALABURGI-1 | 12 | 1 | KALABURGI | SHIRADI | 452 | 0900 | 2015 | Express | 452 | Aland | Solapur | Temburni | Karmala | AhemAdarsha |
| KALABURGI-1 | 13 | 1 | SHIRADI | KALABURGI | 452 | 0715 | 1730 | Express | 452 | Ahem nag | Temburni | Solapur | Akkalkot | AAland |

*Excel based KKRTC timetable database*

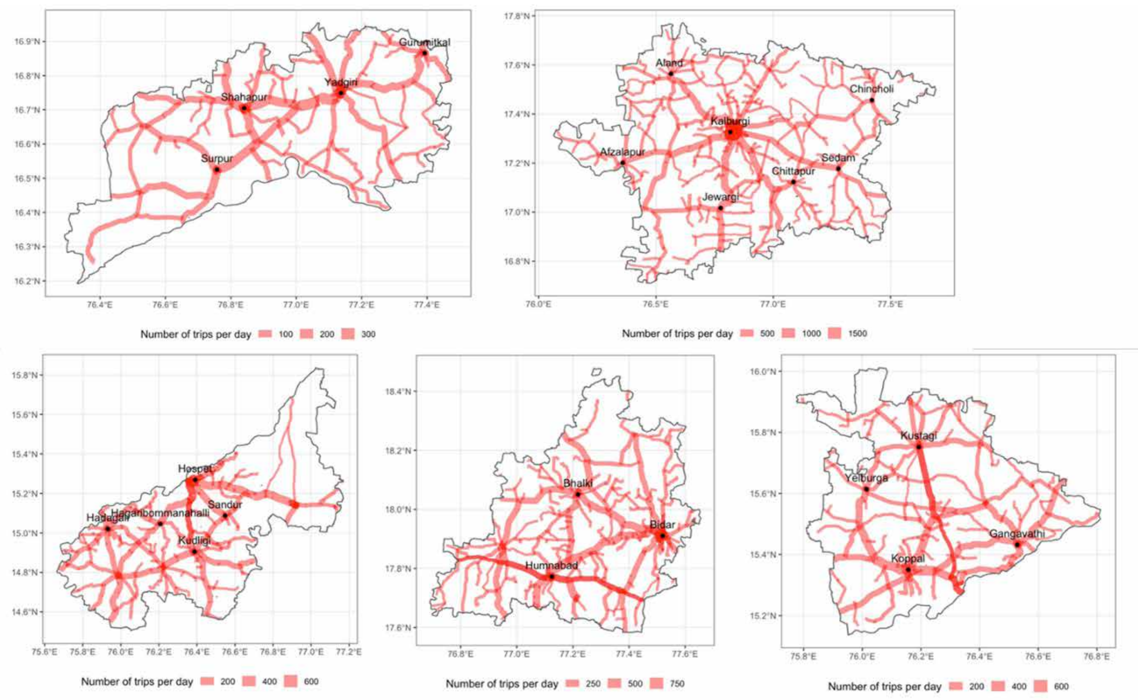



*Figure 2 Route overlap and charging infrastructure siting analysis results for 5 KKRTC divisions*

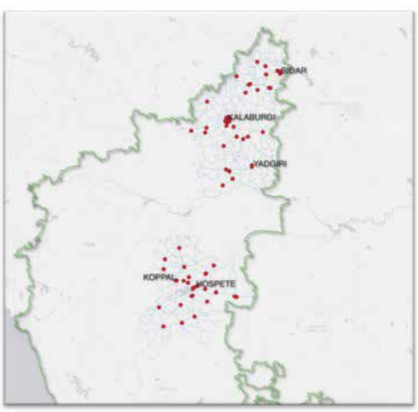


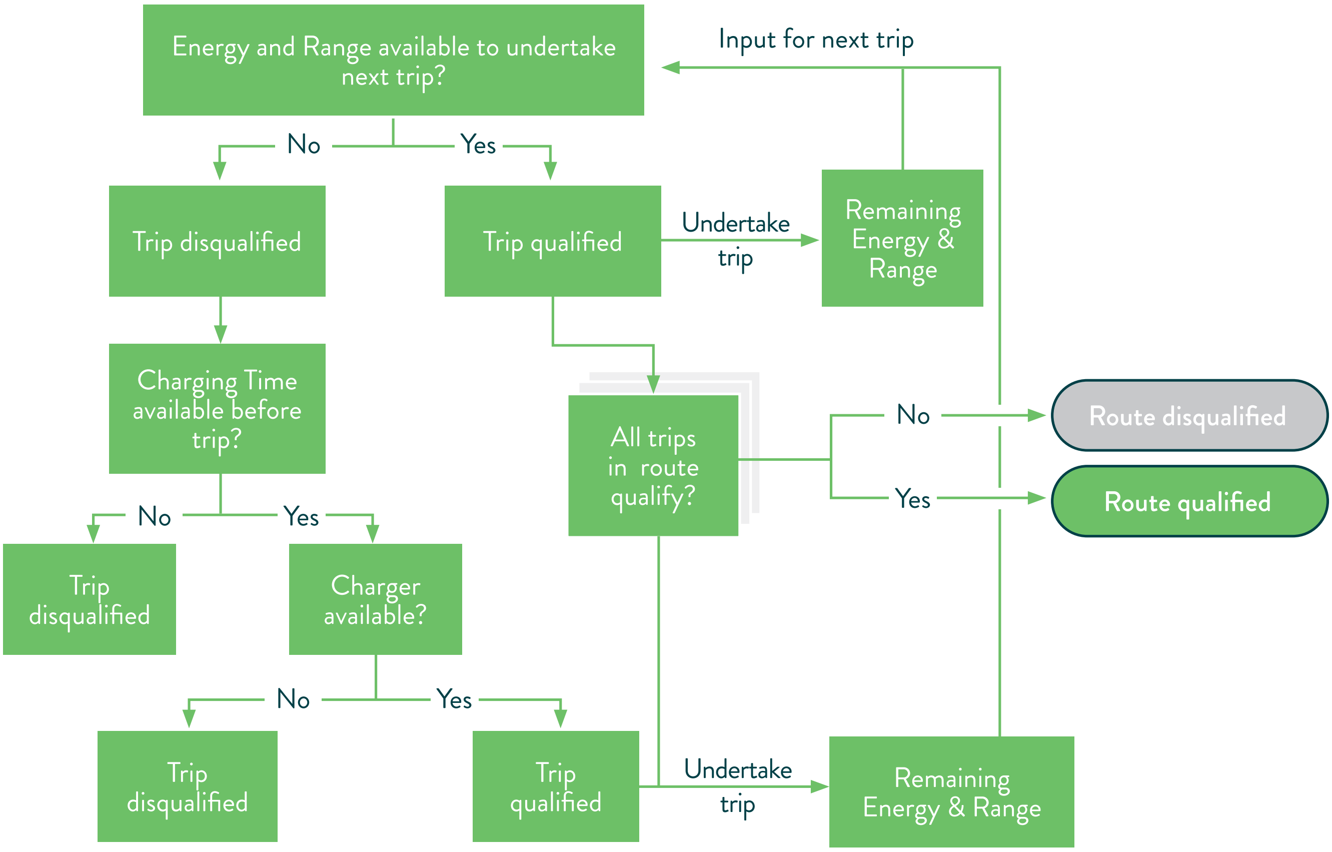

*Figure 3 Identified depot and opportunity charging locations for KKRTC*

## STEP 5: SELECTION OF ROUTES AND SCHEDULES

The data for the 4,136 schedules operated by KKRTC in November 2021 was analysed using the four steps explained above, and the priority list of routes was identified through analysis of each bus schedule using the following approach:

- Selection of one of the three bus types
- Estimation of number of trips within the schedule that can be performed with overnight charging
- Estimation of number of trips that can be performed with opportunity charging during the breaks available within the current schedule
- Estimation of number of trips that can be performed assuming that the breaks at locations with charging infrastructure can be extended to up to 30 min


Figure 4 outlines the decision-making process adopted for schedule-wise feasibility analysis for a given bus type.




*Decision-making process for support of schedule and route selection*

## RESULTS OF DEPOT AND ROUTE SELECTION ANALYSIS

The above mentioned five-stage process was used to select the priority KKRTC routes and schedules for electrification. The three types of buses listed in Table 3 have been analysed in the following scenarios:

**1**

**OVERNIGHT CHARGING IS ONLY AVAILABLE AT THE TOP 20 DEPOTS**

**OPPORTUNITY CHARGING IS AVAILABLE AT THE SELECTED LOCATIONS**

**ONLY THE 'EXPRESS' SERVICE TYPE IS SELECTED**

**2**

**OVERNIGHT CHARGING IS ONLY AVAILABLE AT THE TOP 20 DEPOTS**

**OPPORTUNITY CHARGING IS AVAILABLE AT THE SELECTED LOCATIONS**

**ANY SERVICE TYPE IS SELECTED**

**3**

**OVERNIGHT CHARGING IS AVAILABLE AT THE TOP 20 DEPOTS**

**OPPORTUNITY CHARGING LOCATIONS IDENTIFIED ABOVE**

**ONLY THE 'EXPRESS' SERVICE TYPE IS SELECTED**

| BUS TYPE | BATTERY SIZE | TYPE OF OPP. CHARGING | SCENARIO 1 | | SCENARIO 2 | | SCENARIO 3 | | TOTAL SCHEDULES |
|---|---|---|---|---|---|---|---|---|---|
| | | | SCHEDULES SELECTED | % OF TOTAL SCHEDULES | SCHED- SELECTED | % OF TOTAL SCHEDULES | SCHEDULES SELECTED | % OF TOTAL SCHEDULES | |
| BUS 1 | 250 kWh | OPP. CHARGING DURING EXISTING BREAKS | 306 | 7% | 443 | 11% | 756 | 18% | 4135 |
| BUS 1 | 250 kWh | EXTEND OPP. CHARGING TO 30 MIN | 418 | 10% | 632 | 15% | 952 | 23% | 4135 |
| BUS 2 | 320 kWh | OPP. CHARGING DURING EXISTING BREAKS | 371 | 9% | 721 | 17% | 1049 | 25% | 4135 |
| BUS 2 | 320 kWh | EXTEND OPP. CHARGING TO 30 MIN | 444 | 11% | 800 | 19% | 1164 | 28% | 4135 |
| BUS 3 | 395 kWh | OPP. CHARGING DURING EXISTING BREAKS | 387 | 9% | 755 | 18% | 1184 | 29% | 4135 |
| BUS 3 | 395 kWh | EXTEND OPP. CHARGING TO 30 MIN | 427 | 10% | 795 | 19% | 1253 | 30% | 4135 |

*Table 5: Summary of route selection analysis results*

The following are the key results from the analysis:

- E-buses with larger batteries are more suitable for longer-distance operations, as their longer ranges enable electrification of up to 11% of total KKRTC schedules, even when Scenario 1 is considered, i.e. express routes with overnight charging only available at the top twenty depots.
- Relaxing the criteria of selecting only express services, up to 19% of all schedules can be electrified in Scenario 2, which still assumes overnight charging at depots and opportunity charging at identified locations.
- Relaxing the overnight charging infrastructure availability only at the depots to make it available across all opportunity charging locations. Express services makes electrification feasible for 30% of KKRTC's schedules, with minor adjustments to increase break times up to 30 minutes.
- Across all the scenarios, extending opportunity charging time to 30 minutes enables a significant number of additional schedules to be electrified.

*In summary, the scenario analysis shows that the availability of charging infrastructure locations is a greater constraint than the e-bus battery size in the electrification of rural and intercity buses*. Thirty percent of the entire fleet can be electrified using e-buses currently available on the Indian market. With improving technology, e-bus feasibility is going to improve significantly in the coming years. Since express services are generally the preferred service type for electrification, the option of making additional chargers available is recommended as a better alternative to maximise the electrification potential with available bus technologies. Even though the financial feasibility is beyond the scope of this knowledge brief, existing literature indicates that charging infrastructure's share of the TCO of electric buses is limited, and, hence, investment in more and faster chargers to ensure the majority of express services are electrified is a good option.



## THE WAY FORWARD

This knowledge brief provides an approach for prioritisation of depots, routes and charging infrastructure locations for the electrification of intercity and rural public bus services with long-range buses. The key selection criteria for the routes and the approach to derive and analyse data have been laid out.

The proposed approach has been applied to the case of KKRTC, one of the better performing public bus operators in India. A combination of analysis methods using baseline performance monitoring data from KKRTC with advanced mapping routing algorithms was done to carry out the necessary analysis. The analysis has been conducted for alternative bus technology (range), charging availability, charging time, and service type scenarios to identify the most suitable approach to introducing e-buses with minimal disruption to existing services and using available bus models on the market, thereby reducing the additional cost of electrification.

The exercise generates a practical model for decision support of route selection for long-distance routes that can be replicated across State Transport Undertakings in India to design long-distance bus market electrification strategies.

## CONCLUSION

*The analysis demonstrates that range limitations of currently available e-buses is not a critical constraint towards the electrification of rural and intercity buses. Efficient planning of charging locations and improving bus schedules can enable a large share of routes to be electrified even with commercially available bus and charger technologies.*

*Given the higher vehicle utilisation rates and profitable routes of operation, e-bus deployment in rural and intercity bus markets can potentially offer higher energy efficiency and cost benefits compared to urban buses. While some intercity buses may face range issues, many rural and intercity services have adequate time for top-up charging and can be transitioned to e-buses with bus models currently available in the market. Even converting a small percentage of these buses to e-buses would generate a significant scale of procurement, thus reducing e-bus costs through economies of scale as well as delivering significant energy efficiency and emission benefits.*

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1. https://www.pgalabs.in/reports-and-publications/technology-internet/intercity-travel-mobility-market-in-india
2. Data received for March 2022 from the Association of State Road Transport Undertakings (ASRTU) member of UITP
3. https://www.convergence.co.in/public/images/EOI--E-buses.pdf
4. https://theicct.org/publications/deploying-zero-emission-bus-fleets-jun2021
5. UITP offers Standardised On-Road Test cycles for e-buses (E-SORT) which provide reproducible test cycles that cities can use to estimate the likely energy consumption and optimal daily range needed to meet their operational needs (https://www.uitp.org/publications/uitp-sort-e-sort-brochures/)
6. Karnataka Economic Survey (2020-21) (https://des.karnataka.gov.in/storage/pdf-files/CIS/Economic%20Survey%202020-21_Eng_Final_R.pdf)
7. https://uidai.gov.in/images/state-wise-aadhaar-saturation.pdf
8. A schedule is a common term for a bus operating on a given day and the list of all the trips it makes on that day.
9. For the first time, KSRTC to operate electric buses on inter-district routes in Karnataka - The Hindu
10. NWKRTC plans to get 50 electric buses | Deccan Herald
11. Each Origin-Destination pair covered by buses is considered as a route


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