ACTION POINTS

ELECTRIC BUS PERFORMANCE EVALUATION

LESSONS FROM SIX INDIAN CITIES

NOVEMBER | 2022

NEED FOR PERFORMANCE EVALUATION OF E-BUSES

India is witnessing an accelerated uptake of electric buses (e-buses) as about 2,000 units have been deployed over the past three years while an additional fleet of about 6,500 buses are contracted and expected to be operational before the end of 2023. Building on this momentum, Government of India (GoI) has announced the National Electric Bus Program (NEBP) to procure an additional 50,000 electric buses in the years to come. Large scale procurements combined with various fiscal and non-fiscal incentives[1] at the National, State and City levels are all set to accelerate e-bus adoption further . Indeed, as more electric buses are being deployed, it is important to evaluate the performance of already deployed e-buses to improve their operational performance and build knowledge base to inform future procurement choices.

The introduction and scale up of electric buses is ushering in a new era of bus service provision in India. Firstly, the e-bus technology is still evolving. Secondly with the operations, planning, and maintenance practices being significantly different compared to Internal Combustion Engine (ICE) buses as well as between different models of e-bus provided by different Original Equipment Manufacturers (OEMs). Cities are yet to make informed choices and identify the best-fit e-bus technologies available on the market for their operating conditions. Secondly, e-buses are predominantly introduced through Gross Cost Contract (GCC) mode of procurement wherein the technology risk and investment for the buses is covered by the operator, while the contracting authority takes responsibility for service planning and delivery and the revenue risk. Efficient and transparent monitoring of the performance is critical to the success of the GCC model.

APPROACH FOR DATA COLLECTION IN VIEW OF PERFORMANCE EVALUATION OF E-BUSES

UITP India has previously developed a "Framework for Performance Evaluation of Electric Buses in India (2020)[2]" which outlines the various key metrics to be captured, sources of data for these metrics as well as the agency responsible for the data. The framework covers a wide range of data points to understand electric bus performance covering areas like the bus and charger specifications, operational performance, charging needs and energy efficiency performance, depot, staff and financial performance.

Building on this framework, the current study aimed to apply the framework for operational e-buses in cities across India to support cities in their performance evaluation efforts as well as improving the framework further to meet local needs. Towards this, UITP engaged with about eight cities across India to conduct stakeholder outreach activities with the State and Municipal Transport Undertakings (STUs and MTUs) operating electric buses, the private service providers in charge of the operations and maintenance of these buses as well as the Original Equipment Manufacturers (OEMs) supplying these buses. The data template for performance evaluation developed by UITP mentioned above was shared with six cities for them to fill in the necessary information.

Overall, the response to the performance evaluation efforts was limited, primarily because detailed performance data management practices do not exist in many cities and even where they exist, both cities and their service providers were apprehensive about sharing performance data in public domain. The data is received for three to six months of operations from six cities: Delhi, Mumbai, Bengaluru, Pune, Surat and Lucknow. However, the level of detail in the data received and the time periods for which the data was provided varied significantly between cities and even between different months within the same city. At the same time, the period of data collection for the project coincided with various waves of Covid-19 pandemic, during which public transport usage declined and many cities operated limited services. As a result, one month in which data was most comprehensive and the maximum number of services were operational is selected and summarised for each of the cities.

The time period for which data is shared, the duration of operations covered and the metrics against which data is provided varied significantly between cities. Therefore, the data collected is presented anonymously in this paper with the objective of establishing the variance in performance of e-bus across different OEMs and operating conditions.

E-BUSES PERFORMANCE DATA

The six cities for which data is provided are from different parts of the country with varying climate and operating conditions. The e-buses in these cities were deployed between February 2019 and December 2021, making them among the first generation of e-buses deployed in India. Even though Covid-19 pandemic had an impact on the project delivery and scale of operation, the data presented below is generic for it to have implications beyond the pandemic. The performance data collected is summarised in the following two sections on technology specifications and operational performance. The six cities have been labelled as City A, City B and so on while the OEMs providing buses in these cities are labelled as OEM 1, OEM 2 and so on to maintain anonymity as per the data agreements signed with these cities. The operational performance data was not available for one of the six cities and hence is not reported below.

TECHNOLOGY SPECIFICATIONS

Table 1 provides an overview of the e-bus deployment timeline in the case of cities, the month for which data is presented, number of buses for which data is presented as well as the key bus and charger technology specifications for the six cities. The e-buses in these cities are provided by three Original Equipment Manufacturers (OEMs), through a Gross Cost Contract (GCC) to provide e-bus services against a pre-determined per-km fees, wherein they're the lead consortium member. All the cities opted for 9m long midi buses, while one of them also had 12m long standard buses as observed in the initial rounds of procurement in Indian cities[3].

Use case of buses in Cities

Most cities are opting for Air-Conditioned (AC) buses with the advent of e-buses, to position e-buses as a new and better-quality service product as well as because the additional energy cost due to air-conditioning is marginal. In case of diesel and CNG buses, the fuel efficiency of AC buses is typically about 40% lower than their Non-AC variants which added significantly to the overall operating cost given the high energy cost of diesel compared to electricity. Cities opted for standard floor height of 900 mm in case of 9m buses and 400 mm floor height in case of the one 12m bus. The operating conditions of e-bus in these cities varied significantly. While majority of the cities using e-buses operate in regular mixed-traffic urban operating conditions some operated in Bus Rapid Transport (BRT) systems with exclusive bus lanes along the streets, while the rest use e-buses as feeder services to metro rail systems. A combination of these use cases was also observed in some cities. The operating use case has an implication on several variables impacting the performance of e-buses including their daily-km operated, speed profile, road conditions, passenger load and revenue generation.

Battery size and type

The battery size on-board the buses varied between 134 kWh to 180 kWh in case of 9m buses and 320 kWh in case of the 12m buses in one city. Lithium-Iron Phosphate (LFP) and Nickel Manganese and Cobalt (NMC) batteries were the preferred battery chemistries by OEMs. While each battery chemistry has its own advantages and disadvantages, e-bus OEMs have their preferred battery chemistry which they would continue to pursue in the future.

Charging infrastructure

One of the cities had the e-bus OEM providing charging infrastructure as well. However, it was among the first e-bus deployments in India where majority of the e-bus and supporting infrastructure were imported. With increasing Government mandate to 'Make in India' under the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme, recent e-bus deployments are witnessing charging infrastructure for the buses being provided by a third-party OEM specialising in Indian made chargers and other equipment, under a contract by the e-bus OEM.

Guobiao standards (GB/T) and Combined Charging System (CCS) 2.0 were the two types of charging standards adopted by the six cities evaluated. The type of charger used and its capacity varied between cities, even with the same OEM providing e-buses (Eg. OEM 2 using GB/T chargers in City C and CCS 2.0 chargers in City D). More recent procurements like the aggregated procurement of 5,450 buses conducted by the Convergence Energy Services Limited (CESL)[4] have mandated the adoption of CCS 2.0 chargers, indicating that the market is moving towards CCS 2.0 as the default charging standard thereby enabling interoperability of chargers between buses from different OEMs.

The capacity and type of the chargers play a key role in the time needed to charge the buses. The initial deployments used smaller chargers like the 80 kW Alternating Current (AC)-Type 2 chargers used by OEM 1 which required up to 4 hours to charge the buses overnight. However, both cities and operators acknowledge the need for faster charging to improve uptime of buses. As a result, Direct Current (DC) charging with charger capacities of 180-240 kW are being installed in recent deployments. Further, DC chargers with two charging guns are being installed, which allow for the full charging capacity to be utilised when connecting a single gun and the capacity to be split into two when both the guns are used to charge. Cities typically use single gun for fast charging during breaks within the day and split the capacity while charging overnight.

Buses per charger

The number of buses served per charger is a useful indicator to measure the efficiency of the charging system installed. Serving more buses per charger leads to fewer chargers required to be installed, thereby reducing the space needed for charging infrastructure and associated bus circulation within the depot, which is a significant constraint in many urban areas. The buses served per charger for the case cities varied between 2 to 5.5. Cities with lower buses per charger either have lower capacity chargers (City A and City B) or few buses in a given depot. In case of City C, the lower buses per charger is because only a few of the total buses contracted were delivered and the chargers were built even for the remaining buses. In addition to the advantage of higher capacity chargers, this metric also demonstrates the advantage of concentrating e-bus deployments in larger sized depots, thereby reducing charging infrastructure needs.

Power connectivity to the depot

The number of chargers per depot and the capacity of power connectivity to the depot are a function of the lower power supply dynamics, charging schedule of buses and the number of simultaneously charged buses. Table 1 provides the data available for the six cities.

NO.	INDICATORS	CITY A	CITY B	CITY C	CITY D	CITY E	CITY F
1	Bus OEM	OEM 1	OEM 1	OEM 2	OEM 2	OEM 1	OEM 3
2	Induction month and year	August, 2021	February, 2019	August, 2021	November, 2021	February, 2021	December, 2021
3	Month and year (data analysed)	January,2022	January, 2020	January,2022	November, 2021	January, 2022	May, 2022
4	Type of opera-tions	Urban	BRT + Urban	Metro feeder	Urban	BRT	Metro feeder + Urban
5	Number of buses evaluated	40	25 (9m)/ 125 (12m)	24	60	150	90
6	Bus length	9m	9m/12m	9m	9m	9m	9m
7	Air-conditioning	Non AC-10; AC- 30	AC	AC	AC	AC	Non-AC
8	Floor Height	900 mm	900 mm (9m)/ 400 mm (12m)	900 mm	900 mm	900 mm	900 mm
9	Length/width/ height	8900/2465/ 3300 mm	8900/2465 /3300 mm (9m) 12000/2520/ 3340 (12 m)	8540/2450 /3050 mm	8540/2450 /3100 mm	8950/2360/ 3800 mm	9300/2477 /3530 mm
10	Seating capacity	31+D	31+D (9m)/ 35 + WC + D (12m)	21+D+2F/W	21+D+2F/W	24+WC+D	33+D
11	Battery size	180 kWh	180 kWh/ 320 kWh	150 kWh	150 kWh	180 kWh	134 kWh
12	Battery type[5]	LFP	LFP	NMC	NMC	LFP	NMC
13	Charger socket type	GB/T	GB/T	GB/T	CCS2	GB/T	CCS2
14	Charger capacity (kW) and type	80 kW (AC-type 2)	80 kW (AC-type 2), 150 kW (AC-type 2)	240 kW DC (Double gun)	180 kW DC	80 KW (AC-type 2), 150 KW (DC)	240 kW DC (Double gun)
15	Number & type of chargers	20 AC chargers	70 AC and 3 DC chargers	11 DC chargers	11 DC chargers	13 AC & 2 DC chargers	10 DC chargers
16	Number of depots	1	2	2	1	2	3
17	Buses per charger	2.0	2.1	2.2	5.5	5	NA
18	KW capacity of depot charging infrastructure	2000KW	3895 kW	2500 kW	1350 kW	3445 kW	900 kW
19	KV of power to the depot	11kV	4.1 kVA	50	11 kV	11 kV	11 kV

Table 1: Bus and charging technology specifications of e-buses deployed in six Indian cities

OPERATIONAL PERFORMANCE AND ENERGY CONSUMPTION

All the cities adopted GCC as their business model, wherein the bus operator is paid by the contracting authority based on Service Level Agreements (SLAs) such as km of service performed, punctuality, reliability etc. Energy consumption performance of e-buses is among the key Service Level Agreements (SLAs) between the authority and bus operator while in some cases, the energy cost is borne by the contracting authority. Therefore, monitoring operational and energy consumption performance of e-buses is crucial to their contract management. The operational performance and energy consumption of e-buses in five of the six case cities for which access to data is available for a period of at least one month is summarised in Table 2.

The per-km fees to be paid by the city varied between INR 40.35 per-km to INR 64 per-km across the cities due to a combination of factors such as the assured-km of payment to the operator, operational and contractual risks perceived by the service providers and others as discussed in the report 'Electric Bus Procurement Under Fame-II (UITP, 2020)'7. Nevertheless, the GCC fees per-km, unit cost of electricity (INR per kWh) and whether the GCC quote includes electricity cost is included here for ready reference. The electricity costs also vary between INR 4.93 per kWh to INR 6.57 per kWh between cities leading to significant variance in operating costs per km.

The number of operational days per month along with the scheduled-km, operated-km and dead-km (non-revenue-km from depot to trip start point) per bus are summarised below to demonstrate the operational performance of e-buses. While 3 out of 5 cities reported 30-31 days of operations per bus per month, the remaining days when the buses were unavailable can be due to a combination of vehicle technology issues as well as Covid-19 related non-operation of buses. Overall, it is observed that e-bus demonstrate more than 98% fleet availability, which is much higher compared to diesel or CNG buses which typically face difficulty in ensuring availability beyond 95% due to their periodic maintenance needs.

Scheduled and operational-km per bus: The operated-km by buses across cities and OEMs with varying operating conditions, range availabilities and charging technologies is observed to be 194-213 km per bus per day. The scheduled-km of operation in these cities varied between 194-272 km. While in some cases, operated-km exceeded scheduled-km, they were lower than scheduled km in other cases. Quantitative data on the reasons for cancelled-km is not available in significant detail, but consultation with the operators and authorities indicated that the cancellation was primarily due to operational issues like crew unavailability or traffic conditions rather than due to technological reasons such as bus breakdowns or range limitations. The need for improved vehicle and crew scheduling practices incorporating various operational and technological constraints for efficient e-bus operations was highlighted by both cities and operators.

Dead- km indicate the number of km the bus operated without generating revenue, typically to reach the route origin or destination points from their depots or parking facilities. While is a function of local operating conditions. The observation that it can vary between 1.24 to 6 km between cities indicates the need for efficient planning to reduce dead-km where possible and incorporate them while planning for the payment-km to be included in the GCC contract, the energy needs for these km, charging time available for buses and their locations.

Service hours, time spent at depot and no. of charging events per day: Service hours are a function of the local bus services requirements and are crucial in determining the range and type of charging infrastructure to be specified while procuring e-buses. The actual performance of up to 18 hours of service-hours indicates e-bus technology readiness to meet local requirements. City D's scheduling of 11 service hours in a day and only 1 charging event combined with their scheduled-km of 272 km indicates inefficient scheduling. By planning for additional charging events, the city is likely to increase its service hours and improve its operated-kms.

Other bus route characteristics like no. of routes, average route length, buses per route, stops per route, trips per route and average speed are also presented to provide a comparision of the current practices across cities.

Energy consumption of e-buses varied between 0.8 kWh per km to 1.2 kWh per km covering 9m and 12m AC and Non-AC buses. These were derived using data on the total power consumed data available at the depot level along with data on the fleet availability and daily utilisation. Because of this, data on further split of AC Vs Non-AC bus efficiency in City A and 9m Vs 12m bus efficiency in City B were not available. The comparision of energy efficiency of City C with metro feeder operations compared to City E with BRT operations makes for an interesting case. While metro feeder services involve regular stop-start operations during which the AC continues to consume energy, BRT operations are typically more streamlined. However, City E has 50% higher energy consumption per km compared to City C. This could be due to a combination of factors such as the weight of the vehicle (due to the battery size, battery chemistry and passenger loading), the speed profile of bus operations as well as the ambient temperature at which the buses are operating .

In addition to the energy consumption per km, the electricity tariffs of different cities also provide a few interesting insights. The tariffs vary by up to 20% between different cities based on the prevailing state policies towards electric buses and their overall tariff structure. Some of the cities included the cost of electricity within the operator's responsibilities while the rest have absorbed it under the authority's responsibilities. Including electricity costs under the operator's responsibility will increase their cashflow needs but will also encourage energy efficient practices. Therefore, the cost of electricity and the responsibility of payment need to be adequately accounted at the time of procurement and while comparing the GCC prices between cities.

NO.	INDICATORS	CITY A	CITY B	CITY C	CITY D	CITY E
1	Business model	GCC	GCC	GCC	GCC	GCC
2	GCC rate (INR per km)	AC- 55 Non-AC- 51	9m- 40.35 12m- 58.50	64	62.5	55.26
3	Electricity tariff (INR per kwh)	4.93	5.52	5.3	6.57	5.90
4	Electricity cost included in GCC rate?	Yes	No	Yes	No	No
5	Average no. of operational days per bus per month	26	30	30	28	31
6	Scheduled km per bus per day	200	225	200	272	194.2
7	Operated km per bus per day	210	205 (9m)/ 213(12m)	200	198	194
8	Dead km per bus per day	4	1.24	2	NA	6

NO.	INDICATORS	CITY A	CITY B	CITY C	CITY D	CITY E
9	Service hours per bus per day	18	16	16	11	14
10	Time at depot per bus per day (in hrs)	6	8	8	13	10
11	No. of charging events per day	2	2	2	1	2
12	Number of routes	3	6	3	5	3
13	Average route length (in km)	35	28.8	10	40.5	24
14	Buses per route	6	25	3	10	15
15	Stops per route	15	NA	18	24	32
16	Daily trips per bus	5	4	11	4	10
17	Average speed (in kmph)	11.7	13.1	12.5	18.0	13.9
18	Energy consumption (kWh/ km)	0.95 (Average of AC and Non-AC)	1.1 (Average of 50-12m & 10 9m buses)	0.8	0.8	1.2

*NA-Not Available

Table 2: Operations and energy consumption performance of e-buses for 5 of the 6 cities

CONCLUSIONS AND LESSONS LEARNED

E-buses are gaining rapid momentum in India as Government of India (GoI) announced its plans for deployment of 50,000 e-buses under the National Electric Bus Program (NEBP) along with ambitious public transport electrification targets set by many States and Cities. Performance evaluation and efficiency improvement in procurement and operations is a low-cost and high returns strategy to reduce the cost of e-bus uptake and enhance service delivery. This paper presented the key specifications of e-buses deployed in six Indian cities and performance metrics in five of them, as an input to developing a more comprehensive country-wide approach towards performance evaluation.

The comparative analysis of vehicle specifications, charger specifications and power infrastructure requirements demonstrates several alternative combinations in which cities can deploy e-buses. The operational and energy consumption performance analysis indicates significant variance in performance based on the city's bus and charger technology specifications as well as its operating conditions. Similarly, the electricity tariffs and the responsibility for their payment results in significant difference in the overall cost implications for the operator and the authority between different cities. Therefore, careful planning prior to procurement is crucial in identifying the vehicle, charger and power infrastructure specifications which are most appropriate for a given context. At the same time, efficient service planning and scheduling practices post deployment offer significant efficiency improvement potential.

Even though the performance evaluation exercise provided valuable insights into the current functioning of e-buses in India, significant gaps in the current data and performance management practices of both authorities and operators are observed. The following are the key findings from the current study and our recommendations for improved performance evaluation practices in the future:

- **Increased focus on performance evaluation:** The data maintained on e-bus performance is predominantly limited to the total-km operated in a day by each bus and the total electricity consumed at the depot level. Many key metrics such as the energy efficiency of each bus and route, time needed for overnight and opportunity charging, state of charge at the beginning and end of each charging event, energy losses during charging, and causes of cancellation of services are not maintained in most cases. As highlighted at various points throughout the paper, detailed performance management plays a crucial role in enhancing efficiency of operational systems as well as informing procurement specifications in the future. It is recommended that National level agencies such as the Association of State Road Transport Undertakings (ASRTU) takes up advocacy and capacity building activities towards improved performance evaluation.

Standardisation of performance evaluation practices: Performance evaluation approach for diesel and CNG buses in India has been standardised over several decades through the annual reports of the Central Institute of Road Transport (CIRT) and the Transport Research Wing (TRW) of the Ministry of Road Transport and Highways (MoRTH). As explained in this paper as well as the 'Framework for e-bus performance evaluation (UITP, 2020)'[2] e-buses need a few additional technology specific indicators. Further, with increasing number of stakeholders in bus operations such as GCC operators, OEMs, charging service providers, grid- and energy providers, agency specific benchmarks need to be evolved for efficient performance management. The lack of such standardisation in performance management is leading to different cities adopting different metrics of evaluation and many cities not collecting several key metrics. As a result, it is difficult to compare performance of e-buses across cities. Hence, it is recommended that CIRT/MoRTH to publish a standardised approach for e-bus performance management and encourage bus agencies across India to adopt it. If asked for, UITP can play a role in that through it's global network and access to international benchmark standards.

Automation and transparency in contract management: Key contract management activities such as estimating km of service for payment and adherence to SLAs is being predominantly taken up through manual methods. Automated contract management using available Automatic Vehicle Location (AVL) systems, on-board devices and charger data has not been adopted by any Indian city, despite the availability of the necessary hardware tools. Cities would need to invest in developing the backend systems to use the hardware to manage contracts automatically, thereby improving transparency in the process.

Trust building and partnership approach for efficient performance: In many of the case cities, significant scope for improvement in the trust between contracting authorities and operators is observed. During the various waves of Covid-19 during which period this study was conducted, services faced significant disruptions which led to 'Force Majeure' conditions of contract where the operator would not receive their assured payment. Further, lack of timely payments to the operators in some cities has also led to some erosion of trust between the parties. Timely payments, improvements in transparency in contract management, along with a more inclusive approach in various activities such as designing routes and service schedules can build trust between various actors in the system. This would further enhance the partnership between authorities and operators towards delivering efficient e-bus services.

1 Performance Linked Incentives (PLIs) worth USD 5.5 billion for manufacturing of electric vehicles, components and batteries in India, lower Goods and Services Tax (GST) on electric vehicles, relaxation of motor vehicle tax, permit requirements etc. are some of the incentives available across India.
2 https://www.uitp.org/publications/performance-evaluation-framework-for-electric-buses-in-india/
3 https://www.uitp.org/publications/electric-bus-procurement-under-fame-ii-lessons-learnt-and-recommendations/
4 https://www.uitp.org/news/aggregation-delivers-more-savings-than-subsidy-in-recent-indian-electric-bus-tenders/
5 LFP-Lithium Iron Phosphate, NMC- Nickel Manganese Cobalt

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