WRI INDIA

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Foundation for Interoperability in Digital Economy

WORKING PAPER

Open e-bus blueprint

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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HIGHLIGHTS

- With the unprecedented success of bus electrification in India and our broader goal of 30 percent electric vehicle (EV) penetration by 2030, we have an opportunity to electrify over 8 lakh buses.
- Given the different dynamics of operating electric buses – along with legacy communication issues in India's bus sector – a digitalized system of managing bus operations is a potential game changer in this transition.
- India has been a pioneer in using Digital Public Infrastructure (DPI) to resolve systemic problems at scale. This paper frames the concept of the open e-bus blueprint for e-bus service platforms based on successful DPI principles.
- Key benefits include shifting from specific technologies to foundational building blocks, allowing scalable e-bus infrastructure while empowering innovators and stakeholders to contribute and benefit from the e-bus transition.
- The paper curates the principles, key elements, and potential use-cases of the open e-bus blueprint, offering a framework for wider stakeholder discussion.

EXECUTIVE SUMMARY

Context

Buses play a vital role in India's transportation system, serving millions of passengers daily across urban and rural areas. As part of a broader strategy to reduce emissions and improve passenger services, India plans to electrify up to 800,000 buses over the next seven years, a transition involving public, private and institutional fleet operators. The government is creating policies and partnerships that aim to reimagine contracting and operating models for buses.

The transition from internal combustion engines (ICE) to EVs poses both opportunities and challenges in the complex bus transportation system. It will require an approach that can manage the added complexities of batteries replacing ICE, charging stations replacing fuel pumps, and renewable energy replacing conventional fuels. In addition, current bus operations and maintenance systems were designed in isolation from one another. They are not integrated in ways that support communication across stakeholders—passengers, operators, manufacturers, financiers, and regulators. This disjointed setup results in delays and higher operational costs and hinders the cost-effective and sustainable deployment of EV buses at scale. Two key challenges impede progress: The absence of standards for exchanging information limits seamless communication and integration, and persistent information silos limit visibility and stakeholders' ability to fully understand the system and take informed action. A more connected and unified digital ecosystem could help overcome these challenges.

India's experience deploying Digital Public Infrastructure (DPI) in other sectors reveals why this approach holds so much promise. It combines open technology standards, governance frameworks, and a stakeholder ecosystem to drive innovation. The DPI approach has demonstrably reduced costs and improved accessibility to services across sectors like banking, payments, e-commerce, and healthcare. Whether it could help address the unique challenges of transitioning to e-buses remains an open question, but one that should be explored.

About this working paper

In this working paper, WRI India and FIDE seek to frame and contextualize the challenges the bus transport system will confront amid the complexities of a large-scale digital transition. It finds that, despite the technological solutions available, the absence of standards and limited observability- the ability of stakeholders to access, monitor, and analyze information - can drive up costs and hinder scalability. Proprietary systems from various vendors are tough to integrate and upgrade, making it harder to effectively find and use limited resources, improve operations, and increase transparency and accountability.

The paper proposes a novel approach that leverages DPI principles to guide bus electrification and a roadmap for translating this blueprint into reality. To ensure effective implementation, the "open e-bus blueprint" requires interaction across a wide range of stakeholders, including passengers, e-bus operators, original equipment manufacturers (OEMs), charge point operators (CPOs), financial institutions, government agencies, and technology-energy-mobility service providers.

We invite and seek to enable wider stakeholder comments and consultation on strategic and functional considerations to design an "open e-bus blueprint" for e-bus service platforms based on DPI principles. The goal is to cater to the diverse needs of key groups involved and prepare a smooth roll-out of e-buses at scale with the associated infrastructure and services.

Key findings

Business-as-usual approaches based on proprietary vendor technologies, lock in inefficiencies and make integrating and upgrading systems harder. Traditional bus operations depend on various systems, such as those for Vehicle Location and Tracking (VLT), Automatic Fare Collection (AFC), and fleet management. E-buses require new services for energy management, battery health, charging schedules, and power purchase contracts. If standards for exchanging information are not clear, if each vendor must develop its own proprietary solutions, with no opportunity to share, and integrate these, costs for technology and upgrades will be far higher than necessary.

Transformative outcomes seen in India's DPI efforts come from careful planning. In identity, banking, payments, e-commerce, and healthcare, these outcomes were not simply the result of isolated technological solutions but stemmed from a systemic approach that focused on creating foundational digital building blocks that were available to the ecosystem. In this case, *ecosystem* refers to a complex network of actors and their services that interact with and rely upon others to function effectively. The small interventions that created these building blocks allowed different actors in the ecosystem, both public and private, to innovate and create scalable solutions, proving that doing less can, in fact, achieve more. By rethinking the bus sector through the DPI model, we can envision a core framework that integrates technology architecture, governance, and market-driven innovation.

The open e-bus blueprint, based on DPI principles, presents a vendor-agnostic and specification-driven architecture that enables observability (the ability to monitor and understand a system's state by analyzing its outputs, performance metrics, and logs) as well as easier integration of solutions from various providers. This reduces costs, simplifies system-wide integration, and ensures smoother operations while allowing flexibility for future technological upgrades.

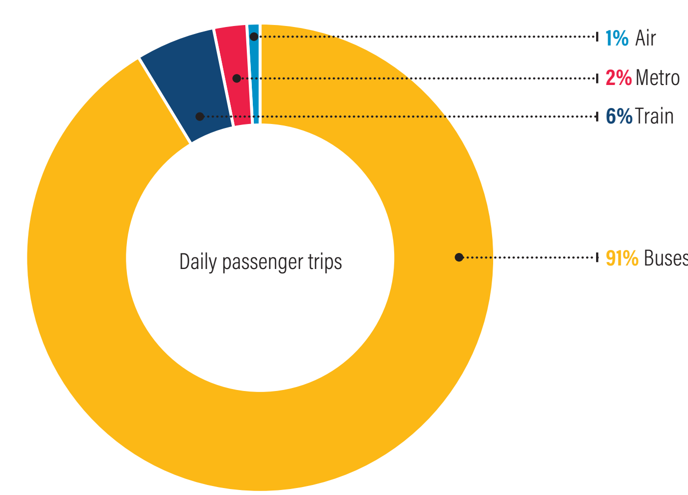
The paper analyzes real-world use cases (descriptions of how ecosystem actors interact with services, systems, or business in a real-world scenarios) for various stakeholders. It showcases the blueprint's versatility in achieving goals such as using market demand to guide infrastructure development, mobilizing finance, building capacity, to name a few.

INTRODUCTION

Setting the stage

Buses are the backbone of public transportation in India, serving around 39.9 Crores (399 million) passengers daily and accounting for over 90 percent of all public transport trips[1] (see Figure 1). As the primary mode of public transportation nationwide, they provide millions of Indians with affordable and accessible mobility. However, the sector is highly fragmented, with numerous small operators and a lack of coordination, leading to inefficiencies that hinder its ability to scale and meet growing demand. Their central role underscores the need to strengthen and modernize the bus sector to enhance India's public transport system.

Figure 1 | **Role of buses in India's public transport**



Source: Based on information collated from Gadepalli et al. 2024; TOI Education 2023; Press Information Bureau, GoI 2024; Ministry of Civil Aviation 2024; De et al. 2017.

The Government of India is increasingly recognizing the role of enhanced bus systems in reducing emissions and improving passenger experiences. Central to India's sustainable transportation strategy is the rapid adoption of electric buses (e-buses). India is aspiring to electrify a significant portion of its 23 lakh (2.3 million) bus fleet, with up to 800,000 buses estimated to be electrified by 2030 (Mukherjee and Mishra 2023). This aligns with the country's broader goal of achieving a 30 percent EV market share, a transition involving public, private and institutional fleet operators (Press Information Bureau, GoI 2024a). The government is supporting this transition through various policies and partnerships (Press Information Bureau, GoI 2023; Press Information Bureau, GoI 2024b).

The transition is not just about adopting new technology but also about rethinking contracting and operating models to run these buses cost-effectively. It shifts from the traditional approach where the government procures and operates buses, towards greater involvement of the private sector through public-private partnerships (PPPs). By leveraging the private sector's strengths in financing and operational efficiency, this approach seeks to reduce the burden on government resources and enables many small and medium-sized cities to initiate and expand bus services, thus accelerating the transition to sustainable transportation.

While the transition to electric buses offers significant environmental benefits, the legacy structure of India's bus system presents several challenges that hinder progress. Ninety-three percent of buses are privately owned (for rural, intercity, and fleet operations—school, employee, tourist transport, and other use cases) and over 90 percent of operators manage fewer than five buses. So, the sector is highly fragmented, leading to inefficiencies and a lack of scale (Mulukutla and Rajagopal 2024). This fragmentation creates a low-growth environment where operators have little leeway or incentive to expand. Their small size constrains the types of investments and technology upgrades they can afford. For small operators, transitioning to e-buses is particularly challenging because, in addition to the already high cost of the buses, they must also invest in expensive charging infrastructure. The lack of a widespread public charging network forces them to set up their own charging stations, which can add 10-15 percent to the cost of each e-bus, making adoption economically unsustainable (CSTEP 2021).

In addition, integrating digital technology into traditional bus operations requires combining various information technology (IT) systems, including vehicle location and tracking, ticketing, passenger information, contracts, and fleet management. The current reliance on proprietary solutions not based on open technology and data standards limits IT's potential to improve operations (Bachu, Roy, and Roychowdhury 2024). This can lead to higher costs, increased vendor dependency, and difficulties in integration and future upgrades, for instance, forcing operators to switch between hardware vendors for bus tracking or upgrading the ticketing system to Bharat Bill Pay Standards.[2] These challenges hinder operations and service quality. With e-buses come new challenges in several key areas: planning for e-bus deployment and charging infrastructure, establishing financing and procurement mechanisms, and monitoring and evaluating operations. Managing charging infrastructure, navigating power contracts, ensuring effective energy management, and addressing battery health and degradation all pose challenges (Sclar et al. 2019). Together, these complexities underscore the need for a standardized, alternative approach to digital technology that can efficiently accommodate emerging needs.

Lastly, the fragmented bus sector limits multi-sectoral alignment: the ability for multiple sectors and stakeholders to collaborate to reach common goals. Fragmented and/or missing information can prevent secondary stakeholders—beyond bus operators—from participating. This includes experts in energy, finance, insurance, and mobile phone applications. These stakeholders could play a crucial role in the large-scale rollout of e-buses and the associated infrastructure and services while benefiting from the opportunities this transition presents.

Achieving India's e-bus transition targets will require a concerted effort across the entire stakeholder ecosystem, and at the same time, this transition offers an opportunity for these stakeholders to rethink buses and ways this sector can tap the potential of something it has missed out on so far: the significant digital innovations taking place in India.

India's experience in deploying Digital Public Infrastructure (DPI) demonstrates its promise. DPI is an approach that shifts focus from providing technology solutions to providing foundational digital building blocks to enable broader, more inclusive innovation (CDPI 2024a). These building blocks include shared specifications and frameworks that support multiple use cases and stakeholders in the ecosystem. DPI fosters vibrant market innovation and has demonstrably reduced costs and improved accessibility to services across sectors like banking, payments, e-commerce, and healthcare in India (Gupta et al. 2024; Mohanty 2023).

While the bus sector poses specific challenges, could DPI hold the key to unlocking sustainable mobility through the large-scale deployment of e-buses in India? There are reasons to suggest it could. Creating a high-trust, low-cost ecosystem for key stakeholders—commuters, bus operators, original equipment manufacturers (OEMs), financial institutions, government agencies, and technology service providers[3]—could enable them to co-develop and implement cost-effective, market-driven strategies for deploying e-buses along with the necessary infrastructure and services.

Objective

The primary objective of this working paper is to identify key challenges and opportunities in extending DPI principles to e-bus transition and adoption.

It proposes a new blueprint for designing e-bus service platforms based on DPI principles and referred to as the open e-bus blueprint (see *Digital Public Infrastructure—An Approach to Population-Scale Complex Problems*) that addresses major challenges in transit operations and service.

We invite stakeholder comments and consultations on strategic and functional considerations for designing this technology blueprint. Its implementation roadmap are designed to stimulate discussion rather than present final recommendations. WRI India and the Foundation for Interoperability in Digital Economy (FIDE) understand that there might still be gaps with respect to practical implementation.

Approach for developing this working paper

This working paper employs a qualitative research methodology, combining unstructured interviews with a comprehensive review of secondary literature.

A review of the academic literature, government consultation papers, think-tank reports, articles, and blogs were conducted with focus on the following:

1. Technology implementation challenges in public transport and corresponding policy recommendations.
2. Systemic issues with current technology deployments in Indian public transport agencies.
3. DPI implementation experiences in other sectors.
4. DPI principles and architectural considerations derived from diverse sectoral applications.

To ensure data reliability and credibility, we focused primarily on English national dailies and reputable think-tank blogs to illustrate real-world examples of challenges and successes.

We conducted unstructured interviews with key stakeholders involved in public transportation, IT, and policymaking to gather qualitative data on their perspectives and experiences.

We applied thematic analysis to the secondary literature to identify recurring themes, patterns, and critical insights related to DPI implementation challenges, policy implications, and potential solutions.

We combined these methods to provide a comprehensive understanding of the potential and challenges associated with extending DPI principles to e-bus transition and adoption.

Scope of the paper

This paper outlines WRI India and FIDE's current thinking on how a proposed open e-bus blueprint could create an ecosystem for software applications that accelerate the adoption of e-buses and related infrastructure services. The blueprint is designed to be versatile, not only supporting e-buses but also extending seamlessly to non-electric buses, thereby broadening its scope and applicability across the entire bus sector.

The Introduction describes the current fragmented vendor-led, non-interoperable approach to bus operations and service delivery which cannot handle the complexities and scale required for the transition.

The second section, "Pressing reasons for action", highlights legacy and emergent issues in the current bus ecosystem. It explains the need for a digital technology blueprint for developing applications for e-bus and related services based on DPI principles.

The third section, "Digital Public Infrastructure," discusses the DPI principles and India's experience with DPI. It explains how interoperability with open standards and protocols catalyze the innovation in and leverage the power of digital infrastructure to build scalable solutions. It discusses the design principles and key digital functionalities that highlight the essential capabilities for the blueprint.

The fourth section, "Potential use cases for various stakeholders," showcases the versatility of the blueprint and its ability to integrate with existing digital public infrastructure to enable a dynamic ecosystem of solution providers.

The last section, "Rolling out the open e-bus blueprint—A tactical roadmap," discusses a series of strategic actions needed to bring the open e-bus blueprint from idea to reality.

PRESSING REASONS FOR ACTION

The bus transport ecosystem is a complex network involving a wide range of stakeholders, each with unique needs and requirements, as laid out in Table 1:

Table 1 | **Key stakeholders and their needs in the bus transport ecosystem**

STAKEHOLDER	DESCRIPTION	BROAD NEEDS
Bus operators	70+ public bus companies operating about 150,000 buses[a] With over 26,000 small and large private operators, the market is largely fragmented[b]	Maximize bus utilization by efficiently managing fleet operations, maintaining cost-effective practices, and integrating new technologies
Device manufacturers (buses)	Vehicles are equipped with devices such as tracking units, electronic ticketing machines, cameras, ticket validators, onboard units, and wi-fi systems, either pre-installed or retrofitted	Ensure seamless communication and interoperability between onboard systems for reliable information broadcasting
Financial institutions	Banks, insurance companies, and non-banking financial institutions providing financing for buses and their operations	Assurance of financial stability, risk management, and return on investment through reliable operations
Government ministries	Multiple ministries (MoRTH, MoHUA, MHI, MoP) and government bodies (ASRTU, CESL CMVR-TSC, BEE) involved in regulating and supporting the sector	Regulatory compliance, safety standards, and the promotion of sustainable and efficient public transport systems

Table 1 | **Key stakeholders and their needs in the bus transport ecosystem (continued)**

Other players	App developers, Intelligent Transport System (ITS) providers, advertisers, charge point operators, and energy and mobility service providers	Access to accurate and timely data for service enhancement, innovation, and revenue generation through advertising, apps, and energy services
Passengers	The end-users who rely on accurate and timely information for their journeys	Access to accurate, real-time trip information, safety, and a reliable, user-friendly travel experience
Original equipment manufacturers (OEMS) and components manufacturers	Bus, bus components – sensors, software and system providers	Fulfill operator requirements by ensuring compatibility with various operational systems, feedback on product performance, and the ability to integrate their equipment seamlessly into diverse fleet environments

Sources: (a) ASRTU 2024, (b) Banerjee 2022.

Each stakeholder has distinct needs, ranging from operational efficiency and financial returns to passenger satisfaction and regulatory compliance, as depicted by Figure 2. However, current bus operation systems have historically been designed as standalone solutions, lacking the integration and communication necessary to meet these diverse requirements effectively.

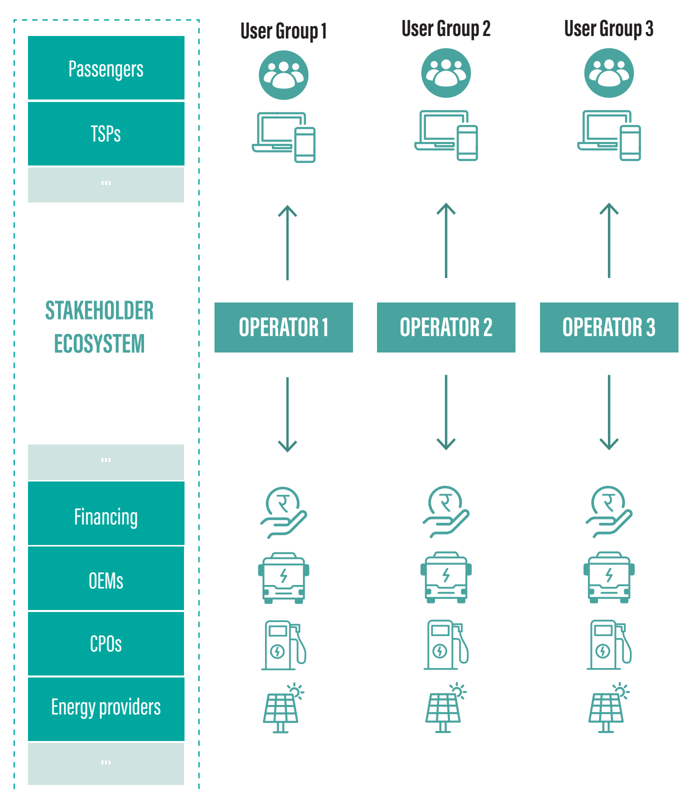
These isolated systems weren't designed for broader communication between various information sources as shown in Figure 3. They rely on separate IT services, create bottlenecks, and highlight the following two challenges:

Standards: The absence of a consistent and interoperable framework for bus operations across different information systems and organizations impedes seamless communication and integration within the transport network.

Observability: Limited access to relevant information sustains silos, preventing stakeholders from gaining full system visibility and making informed decisions.

This fragmented landscape hampers not only efficiency but innovation.

Figure 2 | **Fragmented bus ecosystem**



Source: Authors' analysis.

Note: TSPs is Technology Service Providers. OEMs is Original Equipment Manufacturers. CPOs is Charge Point Operators.

Box 1 | **Learnings from previous experience**

The Intelligent Transport System (ITS) initially emerged as a promising solution for public transit agencies seeking improved operational efficiency and reliability. ITS encompasses a range of technologies offering real-time tracking, smart ticketing, and integrated information systems for planning and scheduling. It promised a future of empowered commuters and data-driven operations. However, these deployments faced challenges.

Despite investments exceeding Rs 1,000 crore ($120 million) across multiple Indian cities, achieving value addition and capturing essential operational data proved difficult. These systems struggled to consistently generate usable data. Consequently, bus operators continued relying on manual methods.

Existing ITS implementation faces the following challenges that hinder their effectiveness and investment potential:

Flawed procurement model

- **One-time purchase model**: Funds are often spent on single-time technology purchases rather than continuous services that include maintenance and updates. This is like buying a smartphone you can never upgrade, leading to outdated tech over time.
- **All-in-one vendor bundling**: Hardware, software, and services are often bundled with one vendor, creating conflicts of interest—like hiring a builder who's responsible for design, construction, and inspection. This setup reduces quality control and flexibility.

Siloed systems

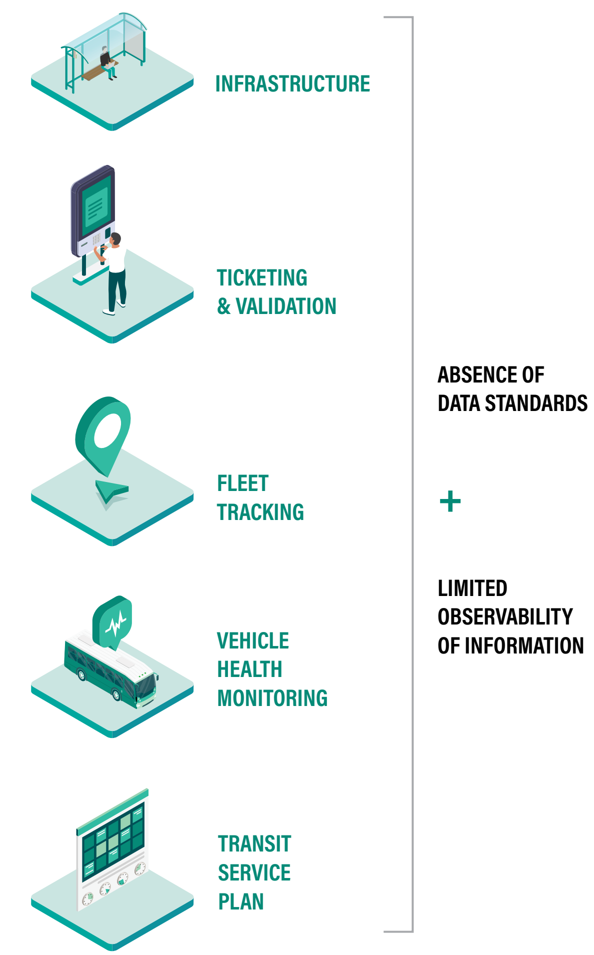
- **Isolated data limits functionality**: Each ITS system (tracking, ticketing, etc.) operates separately, preventing them from working together. For example, if real-time tracking isn't connected to ticketing, users can't get live schedule updates.
- **Vendor lock-in**: Proprietary solutions mean only the original vendor can service or update the system, which drives up costs and reduces flexibility over time.

Limited oversight and management

- **Lack of monitoring and reporting**: Often, there's little tracking of whether the technology is performing well, which makes it hard to identify issues. For instance, without regular reports, agencies may not know if GPS trackers on buses are faulty or if ticketing systems are creating bottlenecks, leaving them with an incomplete picture of service quality.
- **No transition planning for technology end-of-life**: Without planning for when systems become outdated, agencies face service interruptions when technology fails.
- **Restricted data access**: Limited ability to access or share data makes it harder for agencies to use data in decision-making. For example, without comprehensive access to tracking and ticketing data, agencies struggle to make informed choices about adding routes or adjusting schedules to meet demand.

Source: Bachu, Roy, and Roychowdhury 2024.

Figure 3 | **Information sources and existing technology gaps in bus operations**



Source: Authors' analysis.

Problem of standards

Standardizing information flow for bus operations has not been a priority in India. Traditionally, bus systems have come up with a patchwork of solutions to manage operational data (route network, passenger count, schedules, stops) and passenger information (Real-time data, PIS boards, timetable, etc.) This fragmented landscape creates the following problems:

Larger bus agencies or fleet owners: These often rely on proprietary systems tailored to specific needs, where hardware and software are bundled together, allowing vendors to impose proprietary protocols and operations and management contracts. The absence of standards leads to a lack of interoperability within and outside the agency, resulting in vendor lock-in (Bachu, Roy, and Roychowdhury 2024). This limits operators' ability to choose optimal solutions and complicates the integration of new technologies. For example, in Bengaluru, a crisis forced the public bus operator BMTC to revert to paper tickets from electronic ticketing machines (ETMs) because the intelligent transport systems (ITS) provider refused to repair or replace failing ETMs. Locked into a proprietary system, BMTC had no other options (Philip 2019).

Smaller agencies or fleet owners: These struggle with manual methods like handwritten logs and spreadsheets (Ministry of Housing And Urban Affairs, GoI 2020).

Standardization ensures that bus operation data remain consistent and accessible for passengers, operators, and other intermediaries. Aligning different systems enables various applications to work seamlessly together. Here's how standardization helps:

- **Provides a common structure and format:** By adopting a universal format (like Network Timetable Exchange [NeTEx][4] or General Transit Feed Specification [GTFS][5]), data from different systems, like GPS trackers and ticketing apps, becomes easier to integrate. For instance, when arrival times and ticketing systems use the same format, it's possible to book and track live location accurately for passengers across apps/or platforms.
- **Maintains data usability over time:** Standardized data ensures that historical information remains readable and compatible, even as technologies evolve. For example, route performance data from a decade ago can still inform planning if the format hasn't changed, helping operators see trends and adjust future schedules.
- **Enhances data quality:** Consistent formats reduce errors and remove duplicates, improving the accuracy of each data point. For example, standardizing how GPS coordinates are logged across buses ensures that location updates aren't conflicting or missed, resulting in reliable real-time information.

Problem of observability

Observability helps various stakeholders in the bus ecosystem to monitor and understand the performance of bus operations, infrastructure, and services by examining critical data points—such as vehicle location, ticketing transactions, charger utilization, battery health, and schedule adherence, etc.—through outputs, logs, and other performance metrics.

Observability is achieved through a combination of tools and policies: Application programming interfaces (APIs) or software applications gather and aggregate data from different systems, networks, applications, and platforms, while policies ensure data gathering aligns with specific needs of the stakeholder, is securely managed, and is retained appropriately.

The purpose of observability is to ensure that all relevant information about the bus is available to stakeholders for informed decision-making. This leads to the following benefits:

- **Improved service delivery:** Operators can provide timely service and updates to passengers, reducing downtime, and enhancing the overall experience.
- **Reduced risk:** End-to-end visibility minimizes exposure to avoidable risks, such as equipment failure, operational inefficiencies, and revenue leakage for operators, financial institutions, and OEMs.
- **Lower operational costs:** Observability helps organizations identify and address inefficiencies quickly and reduce operational costs, such as reducing downtime and avoiding costly repairs with predictive maintenance. It also helps with optimizing route planning, forecasting revenue, and budget management and cost control.

The lack of observability harms passengers, operators, and other stakeholders alike.

Implications

Discovery issues for passengers

Inconsistent standards and poor observability make it difficult for passengers to search and discover bus services, as follows:

- Public buses often suffer from unreliability in their services. Non-standardized data on bus schedules, limited options with ticketing and payments, and long wait times make it difficult for passengers to plan trips effectively.
- The lack of integration with other modes of transport and shared mobility services creates a fragmented network. This limits the effectiveness of bus-based public transport, making it less attractive than private vehicles despite potentially lower fares (Rollison, Caitlin, and Matthew Coombes. 2023).
- These issues discourage ridership, particularly on less-frequented routes and consequently weaken the cause for the operator to expand services with additional buses.

Utilization challenges for operators

Poor observability and lack of data standards limits the efficient utilization of bus as a resource. This can manifest the following:

- **Planning inefficiencies:** Due to limited observability of bus performance, bus operators cannot estimate charging infrastructure requirements. This constrains service coverage and route planning, leading to inefficient resource allocation and underutilization of e-buses. In Nagpur, for example, 34 percent of the electric bus fleet remained idle due to a lack of charging stations (Chakraborty 2024).
- **Scheduling inefficiencies**: Without consistent information exchange on bus tracking, crew and bus schedules, passenger counts and network information, route planning and scheduling becomes cumbersome and potentially inefficient.
- **Gaps in passenger information**: Inconsistent data formats block a unified view of bus operations, hindering resource allocation and smooth service. Passengers experience this in Delhi, where one of the operators, DIMTS' proprietary application Poocho (offering real-time information for cluster buses) is unable to integrate with another operator, Delhi Transport Corporation's systems, leaving most buses with static route and schedule data that may not be up to date (Abisla 2019).
- **Stifling of innovative models and sustainability:** Observability extends beyond data—it's about fostering innovation and sustainability by enabling policy interventions that leverage digital infrastructure within the transportation network. For instance, in Telangana, repurposing school buses for passenger transport faced roadblocks as there was no system in place to assess and adjust risk for such a unique use case, which made it challenging for insurers to justify lower insurance premiums for buses used as passenger vehicles during off-hours (*The Times of India* 2019).

Poor visibility in public-private partnerships in bus operations such as leasing buses on a gross cost contract (GCC)[6] or net cost contract (NCC)[7]—where agencies partner with private operators to manage and maintain buses—causes friction between public agencies, operators, and other stakeholders in the following (Kharwal and Khandelwal 2021):

- **Managing contracts and service levels.** This requires strong contract management and performance monitoring systems in place to ensure timely payments, service quality, and compliance with contractual obligations. Poor visibility and data validation have led to significant friction between bus operators and agencies, resulting in disputes and service disruptions.
- **Bankability.** Lack of clear, real-time data on bus operations, payment statuses, and contract compliance prevents creditors from accurately assessing performance and risks, which diminishes investor confidence in bus operators, limiting the flow of capital into the bus sector.
- **Financing challenges in e-buses.** Without accurate data, the financial viability of e-bus investments remains uncertain, deterring potential investors and slowing the adoption of e-buses. Investors require reliable data on asset quality, particularly battery performance and degradation, to assess risk and make informed decisions. This data gap hinders understanding of total cost of ownership (TCO), operational efficiency, and repayment ability. For instance, research points out that a 20 percent reduction in battery life can increase TCO by 2.2 percent. This effect is magnified as reduced battery range (10-30 percent decrease) leads to further TCO increases of 13-30 percent. These figures can vary significantly across geographies due to differences in climate, terrain, and usage patterns. However, without real-world data on battery performance, investors can't predict future maintenance costs or battery lifespan. This uncertainty discourages investment, even when it might be financially viable, because the risk of unexpected costs remains too high (Vijaykumar et al. 2020).
- **Estimating demand.** Limited real-world data on e-bus operations, particularly in India, hampers understanding of factors like battery degradation and operational efficiency (Kumar, Mulukutla, and Doshi 2023). For example, slower charging times for e-buses reduces their hours of service each day, meaning that a larger fleet may be needed to match daily service hours of a diesel fleet and avoid disrupting city-wide replacement plans.

Future impacts of low observability

Limited observability in bus operations poses significant challenges as fleet sizes and passenger demand grow. The absence of comprehensive visibility restricts operational scalability and hinders the full potential of buses within a broader transport ecosystem, leading to trust issues and aligning stakeholder incentives to contribute and benefit from increased bus adoption. Several instances have highlighted this.

Ultimately, these inefficiencies not only affect bus operators but also have ripple effects across the entire ecosystem, hindering the development of a connected, efficient, and sustainable bus transport system.

How to confront these problems

Implementing isolated technological solutions will not solve these looming problems. An alternative paradigm that looks at creating a robust, foundational digital infrastructure could be helpful for achieving sustainable and scalable outcomes.

DIGITAL PUBLIC INFRASTRUCTURE—AN APPROACH TO POPULATION-SCALE COMPLEX PROBLEMS

The DPI model

In the realm of national development, the significance of DPI is comparable to that of physical infrastructure like roads and railways. Just as roads and railways form the backbone of physical connectivity and drive socio-economic activities, DPI provides the foundational digital building blocks that fuel sustainable innovation in the digital space.

The DPI movement is inspired by the open standards and specifications that created the Internet and mobile networks, which operated as the original digital infrastructure of the late 20th century, catalyzing a wave of public and private innovation that drove inclusion (CDPI 2024a). The DPI model illustrates an approach to solving socio-economic problems at scale. (See Box 2 for more details on how the Internet became an early example of the DPI model.)

At its core, a DPI integrates three key elements: 1) minimalist technology interventions, including the right technology architecture and standards for information exchange, 2) governance frameworks that are transparent, accountable, and participatory, and 3) a robust environment for both public and private sector innovation (CDPI 2024a).

Box 2 | **Case: Internet architecture and "the hourglass design"- achieving more with less**

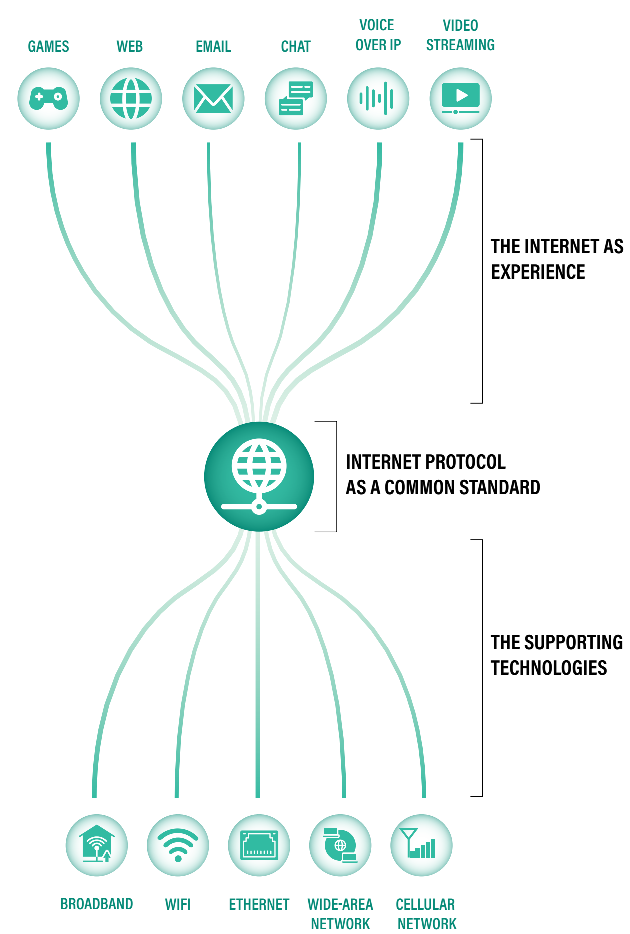
The hourglass model is a powerful analogy for minimalist technology interventions, exemplified by the design of the Internet. At its core is the Internet Protocol (IP), an algorithm which acts as a universal intermediary, as depicted in Figure B2. IP connects a wide range of software applications on one end with diverse underlying services for information transfer on the other, facilitating efficient communication across networks.

Pre-internet era: Complexity in communication. Before the Internet, applications like email were network specific in design, requiring dedicated connections between computers within a network. Each network required the applications to be configured uniquely, making cross-network communication complex and inefficient.

Post-internet: Communication simplified. With the IP as the common core, applications and physical services now only need to interface with IP, streamlining communication and significantly reducing complexity.

This model illustrates how a strong, central, and interoperable core, exemplified by the IP, can support a wide range of software and hardware systems. It shows how a principle-based minimalist intervention not only addresses current challenges but also establishes a flexible core that can adapt to future needs.

FIGURE B2 | Hourglass model: Rethinking technology



Source: Georgia Institute of Technology 2011.

Over the last decade, India has championed the development and deployment of several DPIs. Guided by certain key principles they ensure that the minimalist technology interventions are effective, inclusive, and scalable.

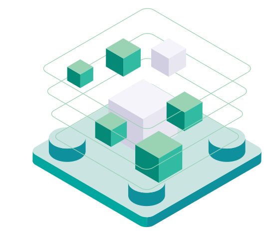
DPI principles

The development of DPIs in India is grounded in the philosophy of collaboration among three key sectors: the government—"Sarkar," the market—"Bazaar," and society—"Samaj" (Nilekani 2022). This tripartite model emphasizes the importance of each sector working in harmony to achieve common goals. It champions the idea that public infrastructure should be open, accessible, and governed by principles that ensure it serves the public interest first and foremost. For instance, the United Payments Interface (UPI) protocol developed by the National Payments Corporation of India (NPCI) for instant real-time payments to facilitate inter-bank transactions through mobile phones ensured that technology service providers gave citizens an affordable and secure means of digital payment for all types of transactions—whether between people, businesses, or government—all powered by the same protocol that allows for interoperable payments. The protocol is agnostic to payment devices, currency, or type of transaction (CDPI 2024b).

Systems designed to facilitate the substantial expansion of such design principles across sectors can promote inclusivity. Figure 4 gives a brief description of the general principles for a DPI-led approach (CDPI 2023).

Thus, rather than building bespoke solutions for each use case, DPIs employ reusable building blocks that can be combined to serve multiple purposes. These principles enable DPIs to achieve societal outcomes such as fostering inclusive innovation, enhancing user choice, scaling service delivery, accelerating speed, building public trust, and promoting competition—all while prioritizing data sovereignty and ensuring cost effectiveness.

Figure 4 | **Distinguishing DPI from regular digitization efforts: Key principles**

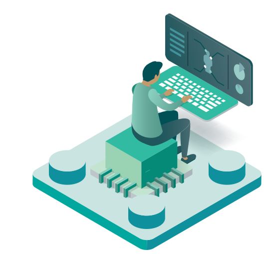


MINIMALIST, REUSABLE BUILDING BLOCKS

Designed to foster high trust and low costs for both public and private entities.

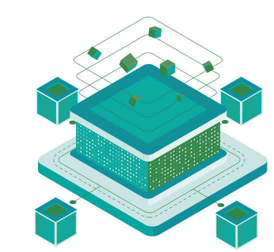
INTEROPERABILITY

To promote and ensure value derived by the participants is not locked in a particular platform/system liberates the members.



DIVERSE, INCLUSIVE INNOVATION

Open access enables innovation by both "challenger"market players and incumbents, focusing on solutions for diverse problems and requirements.



FEDERATED & DECENTRALIZED

Technology should be a catalyst to the ecosystem and not a gatekeeper. Instead of concentrating power within one particular or a handful of participants.

SECURITY & PRIVACY

Design systems with optimal ignorance—each system should know as little as possible, ensuring high auditability and traceability through digitally signed data, non-repudiable change logs, and authenticated transaction trails.

Source: CDPI 2023.

India's digital public ecosystem— The story so far

India has effectively utilized these principles and scaled up the use of DPIs in fields such as identification (ID), payments, data exchange systems, and transactions to deliver vital services to its citizens.

Building block for identity

Aadhaar, India's national identification system, assigns a 12-digit unique ID to each resident based on their demographic and biometric information and has issued credentials to over 1.36 billion individuals, providing low-cost authentication and electronic know your customer (eKYC) services (Aadhaar 2024). Aadhaar's design provides inclusion with minimal data (collecting only essential details to avoid exclusion errors), a federated model with one-way linkage (ability to link to other systems and not collect data from them), an ecosystem approach (standardized interfaces for authentication with public and private partners), and privacy by design.

These core principles have significantly expanded its impact (UIDAI, GoI 2014). Beyond its government applications, these principles have unleashed a wide range of private sector innovations, accelerating access to formal financial systems and affordable services in health, education, and consumer services. The combination and synergies between the trinity of JanDhan (bank accounts), Aadhaar, and mobile phones, made it possible for a huge swath of India's population to access its financial system for the first time. It allowed the government to target delivery of government subsidies to identified beneficiaries. Between 2011 and 2017 nearly half a billion adults opened bank accounts. A study by the Bank for International Settlements notes that this progress, which took 9 years since Aadhaar's launch, would have taken 47 years using traditional methods (D'Silva et al. 2019).

Aadhaar's architecture empowers government departments and entrepreneurs to innovate and scale digital applications and services efficiently. By employing secure data storage and consent mechanisms, Aadhaar supports ecosystem growth while ensuring security and cost effectiveness.

Building block for payments

The United Payments Interface (UPI) has revolutionized digital payments in India with its open, mobile-first system that is modular, secure, and interoperable across banks. The participation of private players to build solutions using UPI has accelerated the adoption of digital payments, making India the global leader in digital transactions, accounting for 46 percent of the world's total (Press Information Bureau, GoI 2024b). With over 500 million users, UPI now processes more than 14 billion transactions monthly, worth over INR 20 trillion, all while maintaining secure and vendor-neutral operations (Business Standard 2024).

Building block for sharing financial data

The Account Aggregator framework launched by the Reserve Bank of India (RBI) streamlines the secure sharing of financial data between service providers and users and is expanding access to a wide range of financial services for consumers and businesses. By allowing users to consolidate and securely share their financial data, the framework offers several benefits: faster loan approvals, personalized financial services, and improved financial planning. It also reduces paperwork and eliminates the need for repeated KYC processes by making use of other building blocks, such as Aadhaar for identification and UPI for secure payments. Designed based on the principles of interoperability, consent-based sharing, security, and privacy at its core, the framework has simplified financial processes, lowered costs, and enhanced consumer security, integrating over 2.2 billion financial accounts and creating new socio-economic opportunities (DoFS 2024).

The contrast between India before and after DPIs is a compelling story of transformation, as depicted in Figure 5.

These transformative outcomes were not simply the result of technological solutions but stemmed from a systemic approach that prioritized foundational digital infrastructure on which the solutions could operate. By focusing on minimalist but robust and flexible digital building blocks for identity, payments, and sharing financial data, India empowered its ecosystem actors to innovate and develop scalable solutions, driving widespread socio-economic progress—demonstrating that by doing less, more can be achieved.

Figure 5 | **India's DPI story**

Note: 1 USD = INR 84

Sources: Based on data retrieved from official dashboards (DBT Bharat 2024; NPCI 2024; Aadhaar 2024; D'Silva et al. 2019).

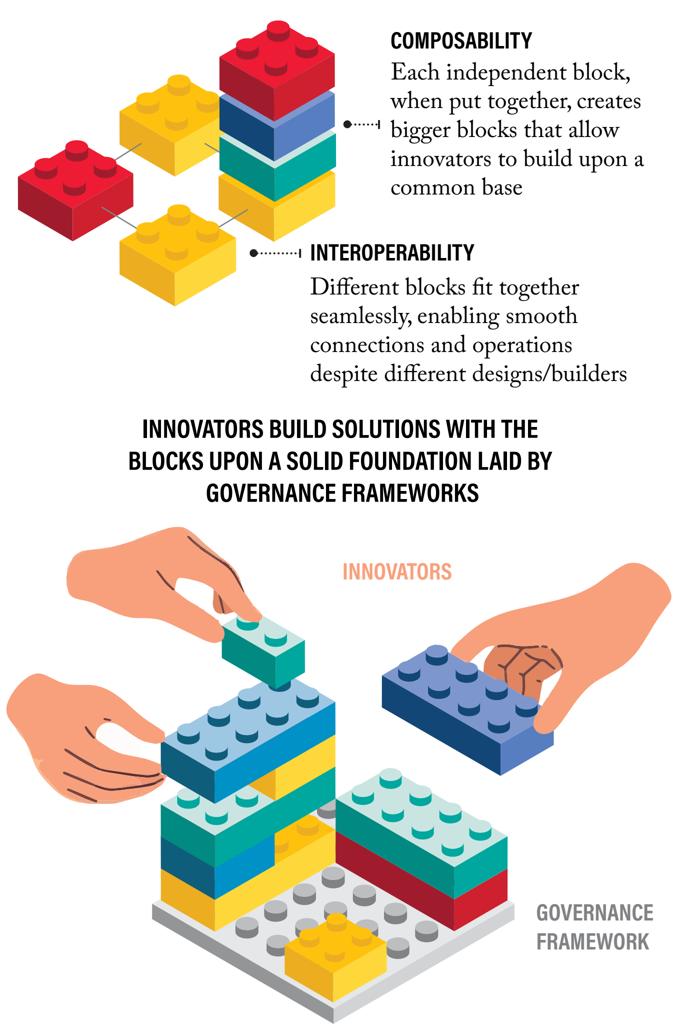
Box 3 | Case: Regulatory intent and India's banking transformation—Lessons for the public bus system

In the late 1980s, with the rise of personal computers and the Internet, the RBI recognized the need to modernize banking operations for greater efficiency and economic growth. Banks began adopting various technology systems to digitize and automate their processes, leading to the installation of multiple, often incompatible, software applications across branches, sometimes even within the same bank.

This fragmented approach resulted in high costs and complexity, as vendors provided proprietary solutions to bank branches; for instance, previously, transactions took a day to reflect because each branch had its own server, sending data to the central system only at the end of the day. This approach led to high costs and complexity, as proprietary systems were challenging to integrate or upgrade. Recognizing these issues, the RBI stepped in with a clear regulatory mandate: the implementation of a unified Core Banking Solution (CBS) across all commercial banks. This regulatory intent not only streamlined operations but also enabled a wave of financial innovation, demonstrating how proactive governance can shape the success of digital infrastructure initiatives.

Source: Hariharan and Reeshma 2015; Fathima 2015.

Figure 6 | Underlying elements of DPI model



Source: Authors' analysis.

Open e-bus blueprint: DPI approach to bus ecosystem

The transformative potential of the DPI model, with its emphasis on minimalist technology interventions and systemic approaches in the form of building blocks, offers a compelling case for reimagining the bus ecosystem. These interventions are minimalist because they focus on core functions—such as data exchange standards and specifications, simple protocols, and lightweight architectures—that can be extended or built upon without over-specifying or locking in particular technologies.

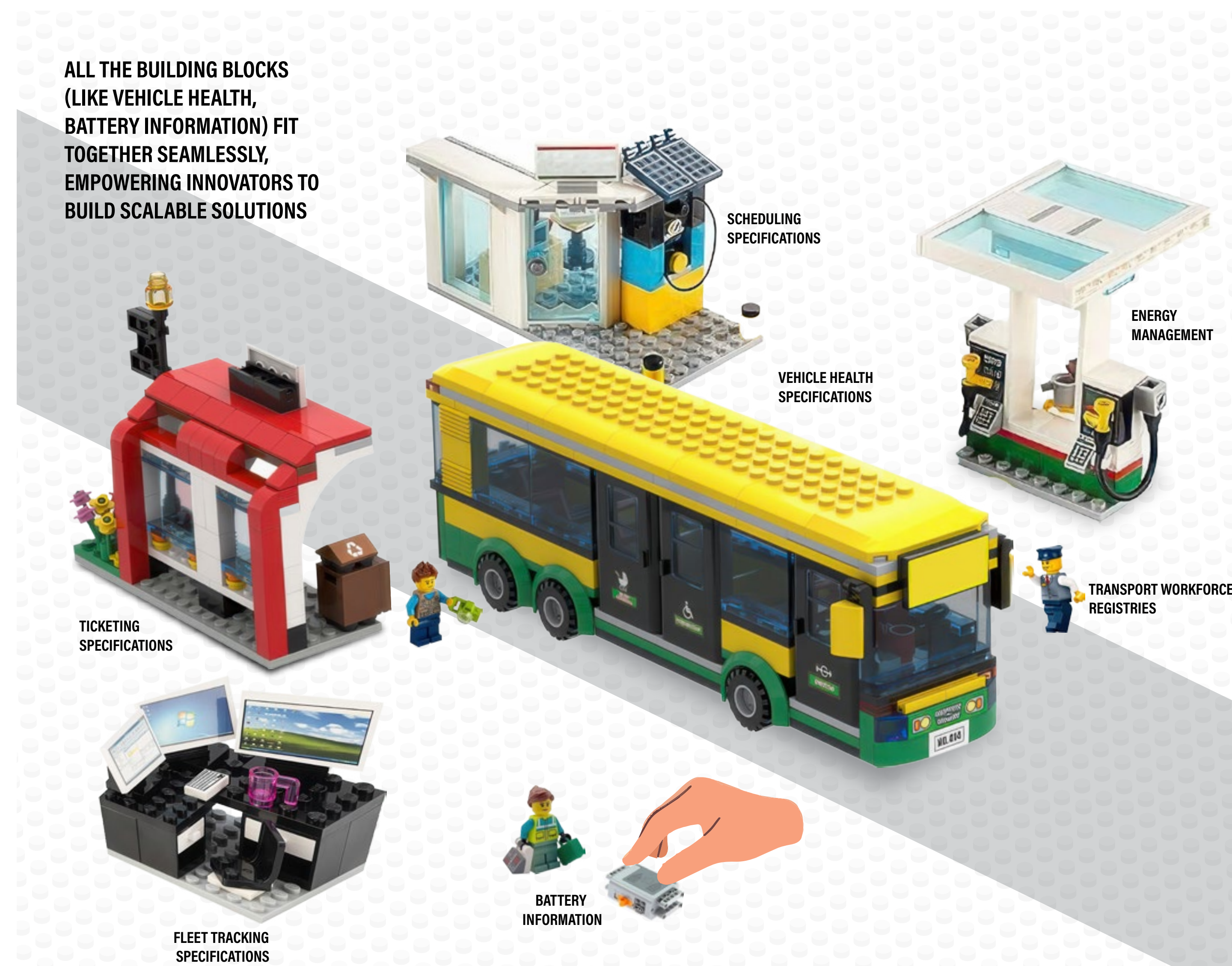
The current fragmented and isolated systems in bus operations resemble the pre-Internet era's communication challenges—complex, inefficient, and limiting. By rethinking the bus sector through the DPI model, we can envision a core framework that integrates technology architecture, governance, and market-driven innovation, as illustrated by Figure 6. Much like the Internet's hourglass design, or other DPIs like Aadhaar and UPI, which provide basic frameworks that are adaptable and interoperable, the bus sector can benefit from establishing a foundational infrastructure that supports its diverse stakeholders and their needs, allowing future innovations and evolving technologies to integrate seamlessly.

This blueprint has the potential to address current inefficiencies and create a flexible, scalable foundation for the e-bus transition and future growth. This would enable the bus sector to enhance stakeholder collaboration, align incentives, and drive the transition to a cleaner, more efficient system while creating a conducive environment for deploying the infrastructure for 800,000 e-buses.

In rethinking the bus ecosystem through the lens of a DPI, we can envision a blueprint built using a series of modular building blocks, as illustrated in Figure 7. These building blocks—whether platforms, protocols, pieces of code, or applications—are like Lego pieces: each one is independently functional, but when connected, they create a strong and adaptable foundation. Just as different Lego pieces snap together to build countless structures, these digital blocks interconnect seamlessly with other DPIs, supporting the essential services the bus ecosystem relies on.

For example, core building blocks like scheduling, ticketing, and tracking specifications can seamlessly integrate with other DPIs, such as the Open Network for Digital Commerce (ONDC)[8] and UPI for payments, as seen in Figure 8. Imagine a passenger being able to search, book, and pay for bus rides directly from any app on the ONDC network, using their familiar UPI app to complete payments. This integration enables passengers to plan trips across multiple modes of transport, view real-time bus tracking, and buy tickets—all in one place. With standardized protocols, providers can develop Mobility-as-a-Service (MaaS)

Figure 7 | Reimagining India's bus ecosystem with the DPI model



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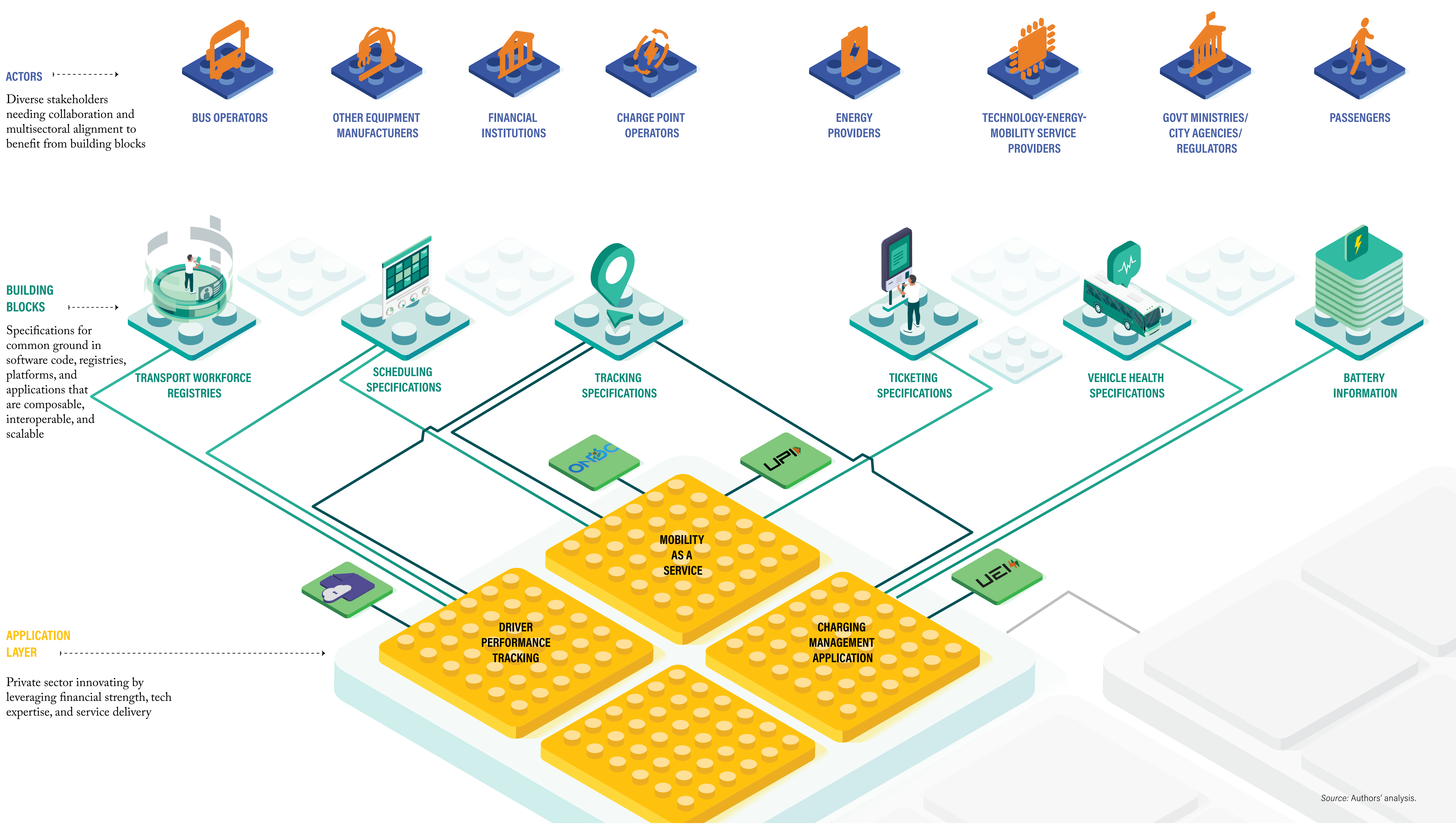
Source: Authors' analysis.

Figure 8 | **Open e-bus blueprint: The DPI for bus ecosystem**



Source: Authors' analysis.

apps that connect to the ONDC network, making it easier for users to find and book transport options, get real-time travel updates relayed by bus, and switch seamlessly between transit types. For bus operators, such apps can provide data to help adjust bus routes and schedules to meet demand efficiently, without extra overhead. As we develop this infrastructure, keeping the guiding principles for these building blocks in mind is essential to ensure flexibility, interoperability, and accessibility for all users.

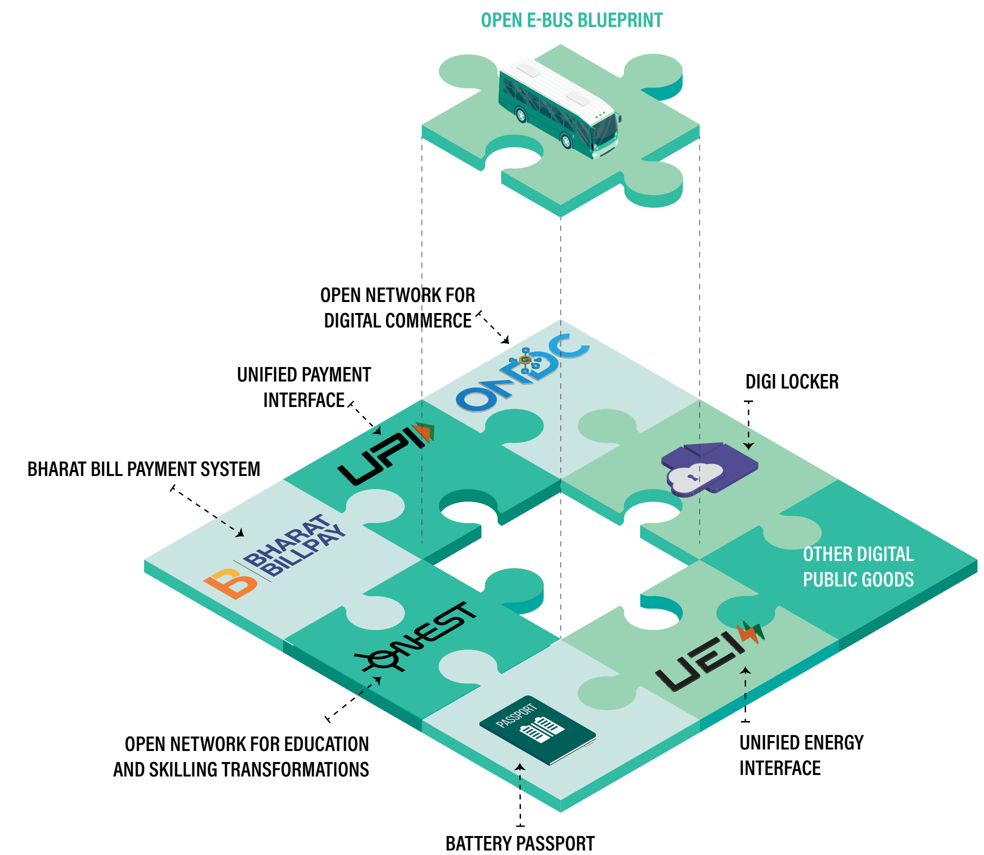
Open e-bus blueprint: Core design principles

For a DPI approach to succeed in the bus ecosystem in India, it must be robust, adaptable, and scalable. While the foundational DPI principles discussed earlier still apply, the following core design principles are additional and specific to the unique needs of the bus ecosystem. These include the following:

- **Vendor-agnostic, specification-driven architecture.** The architecture of the solutions should be based on well-defined, comprehensive specifications that vendors of different scales can adhere to. This prevents lock-in to proprietary, incompatible systems and vendors. For example, the highly successful Unified Payments Interface, which focused on specifications, allowed a wide array of app developers to create payment apps, providing users an opportunity to move away from convoluted banking apps.
- **Technology-agnostic architecture.** The architecture of the solutions should be not tied to any specific technology, allowing for the adoption of new and emerging technologies. This approach ensures far-longer-term viability and adaptability.
- **Open data and observability.** The DPI should emphasize open data and observability. Making data accessible and enabling the bus system's performance to be monitored fosters transparency and continuous improvement. This principle is particularly important in the transport space – for example, TfL, the transport authority in London, opened 62 transit datasets to app developers. This prompted over 5,000 developers to use and combine this data in numerous ways to create passenger information applications, in ways no one had thought of before. The apps did everything from mapping locations to showing passengers where to stand on a train station platform to avoid boarding overcrowded coaches. By sparing TfL from needing to develop all types of in-house apps itself, and attracting more ridership through better information, TfL estimates that the experiment brought in an additional GBP 6.8 billion. In India's (significantly more) complicated bus operating environment, such an approach is likely to yield considerable innovation at scale.
- **Federated governance.** The architecture should promote a federated governance model, emphasizing the autonomy of each geographical stakeholder. This principle allows each stakeholder to operate independently, making decisions and managing operations in a way that best serves their specific regional and local needs. Such a decentralized approach allows for greater flexibility and responsiveness, catering to diverse operational environments while still maintaining overall system coherence and standards.
- **Composability.** Composability is a design principle that allows systems to be assembled from smaller, independent components. This makes it easier to create new systems by combining existing components. Composability is what will allow various players to unlock true innovation in the system. In the bus space, there are several data-emitting "fundamental" blocks of the system (for example, passenger ticketing, vehicle tracking, battery's state of charge). The ability to combine these diverse blocks (as shown in Figure 7) can yield rich insights and applications. For example, data from these three blocks can be combined to create applications yielding rich insights on the type of batteries and charging schedules to deploy on different types of bus routes.

With the foundational principles outlined, we can now explore specific use cases that demonstrate the versatility and potential impact of the open e-bus blueprint. These examples will illustrate how the blueprint can be applied to address real-world challenges in the bus ecosystem.

Figure 9 | **The missing puzzle in DPI for mobility**



Source: Authors' analysis.

USE CASES FOR OPEN E-BUS BLUEPRINT IN THE DPI ECOSYSTEM

The concept of modular building blocks is essential for the open e-bus blueprint to function effectively. Figure 9 illustrates how these blocks provide the missing piece that makes it possible to leverage other DPI components that fit together to create a cohesive and scalable infrastructure for mobility.

Developing and adopting the building block approach offers the following advantages:

- **Encourages widespread participation, especially from smaller or less prominent actors.** By establishing data standards, specifications and protocols, the approach reduces technical and financial barriers to build and deploy solutions. This helps level the playing field and enables diverse contributors to engage in value creation, fostering a more inclusive ecosystem where innovation can thrive.
- **Encourages flow of value, enabling a decentralized network of interconnected actors to collaborate harmoniously.** The decentralization promotes resilience and adaptability and ensures value moves freely across the ecosystem, incentivizing innovation, and partnerships. Interconnected actors collaborate in open-source communities, where developers, companies, and users contribute code, funding, and feedback to co-create solutions without central control.
- **Addressing observability and trust by creating a platform-agnostic environment.** Allows applications built on these building blocks to be easily discovered, accessed, and trusted across various platforms, contributing to a more equitable digital landscape in the bus ecosystem.

The solutions built using a building block approach are demonstrated through the following use cases:

Public-transport-as-a-service (PTaaS)—Optimizing bus utilization with federated governance

By adopting open e-bus blueprint, public bus transport systems can improve overall service quality and ridership, optimize bus utilization, and create a more sustainable, responsive, and profitable transit network.

For example, with appropriate policies enabling standardized data exchange across all bus operators and systems, open e-bus blueprint could allow fleet operators to seamlessly integrate their idle buses into a city or region's transit network during peak times. This integration would be managed via application programming interfaces (APIs) that facilitate flexible agreements.

Benefits of this approach include the following for:

- **Fleet operators:** They can generate additional revenue by utilizing their idle buses during periods of high demand.
- **Transit agencies:** They can meet passenger demand that exceeds their capacity without incurring substantial expenses.

Stakeholders benefited: Commuters, bus operators (both private and public) and transport authority.

Public-transport-as-a-service (PTaaS)—Unbundling of contracts and change in business models

Current model: Public entities that procure e-buses have OEMs handle procurement and operation (including setting up charging infrastructure and covering energy costs), as well as maintenance of the buses according to predefined SLAs. OEMs are reimbursed on a per-kilometer basis for operations. This model places the entire management responsibility on OEMs, whose core competency is bus manufacturing. Conversely, in the private sector, bus operators typically own the buses, financed through banks, and assume responsibility for maintenance and operation.

Challenge: This is done because the initial cost of e-buses is approximately three times that of ICE buses. Because of the high upfront capital expenditure, accelerating e-bus adoption requires getting the private sector involved. Additionally, bus operators and financiers are generally not equipped to handle technology risk, which is better managed by bus OEMs.

Proposed solution: The DPI approach allows for unbundling existing contracts by providing a transparent, interoperable framework that standardizes communication between different actors. Through standards, specifications, and protocols for information exchange, the blueprint allows contract components—such as asset ownership, operations, and energy management—to be separated, while ensuring seamless information flow. This transparency enables clearer roles, reduces information asymmetry, and fosters trust, making it easier to distribute responsibilities according to each actor's expertise, and adopting an open e-bus blueprint allows for a more effective distribution of risk and responsibility, tailored to each participant's expertise. This approach facilitates the separation of various contract components—such as asset ownership, operations, energy, and batteries—but strengthening transparency and trust. This is done by ensuring a seamless flow of information among them. Ultimately, this leads to a more flexible and effective business model.

Benefits of this approach include the following for:

- **Bus OEMs:** Focusing on bus manufacturing and assuming product guarantee risk without involvement in financing or operating the buses.
- **Bus operators:** Concentrating on bus operation without bearing the product guarantee risk.
- **Charging point operators (CPOs):** Focusing on providing charging services.
- **Financiers:** Investing without taking on the product and operational risks.
- **State transport undertakings (STUs):** Securing services with minimal upfront investments and increasing participation of private suppliers during procurement.

Stakeholders benefited: OEMs, CPOs, bus operators, financiers, STUs, transport authority.

Charging up the future: Interoperability allows market demand to guide infrastructure development with unified energy interface (UEI)[9] and open e-bus blueprint

Current model and challenge: Currently, the responsibility for setting up charging infrastructure lies with OEMs and operators. Each plans and deploys charging facilities based on their specific needs and capabilities, as system-wide bus operational data is not accessible to individual operators. The success of large-scale electric bus deployment depends on strategically designed charging infrastructure. A major challenge is identifying the most efficient and profitable locations for new charging stations. Without accurate data on bus movement and energy consumption, there is a risk of either over-investing or under-investing in charging infrastructure.

Proposed solution: Leveraging standardized operational data across electric bus operators by adopting an open e-bus blueprint integrated with the UEI allows energy providers to identify the most strategic locations for new charging stations. This interoperable data-driven approach ensures that investments are directed towards areas with the highest demand, minimizing risk and maximizing return on investment.

Benefits of this approach include the following for:

- **Operators:** Reduces the costs associated with setting up charging infrastructure and increasing the operational coverage area
- **CPOs:** Accurate and timely data, allowing them to efficiently establish charging facilities, increase charger utilization, and boost revenue
- **Energy providers:** Enables better management of power demand based on precise operational data

Stakeholders benefited: Operators, CPOs, energy providers, transport authority.

Mobilizing finance: Enabling affordable financing and unlocking carbon markets with composability, open data and observability

Challenge: Securing financing for electric bus projects is not easy. Traditional financial institutions struggle to assess customer risk, technology risk, operational details, and the environmental benefits and impacts of electric buses. This lack of clear data hinders access to sustainable and affordable green financing, thereby slowing the transition to clean transportation.

Proposed solution: A DPI-driven ecosystem enables financiers to better assess technology and operational risks by accessing necessary information, including capturing credit histories to understand bus operator risk over time. Standardized operational data from e-buses also enhances transparency in estimating emission reductions and tracking carbon credits, making them easier to trade.

This approach helps oversee the generation and verification of carbon credits with transparency and accountability mechanisms. It also reduces costs and increases the likelihood of securing affordable funding for sustainable e-bus projects. This supports a smooth transition to clean transportation, making e-bus projects more attractive to financiers and operators alike.

Benefits of the DPI approach for:

- **OEMs/operators:** Enables access to affordable financing and provides an additional revenue source through carbon credit trading
- **Financiers:** Helps mitigate customer and technology risks and, with transparent emission reduction estimates, facilitates the provision of affordable green financing to e-bus operators

Stakeholders benefited: OEMs/operators, financiers, transport authority.

Powering up the workforce: E-buses, skills, and the future

Challenge: India's 10 million-strong bus workforce faces challenges in training, safety, and efficiency. With the planned expansion of e-buses, finding skilled drivers is crucial. However, without proper documentation of skills and performance, operators struggle to identify qualified drivers and incentivize good practices.

Proposed solution: Integrating and sharing verifiable credentials with platforms like Digilocker[10] brings transparency to driver skill assessment across operators. This would enable the creation of a transparent, structured job market by documenting driver credentials, tracking, motivating skill improvement, and incentivizing performance in areas such as safety and fuel efficiency. It can also connect operators with skilled drivers through standardized registries across geographies. Additionally, operators can upskill their workforce by integrating with other DPI initiatives like Open Network for Education and Skilling Transactions (ONEST).[11] This approach fosters trust, reduces skill development costs, and aligns incentives for a more skilled and efficient workforce.

Benefits of the DPI approach for:

- **The workforce:** Drivers and staff can share verified training and employment credentials across operators, enhancing employability, pay, and incentivizing safe driving practices.
- **Training institutes:** Standardized training modules facilitate effective knowledge transfer.
- **Operators:** Access to a pool of trained staff aids in safer and more efficient bus operations.

Stakeholders benefited: Workforce, operators, training institutes.

Inclusive circular economies: Sustainable battery management

Challenge: The success of large-scale electric bus adoption depends on sustainable battery practices. A lack of transparency in the battery life cycle hinders financing for e-buses and limits efforts towards responsible sourcing and recycling. This creates logistical challenges in managing and maintaining information across the battery supply chain.

Proposed solution: Exchanging real-world operational data from e-buses, including transparent battery performance data, enhances trust and supports financing for electric buses. Combining this with the UEI, offers a multi-stakeholder approach to sustainable battery practices. The UEI enables the implementation of digitally verifiable battery passports, providing a secure record of key information, such as the following:

- **Material provenance:** Tracking the origin of battery materials to ensure responsible sourcing practices
- **Battery chemistry and manufacturing:** Gaining insights into battery composition and production history for informed decision-making
- **Battery health management:** Monitoring battery health data to optimize performance, extend lifespan, and facilitate responsible recycling

Such a multi-stakeholder approach, connecting and engaging businesses, financial institutions, IT solution providers, regulators, auditors, public and international organizations, can help foster trust and bring high levels of transparency to the global battery value chain.

Benefits of the DPI approach for:

- **Operators:** Reliable operational data will help secure affordable financing and enable the deployment of efficient and cost-effective charging strategies. It supports the adoption of sustainable battery management practices and ensures battery circularity.
- **CPOs:** Planning and optimizing charging infrastructure improves service offerings by utilizing transparent battery performance data.
- **Financiers:** Reduces perceived technology risks due to greater transparency in battery life cycle data.
- **Transport authorities:** Enforces regulatory compliance and implement policies that promote sustainable sourcing practices for batteries.

Stakeholders benefited: Operators, OEMs, CPOs, financiers, transport authority.

IMPLEMENTING OPEN E-BUS BLUEPRINT

Bringing the open e-bus blueprint from concept to operation will require deliberate, strategic action. We present our roadmap here, inviting constructive criticism, collaboration, and engagement.

The process begins with forming a multidisciplinary team to initiate the design and to further develop and refine the blueprint, balancing ambition with practicality. Deliberation with broader stakeholder groups will be essential to fully realize its potential. Once the blueprint is designed, the next step involves creating reference open-source software for adoption and customization by bus operators—including State Transport Units (STUs), public, private, and other fleet operators—for various use cases. A detailed implementation schedule will outline immediate goals and long-term ambitions, while early engagement with pioneering stakeholders will provide invaluable insights for broader rollout. Finally, a robust governance framework for will guide this progression, ensuring each innovation is purposeful and measurable.

With this strategic roadmap in place, the open e-bus blueprint would assume three key roles in its journey from concept to implementation:

Developmental role: The blueprint would adopt and adapt necessary building blocks for the bus ecosystem taking into consideration all the stakeholders. This includes the design, development, maintenance, and continuous upgrade of the required technological infrastructure. Additionally, it would work to enlist participants from various sectors, providing them with the necessary support to ensure widespread voluntary participation.

Ecosystem facilitation: The blueprint could help establish policies and rules for the ecosystem in collaboration with participants. These policies will be machine-readable and, to the extent possible, enforceable through software within the ecosystem.

Service delivery: The blueprint would help develop, maintain, and continuously upgrade foundational services for managing the buses, such as registries, certifications, and specifications. It would also develop reference or sample applications to guide new participants (such as bus operators or service providers), especially in the early stages to facilitate onboarding.

Design initiation

Securing government endorsement is vital for the legitimacy and success of the blueprint. Official recognition from Ministries (MoRTH, MoHUA, MHI, MoP), government bodies (ASRTU, CESL CMVR-TSC, BEE), and transport agencies involved in regulating and supporting the sector is needed to validate the blueprint and enable smoother integration with existing infrastructure and regulations. Recommended actions include the following:

- **Forming the design council**: This is a carefully selected group of experts, especially those with a background in establishing or working with large digital infrastructures, standards bodies, free and open-source software (FOSS) communities, and volunteers. They can contribute to the architectural design, draft standards, and ensure system scalability.
- **Establishing an advisory board**: This would comprise experts and stakeholders from various fields and guide the project's long-term success, focusing on regulatory alignment, technological updates, and seamless integration with existing systems.

Implementation strategy

The long-term plan would be to implement the blueprint as a foundational digital public infrastructure for buses to making it an ecosystem-wide utility serving the diverse use cases and players in the bus ecosystem. The blueprint could transform how the bus sector operates today and address challenges like building trust among operators, managing multi-sectoral alignment, and addressing stakeholder concerns. The initial phase of the blueprint needs to be rolled out quickly with e-bus deployment to gain acceptance and assess scalability. The implementation strategy would largely need to focus on three key aspects: technology, business, and institution building, including the following:

- **Pilot projects:** Identifying cities or regions for testing the components of blueprint in diverse environments.
- **Value demonstration:** Highlighting immediate benefits to users and stakeholders, such as improved service reliability through early blueprint features like standardizing schedules, vehicle health and battery health specifications.
- **Scalability plans:** Developing strategies to scale the blueprint from pilot regions to national coverage.

CONCLUSION

The transition to e-buses presents a pivotal opportunity to transform India's public transportation. As the country targets electrifying 800,000 buses over the next decade, the current fragmented bus ecosystem creates inefficiencies and increases operational costs, limiting the scalability of e-bus deployment and infrastructure. Addressing these challenges will require more than isolated technological fixes.

Our proposed alternative is a robust, foundational digital infrastructure. The open e-bus blueprint, rooted in Digital Public Infrastructure (DPI) principles, provides a sustainable approach to technology integration and scalable solutions. Inspired by India's DPI successes, this blueprint emphasizes reusable digital building blocks that reduce core infrastructure investment while enabling significant improvements in efficiency and cost reduction. By "doing less," we can achieve a large-scale impact, driving reach and inclusivity across the bus ecosystem. This approach allows bus operators, OEMs, CPOs, financial institutions, and technology service providers to innovate collaboratively, offering choice and flexibility for future solutions while minimizing the risks tied to proprietary systems.

We invite policymakers, industry leaders, and all stakeholders to engage with these ideas and work collectively toward a sustainable, resilient public transportation system that supports both economic growth and environmental goals.

GLOSSARY

BUS	A motor vehicle carrying passengers by road, either on a stage-carriage or contract-carriage permit. For the purposes of this document, a bus refers only to services having a predefined schedule.
STAGE CARRIAGE	A stage carriage means a motor vehicle carrying or adapted to carry more than six persons, excluding the driver, which carries passengers for hire or reward at separate fares paid by or for individual passengers, either for the whole journey or for stages of the journey.
CONTRACT CARRIAGE	A motor vehicle that carries passenger(s) for hire or reward under a contract, whether expressed or implied for the use of the vehicle as a whole, for a period at agreed-upon rate or sum.
(BUS) STOP	A place (with specified geo-coordinates and a geo-fence) where a bus regularly stops, usually marked by a sign.
BUS STATION (OR) TERMINAL	A place where buses arrive and depart and serves passenger boarding and alighting.
BUS DEPOT	A facility where buses are stored/parked and maintained.
ROUTE	A specified path for movement of a bus from origin to destination along predefined road segments passing through a series of bus stops and/or waypoints. A route is usually represented by a unique number, name, or ID.
TRIP	An instance of a route with specific arrival/departure timings at each of the stops along the route.
TIMETABLE	A passenger-facing chart showing the arrival/departure timings at a single or multiple stops. Timetables at a given stop are usually listed by routes serving the bus stop and color coded by service type.
SCHEDULE	A bus operator–or crew-facing chart indicating the series of trips to be undertaken by them during their work shift. Schedules can be of two types – bus schedule and crew schedule. In most Indian bus operations, the crew is fixed to a bus throughout their work shift on a specific day. Thus, in such cases, the bus schedule and the crew schedule is one and the same for that period.
TRANSIT AGENCY/ AUTHORITY	The agency responsible for planning and monitoring of transit services. This is usually a government entity or a government owned company/corporation.
TRANSIT OPERATOR	The agency or individual, either public or private, responsible for operating the bus fleet as per the schedules planned/prepared by the transit authority.

ABBREVIATIONS

AFC	Automatic Fare Collection
API	Application Programming Interface
ASRTU	Association of State Road Transport Undertaking
BEE	Bureau of Energy Efficiency
BMTC	Bengaluru Metropolitan Transport Corporation
BN	Billion
CBS	Core Banking Solution
CESL	Convergence Energy Services Limited
CMVR-TSC	TSC Central Motor Vehicles Rules—Technical Standing Committee
CPO	Charge Point Operator
CR	Crore
DIMTS	Delhi Integrated Multi-modal Transit System
DTC	Delhi Transport Corporation
DPI	Digital Public Infrastructure
ETM	Electronic Ticketing Machine
FOSS	Free and Open Source Software
GCC	Gross Cost Contract
GoI	Government of India
GTFS	General Transit Feed Specification
ITS	Intelligent Transportation System
IT	Information Technology
IP	Internet Protocol
MaaS	Mobility-as-a-Service
MHI	Ministry of Heavy Industries
MoHUA	Ministry of Housing and Urban Affairs
MoP	Ministry of Power
MoRTH	Ministry of Road Transport and Highways
NeTEx	Network Timetable Exchange
NPCI	National Payments Corporation of India
OEM	Original Equipment Manufacturer
ONDC	Open Network for Digital Commerce
ONEST	Open Network for Education and Skilling Transformation
PPP	Public-Private Partnership
PIS	Passenger Information System
RBI	Reserve Bank of India
SoC	State of Charge
STU	State Transport Undertaking
TCO	Total Cost of Ownership
TN	Trillion
UEI	Unified Energy Interface
UPI	Unified Payments Interface
VLT	Vehicle Location and Tracking

ENDNOTES

1. This estimate is based on data collated from multiple sources for the same time period (Gadepalli et al. 2024; TOI Education 2023; Press Information Bureau, GoI 2024; Ministry of Civil Aviation 2024; De et al. 2017)
2. The Bharat Bill Payment System (BBPS), developed by the Reserve Bank of India (RBI) and managed by NPCI, offers a unified, interoperable platform for secure and reliable bill payments across India. It supports use cases like mobility payments, loan repayments, and utility bills, to name a few.
3. Technology service providers are entities that provide technology solutions or technology services (usually categorized as Mobility-tech, Energy-tech, Fin-tech, Travel-tech, etc.)
4. Network Timetable Exchange is a CEN Technical Standard for exchanging Public Transport schedules and related data. It provides a means to exchange data for passenger information among different computer systems, together with related operational data.
5. General Transit Feed Specification is a community-driven open standard for rider-facing transit information.
6. Gross Cost Contract (GCC) model, the operator/supplier contracts with the transport corporation and is paid on a fixed cost per km basis. The supplier is responsible for procurement of e-buses and related operations and monitoring infrastructure.
7. Net Cost Contract (NCC) model is an agreement between a transport authority and operator/ supplier of contracts that gives the operator the right to provide bus services on a specific route. The bus operator keeps all the revenue from the services, and the transport authority pays the operator a subsidy or royalty depending on whether the services are profitable.
8. Open Network for Digital Commerce' (ONDC), is a Government of India (GoI) backed technology infrastructure. It is a network-centric model, based on Beckn protocol wherein buyers and sellers can transact irrespective of the platforms/ applications they use as long as they are connected to this open network. The protocol enables local commerce across segments, such as mobility, grocery, food order and delivery, hotel booking and travel, among others, to be discovered and engaged by any network-enabled application.
9. UEI, is a DPI built on the Beckn protocol; the same protocol powers India's Open Network for Digital Commerce (ONDC). It enables interoperability between charging networks, energy providers for easy charger discovery, and streamlined payments for energy transactions. It offers a homegrown alternative, inspired by successful Indian models like UPI, compared to global standards like Open Charge Point Interface (OCPI).
10. DigiLocker, an initiative by the Ministry of Electronics and Information Technology, GoI, under the Digital India programme, is a secure, cloud-based platform for storing, sharing, and verifying digital documents. It enables citizens to store government-issued IDs, KYC documents, healthcare records, and more, supporting use cases across sectors like financial services, healthcare, HR, legal, and government agencies.
11. ONEST is an open, decentralized network designed to break silos in education and employment, fostering collaboration between content providers, learners, and job seekers. Its goal is to enhance access to equitable education, skills development, and sustainable livelihood opportunities.

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WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization.

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