Governance-First Architecture for Federated Mobility Systems

Designing Neutral Settlement Infrastructure for Multi-Authority Transport Systems

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1. Executive Summary: The Sovereignty Challenge in Converged Mobility

A typical mobility journey spans multiple services—toll roads, urban transit, parking, and emerging systems such as EV charging. While the journey appears unified to the traveler, each segment is governed by a different authority with its own pricing policies, regulatory frameworks, and revenue systems.

This creates a structural challenge: digital platforms can coordinate the traveler experience, but cannot consolidate the institutional control embedded within infrastructure systems. Each authority retains responsibility for pricing, validation, policy enforcement, and revenue ownership within its domain.

Mobility interoperability is often approached as a problem of system integration. In multi-authority environments, however, the constraint is not technical—it is institutional. Tolling, road usage charging, and mobility services operate under fundamentally different legal authorities, revenue models, and audit requirements.

These systems cannot be merged into a single operational or financial model without creating ambiguity in legal authority, commingling revenue types, and undermining audit independence. As a result, interoperability cannot be achieved through centralization.

This paper reframes the problem: the challenge is not interoperability between systems, but how to enable coordination without requiring authorities to surrender control.

Centralized models concentrate control and encounter resistance. Fully distributed models rely on bilateral integrations and fail to scale. A different approach is required—one that enables interoperability without consolidation.

This paper introduces a Governance-First Architecture that separates mobility systems into three interoperable layers:

- **Orchestration** — coordinates traveler interactions across services
- **Execution** — preserves authority control over pricing, validation, and policy
- **Settlement** — provides neutral financial coordination across participants

This separation distinguishes coordination from control. Orchestration enables a unified experience, while execution remains under authority ownership. Settlement ensures that financial outcomes are consistent, traceable, and auditable across systems without centralizing revenue or decision-making.

By structuring systems in this way, interoperability can scale across jurisdictions and operators without altering institutional roles. Coordination is achieved without consolidation, and financial consistency is maintained without transferring control.

This paper defines the structural conditions required for multi-authority mobility systems to operate at scale. It is intended for transport authorities, regulators, and system architects designing interoperable ecosystems that must align with legal, financial, and governance realities.

Mobility interoperability is not a technology problem to be solved through integration. It is a governance problem that must be structured through institutional separation.

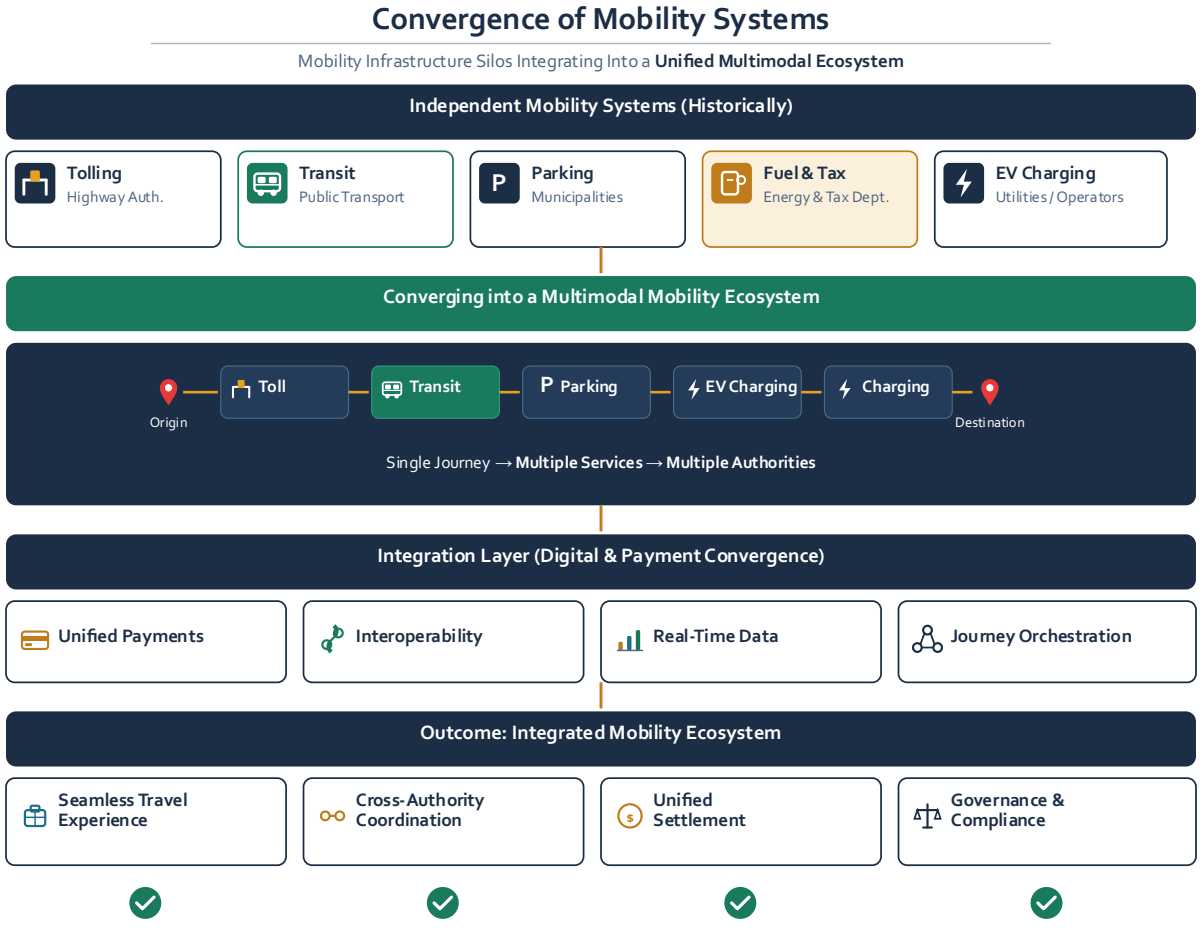

Diagram: Convergence of Mobility Systems

Caption:
Mobility infrastructure that has historically operated independently is increasingly converging into integrated ecosystems that support multimodal journeys.

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2. The Evolution of Integrated Mobility Initiatives

Mobility systems have evolved from standalone, mode-specific services into coordinated journey experiences. Historically, tolling, public transit, parking, and related services operated independently, each with its own infrastructure, payment mechanisms, and operational processes.

Advances in digital platforms and payment technologies have enabled these services to connect at the user interface level. Electronic toll collection, transit smart cards, and integrated payment applications have reduced friction within individual journey segments. More recently, mobility platforms have extended this integration across services, presenting unified interfaces for planning, access, and payment.

However, convergence at the experience layer does not eliminate the underlying institutional structure of mobility systems. Each service continues to operate within its own regulatory, financial, and operational framework under independent authorities.

Integrated mobility therefore represents coordination—not unification—of institutionally governed services. This distinction becomes critical as systems scale across jurisdictions and operators. Integration efforts focused only on interface connectivity often overlook institutional constraints. Authorities must retain control over pricing, validation, policy enforcement, and revenue ownership.
These responsibilities are not technical abstractions. They are tied to regulatory mandates, financial accountability, and operational liability. From an institutional perspective, participants operate with defined incentives:

- **Authorities** — preserve pricing control, auditability, revenue integrity, and policy enforcement
- **Operators** — ensure operational reliability and regulatory compliance
- **Financial systems** — maintain accuracy, traceability, and settlement finality
- **Platforms** — optimize coordination and user experience across services

These incentives do not naturally align within centralized models. As integration expands, attempts to consolidate coordination, execution, and financial control into a single platform create structural friction.

The evolution of mobility systems therefore reveals a consistent pattern: while user experiences converge, institutional authority remains distributed. Effective interoperability requires designing for this distribution, rather than abstracting it away.

A deeper constraint emerges when mobility systems are examined through their legal and financial foundations. Different mobility services are not simply separate technologies — distinct statutory and regulatory doctrines govern them.

Tolling systems are tied to specific infrastructure assets and must maintain revenue traceability at the asset or corridor level. Road usage charging systems operate as statutory levies, requiring strict separation of policy, measurement, billing, and collection under public finance law. Mobility service platforms function as voluntary, market-driven services subject to consumer protection and competition frameworks.

An integrated system that combines these domains cannot clearly answer fundamental governance questions: under what legal authority a charge is imposed, who determines pricing, and how revenue is allocated. This ambiguity creates conflicts in audit, regulation, and accountability.

Interoperability must therefore be designed to respect these distinctions. Coordination across systems is possible, but consolidation of control is not. This establishes federation as a structural requirement derived from legal and audit principles, rather than a design preference.

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3. The Anatomy of Multi-Authority Mobility Journeys

A single mobility journey—such as travel across toll roads, public transit, and urban parking—appears unified from the traveler's perspective. In practice, it consists of a sequence of authority-controlled operational events, each executed within a distinct infrastructure system.

A specific authority controls each segment. Toll operators determine pricing and validate vehicle passage. Transit authorities define fares and manage access control. Municipal systems enforce parking policies and duration rules. These systems operate under separate regulatory frameworks, financial arrangements, and operational processes.

A mobility journey is therefore not executed by a single system, but coordinated across multiple authorities, each responsible for its domain. For each operational event, key responsibilities remain with the respective authority:

- **Pricing** — defined by local policy and regulation
- **Validation** — confirmation of service usage
- **Revenue ownership** — retained by the service provider
- **Policy enforcement** — including exemptions, discounts, and compliance rules

These responsibilities define the boundaries of institutional control. They cannot be transferred to external platforms without altering regulatory accountability and operational liability. This creates a structural distinction:

- **Coordination** can span services.
- **Execution** remains under authority control

This distinction is further clarified through two roles:

- **Coordination rights** — held by orchestration layers to sequence services and present a unified experience
- **Decision rights** — retained by authorities over pricing, validation, and policy rules

This separation allows platforms to enable interoperability without assuming control over infrastructure systems. A unified journey is therefore an overlay on distributed execution—each event independently governed but coordinated to ensure consistency across the journey.

This introduces a core architectural condition: coordination must occur across systems that do not share control. Each authority participates in the ecosystem while retaining decision rights.

Mobility interoperability is achieved not through system consolidation, but through structured coordination across institutional participants.

A typical multi-authority journey, executed across distributed authority systems, is illustrated below.

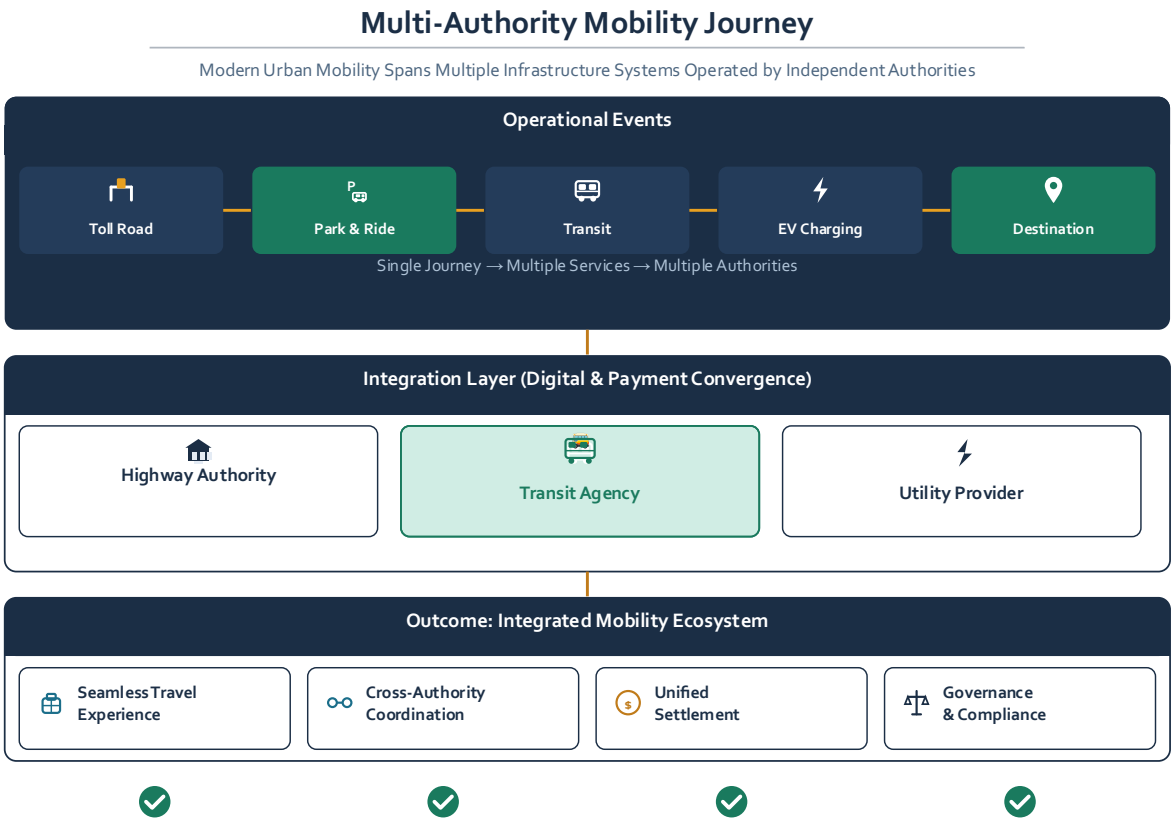

Diagram: Multi-Authority Mobility Journey

Caption:

Modern mobility journeys frequently span multiple infrastructure systems operated by independent authorities.

Mobility journeys require coordination across multiple institutional participants, each operating within defined roles and responsibilities.

The interaction structure between authorities, platforms, and financial systems is illustrated below.

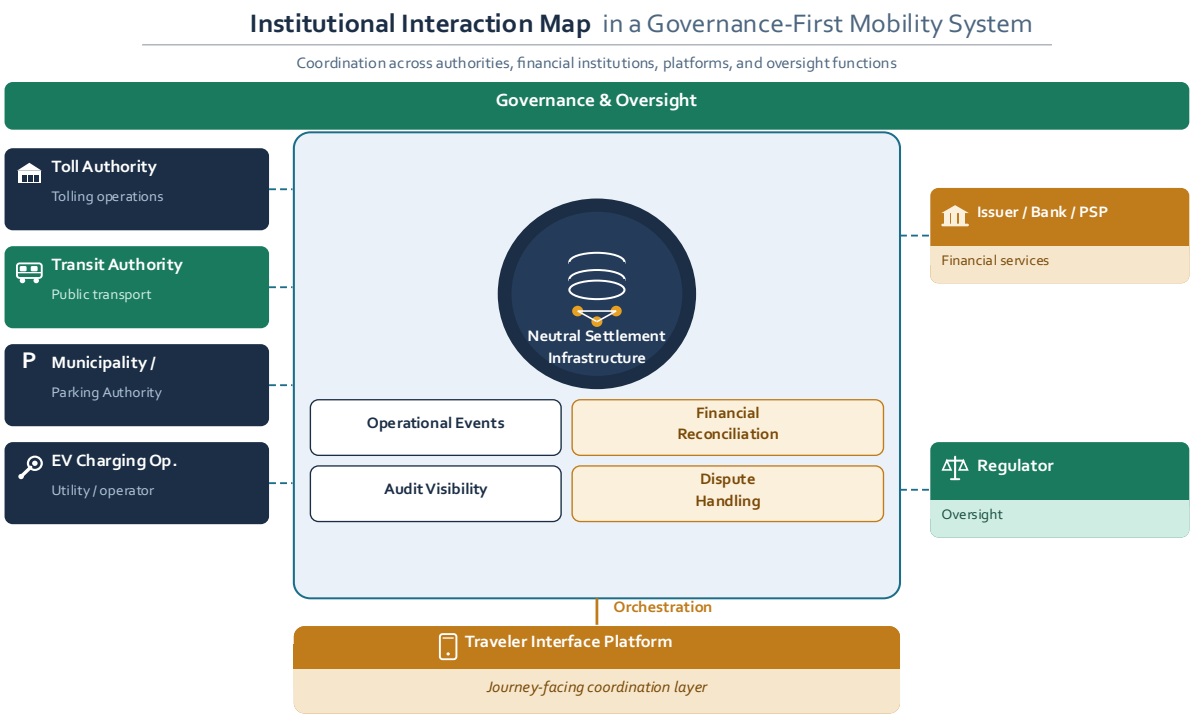

Diagram: Institutional Interaction Map in Governance-First Mobility Systems

Caption:
Mobility systems operate through structured interactions between authorities, financial institutions, platforms, and oversight functions, coordinated through neutral settlement infrastructure while maintaining authority boundaries.

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4. Orchestration vs. Authority: The Control Paradox

As mobility journeys span multiple systems, digital platforms play an increasing role in coordinating the traveler experience. Mobility applications, vehicle interfaces, and payment aggregators enable users to plan, initiate, and complete journeys across services. However, coordination does not imply control over infrastructure.

Each authority retains decision rights over its systems, including pricing, validation, policy enforcement, and revenue collection. These responsibilities are tied to regulatory obligations and operational accountability and cannot be transferred to external platforms.

This creates a structural condition: while the journey appears unified, control remains distributed. Orchestration is therefore limited to coordination—it sequences interactions, routes requests, and presents a consistent interface. It does not determine how services are executed.

Infrastructure systems represent the point of execution. Authorities define pricing logic, access conditions, and policy rules, establishing the source of operational and financial truth. This separation gives rise to the control paradox: a system that appears unified at the experience layer is governed by multiple independent authorities that do not share control. This is not a technological limitation, but an institutional reality. Mobility systems must deliver coordinated experiences while preserving authority and autonomy.

Centralized models attempt to resolve this by consolidating coordination and execution within a single system. In doing so, they absorb decision rights that authorities must retain, creating conflicts over pricing, revenue allocation, policy enforcement, and accountability.

As a result, such models encounter resistance from operators and regulators, limiting their ability to scale across jurisdictions. A scalable approach must preserve the distinction between coordination and control. Orchestration can unify the experience, but it cannot override institutional responsibilities.

This establishes a boundary condition for mobility architecture: coordination must operate across systems without assuming ownership of decision-making. The separation between coordination and control is illustrated below.

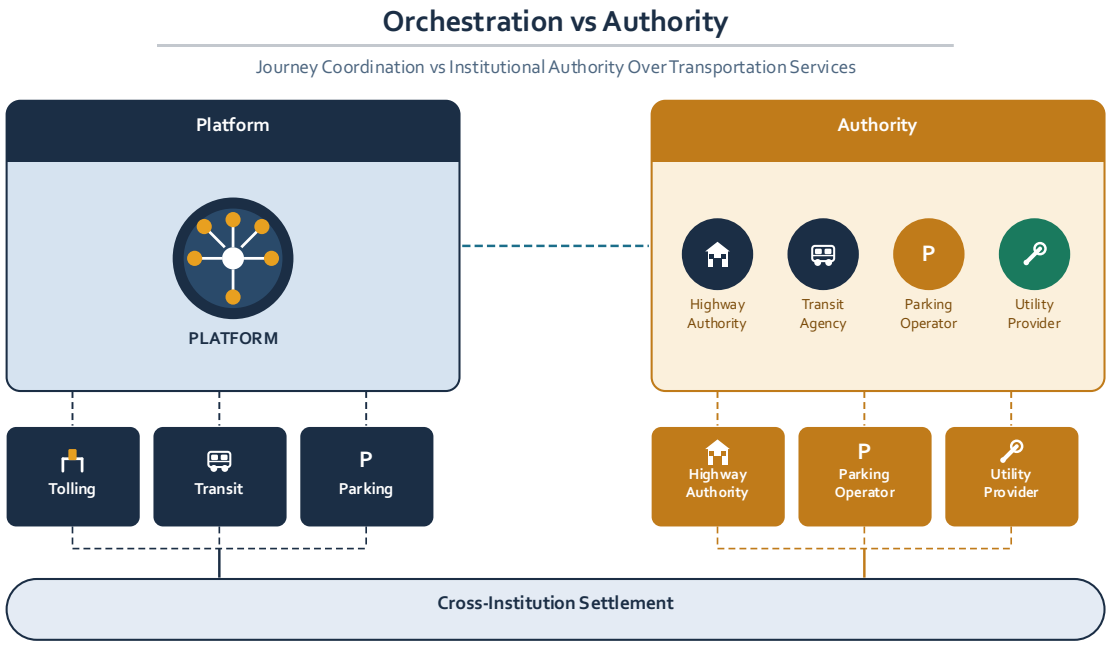

Diagram: Orchestration vs Authority

Caption:
Mobility platforms coordinate traveler experiences, while infrastructure authorities retain control over pricing, enforcement, and operational policy.

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5. Settlement Visibility Shift

In traditional mobility systems, financial settlement is treated as a back-office process. Transactions are recorded within individual systems and reconciled later through periodic clearing and settlement cycles. Each authority maintains its own records, and cross-system consistency is achieved through delayed reconciliation.

This model assumes systems operate independently, with limited need for real-time coordination. As mobility journeys span multiple authorities, this assumption no longer holds. A single journey generates multiple financial events across distributed authority systems. Without a shared and consistent view of these events, discrepancies arise in transaction records, revenue attribution, and settlement outcomes.

This requires a shift in how financial coordination is structured. In this context, settlement is not a payment or routing function; it is the deterministic reconstruction of financial obligations between participating parties, derived from operational events and agreed-upon rules. To clarify this, it is useful to distinguish related financial functions:

- **Switching** — routing transaction requests between systems
- **Clearing** — determining net financial positions between parties
- **Settlement** — executing fund transfers based on clearing outcomes
- **Reconciliation** — verifying consistency of records across systems
- **Dispute resolution** — resolving inconsistencies and exceptions
- **Audit** — ensuring traceability and accountability of financial outcomes

In multi-authority systems, these functions must operate on a shared and consistent representation of underlying events. This leads to a shift from post-processed settlement to event-linked financial visibility. Each operational event—such as a toll passage, transit entry, or parking session—must generate a corresponding financial record that is consistently represented across participating systems.

The financial lifecycle of an operational event, from occurrence to audit, is illustrated below.

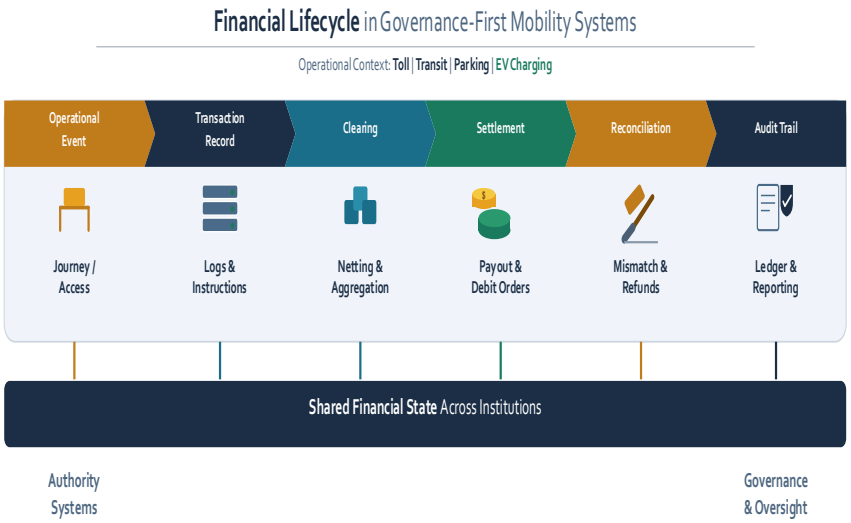

Diagram: Financial Lifecycle in Governance-First Mobility Systems

Caption:

End-to-end lifecycle from operational event to audit trail, ensuring consistency, traceability, and auditability across institutions

The financial lifecycle of an operational event can therefore be understood as:

Operational Event → Transaction Record → Clearing Logic → Settlement Instruction → Reconciliation and Exception Handling → Dispute Resolution → Audit Trail

This lifecycle ensures that financial outcomes are traceable, verifiable, and consistent across institutions, without requiring centralization of operational control.

A critical requirement in multi-authority financial coordination is the preservation of revenue segregation. Each category of mobility charge is governed by distinct legal and financial constraints that must be maintained throughout the financial lifecycle.

Asset-based toll revenues are typically ring-fenced and linked to specific infrastructure financing arrangements, often subject to bond covenants and concession agreements. Statutory charges such as road usage levies must be treated as public funds, governed by treasury controls and legislative oversight. Commercial mobility services generate market-based revenues subject to contractual and competitive frameworks.

Any commingling of these revenue streams within a unified system creates audit risk, regulatory non-compliance, and potential legal exposure. Financial coordination mechanisms must therefore ensure that revenue attribution, clearing logic, and settlement outcomes remain traceable to their originating authority and legal context.

In this model, settlement functions as a shared financial coordination mechanism. It preserves separation across revenue domains while ensuring that financial outcomes derived from shared operational events remain consistent, verifiable, and auditable across participating institutions.

By making the financial state visible and event-linked, mobility systems can coordinate across authorities while preserving institutional independence. Settlement provides the foundation for consistency and accountability, enabling coordination without altering decision rights. The role of settlement as a shared financial coordination layer across institutions is illustrated below.

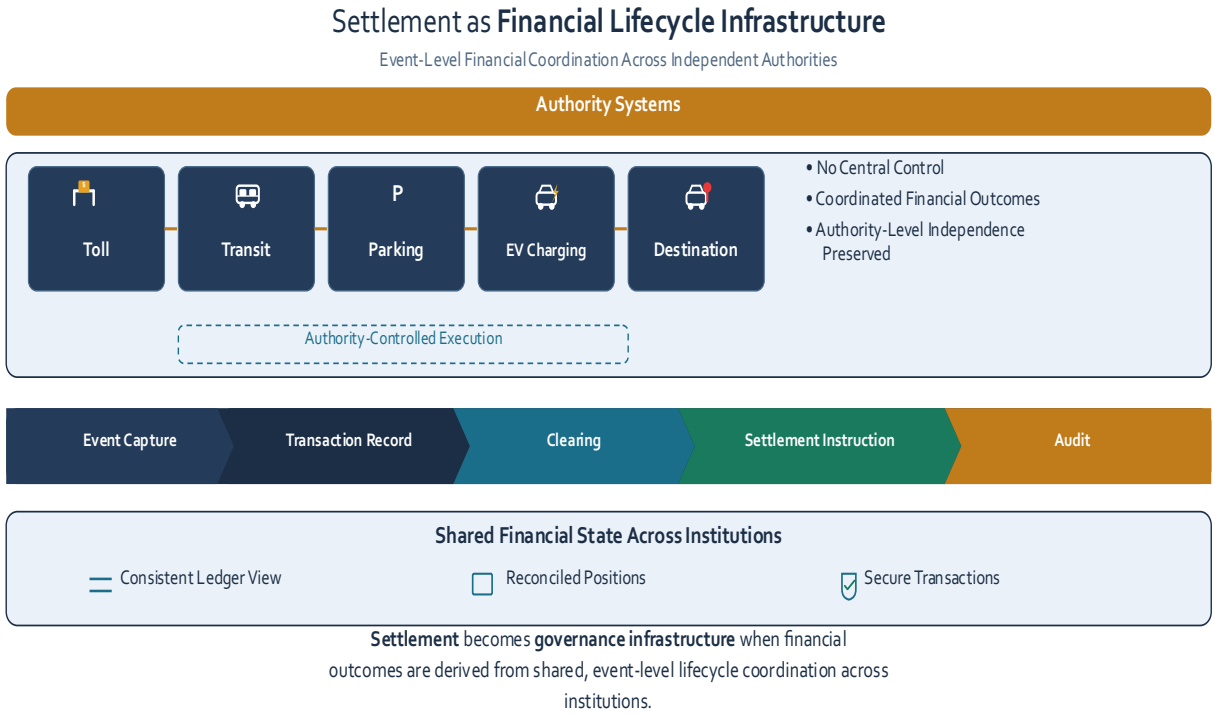

Diagram: Settlement as a Financial Lifecycle Infrastructure

Caption:
Settlement becomes governance infrastructure when financial outcomes are derived from shared, event-level lifecycle coordination across institutions.

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6. Institutional Failure Patterns

As mobility systems expand across multiple authorities, failures increasingly arise not from technology limitations, but from misalignment between system design and institutional structure. These failures occur when distributed authority systems are required to operate as a unified experience without a shared framework for financial coordination and accountability. Several recurring patterns emerge:

Fragmented Financial Reconciliation

Each authority maintains its own transaction and revenue records. Without a shared event-level view, differences arise in transaction status, amounts, and settlement outcomes. This is visible in early multimodal integrations where transit and tolling systems used incompatible reconciliation cycles, leading to multi-day settlement delays. These discrepancies require manual reconciliation, leading to delays, operational overhead, and reduced confidence in financial accuracy.

Ambiguity in Dispute Ownership

When inconsistencies occur—such as incorrect charges, missing transactions, or failed validations—it is often unclear which entity is responsible for resolution. This leads to delayed handling, fragmented escalation, and unclear accountability across authorities, operators, and intermediaries.

Inconsistent Revenue Attribution

In multi-segment journeys, allocating revenue across authorities becomes complex. Without transparent settlement logic, distribution may not reflect actual usage or agreed policies, creating financial misalignment and undermining trust.

Limited Cross-System Visibility

Operational events are recorded within individual systems but are not consistently visible across participants. Authorities cannot independently verify cross-system transactions, thereby limiting auditability and increasing reliance on intermediaries.

Unclear Customer and Refund Responsibility

Customer-facing issues—such as refunds or reversals—do not map cleanly to a single system. Without a clear linkage between operational events and financial ownership, responsibility becomes fragmented, leading to delays and inconsistent outcomes.

Dependency on Central Intermediaries

In the absence of structured coordination, centralized platforms assume responsibility for routing, reconciliation, and settlement interpretation. While this simplifies integration, it concentrates operational and financial visibility within a single system, potentially conflicting with the responsibilities of infrastructure authorities.

Common failure patterns arising from misalignment between system design and institutional structure are illustrated below.

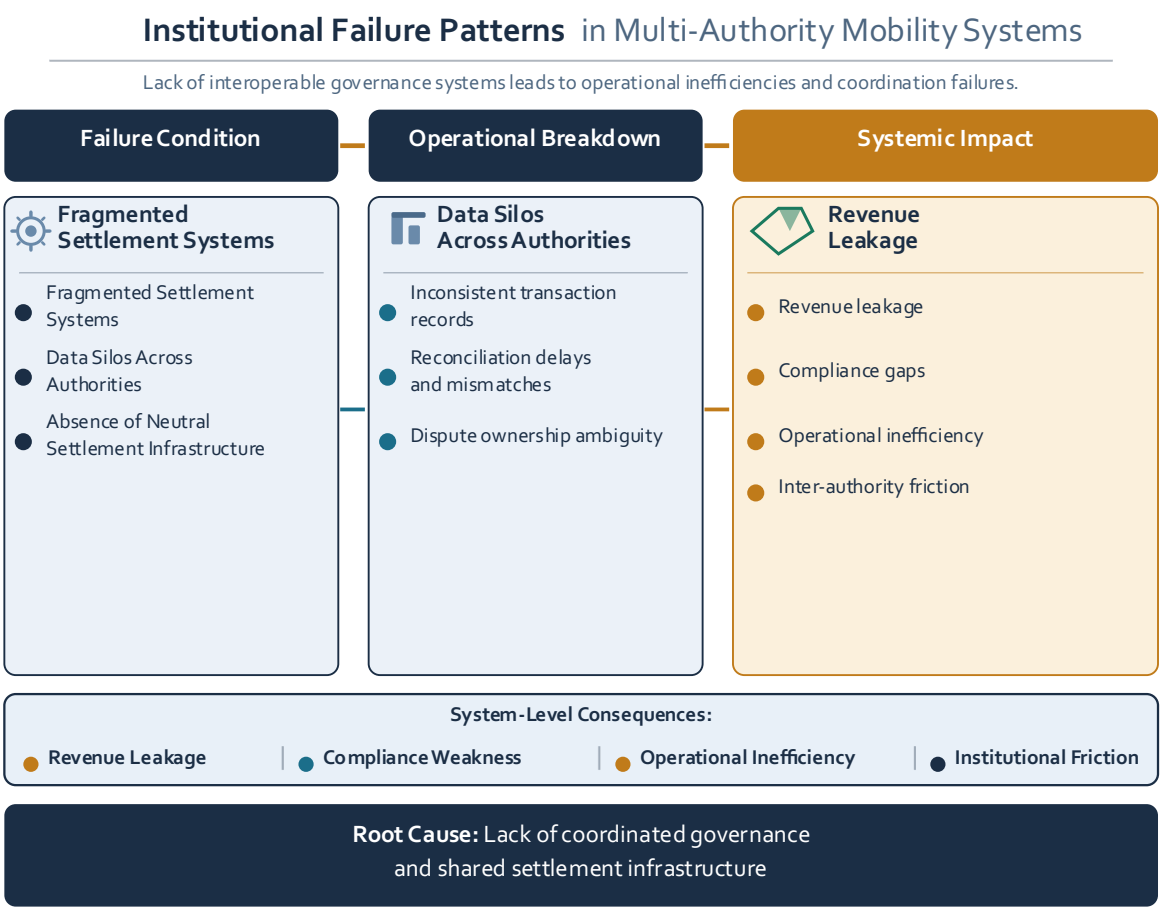

Diagram: Institutional Failure Patterns

Caption:
Fragmented settlement, siloed data, and the absence of neutral clearing infrastructure create systemic failures in mobility ecosystems.

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7. Governance-First Architecture

A Governance-First Architecture defines how responsibilities are structured across institutions in a multi-authority mobility system. It is not a technical specification or platform design, but a framework that enables coordination without consolidating authority. In such environments, interoperability depends on aligning system design with institutional responsibilities. This requires separating coordination, execution, and financial accountability into distinct but interoperable layers:

In addition to functional separation across orchestration, execution, and settlement, multi-authority systems require a governance control plane that operates across these layers. This control plane manages identity, consent, policy metadata, access governance, and participation rules across the ecosystem, ensuring coordination without centralizing execution or financial control.

Importantly, this control plane does not perform transaction processing, pricing, billing, or revenue aggregation. It does not hold funds, determine financial outcomes, or enforce infrastructure policies. Instead, it functions as a neutral coordination layer that enables interoperability while preserving institutional boundaries.

By separating governance from execution and financial processing, this model ensures that coordination does not translate into control. It provides a shared foundation for identity and interaction, while allowing each authority to retain responsibility for its operational and financial domains.

Orchestration Layer

The orchestration layer coordinates the traveler's journey across services. It includes applications and interfaces that enable planning, initiation, and management of journeys spanning multiple systems. Orchestration sequences interactions, routes requests, and presents a unified interface. It does not define pricing, enforce policies, or validate service usage.

Execution Layer

The execution layer consists of infrastructure systems operated by authorities, including tolling, transit, and parking systems. Authorities retain decision rights within this layer—pricing, validation, policy enforcement, and operational control—aligned with regulatory mandates and accountability. Execution systems represent the source of operational truth.

Settlement Layer

The settlement layer provides a neutral mechanism for financial coordination. It ensures that transactions generated from operational events are consistently recorded, reconciled, and settled across participants. Settlement operates as shared financial infrastructure, deriving outcomes from events and agreed rules to ensure consistency, traceability, and auditability. It does not influence pricing, policy decisions, or execution.

Data Trusteeship and Governance

Data governance is a foundational component of multi-authority mobility systems. Operational and financial coordination across institutions requires shared visibility of events, but this visibility must be structured in a way that preserves public accountability, privacy, and institutional control.

In this model, data is treated as a governed public asset rather than a byproduct of platform operations. Authorities retain trusteeship over data generated within their domains, including operational events, financial records, and policy-relevant information. Access to this data is governed through defined rules, consent mechanisms, and role-based permissions.

Participants interact with data based on their institutional role. Authorities access data required for policy enforcement and audit. Financial entities access data necessary for reconciliation and settlement. Service providers and third-party platforms access only scoped, consented, and purpose-limited data. Aggregated and anonymized datasets may be made available for public transparency and planning.

This approach ensures that data sharing enables coordination without transferring ownership or control. It prevents concentration of informational power within a single platform while maintaining traceability, auditability, and compliance with regulatory and privacy frameworks.

Governance Context

While these layers and the associated data governance model define functional separation, interoperability depends on maintaining clear institutional boundaries:

- **Orchestration** — coordinates interactions without assuming control
- **Execution** — enforces infrastructure policies within authority systems
- **Settlement** — ensures financial consistency without centralizing ownership

This separation enables authorities, service providers, and financial systems to participate in a shared ecosystem while preserving their legal and operational roles, without increasing governance friction, and establishing how coordination, execution, and financial accountability interact across institutions.

Unified Orchestration limits platform scope to journey coordination. Federated Execution preserves authority decision rights over pricing, validation, and policy. Neutral Settlement Infrastructure ensures financial consistency without consolidating authority. Together, they define the operating conditions for ecosystem-scale interoperability.

The Governance-First Architecture and its layered separation are illustrated below.

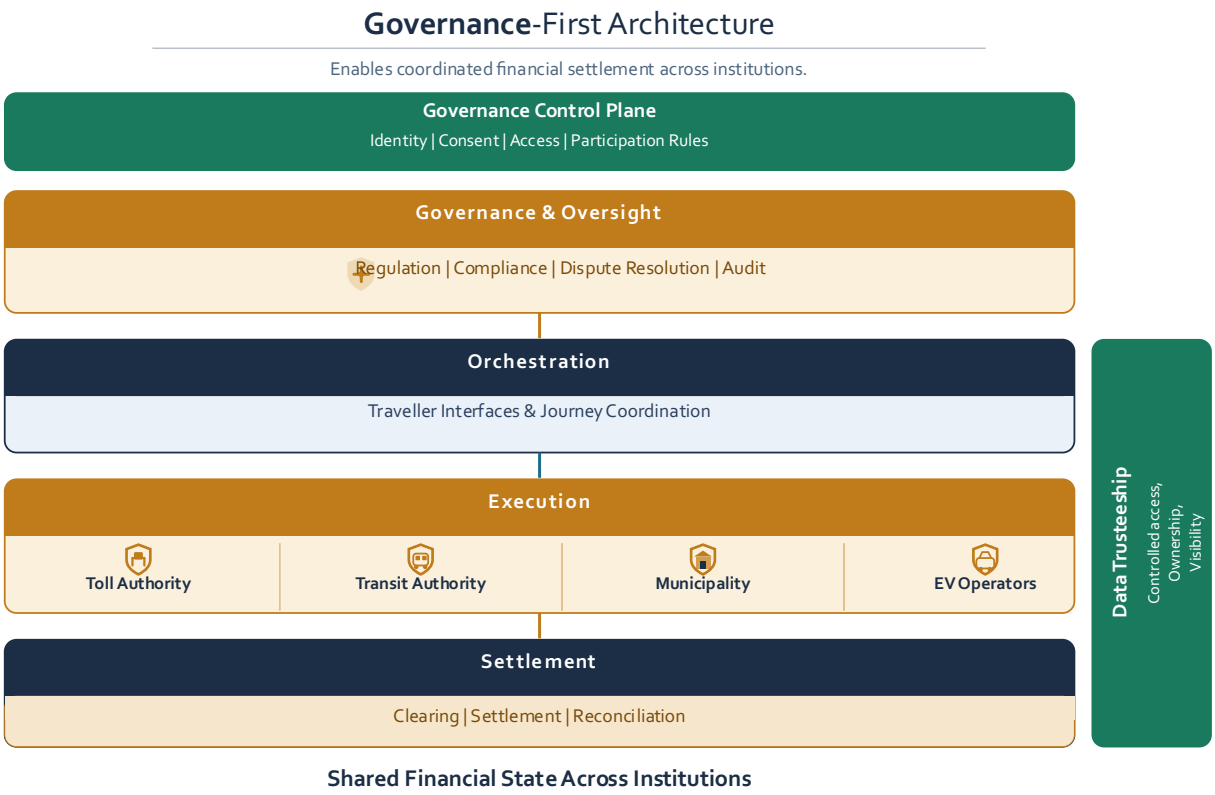

Diagram: Governance-First Architecture

Caption:

The Governance-First architecture separates orchestration, infrastructure execution, and financial settlement, supported by a governance control plane and data trusteeship that operate across these layers.

While the layered architecture defines functional separation, institutional coordination depends on maintaining clear boundaries between orchestration, execution, and settlement. Institutional separation across orchestration, execution, and settlement is illustrated below.

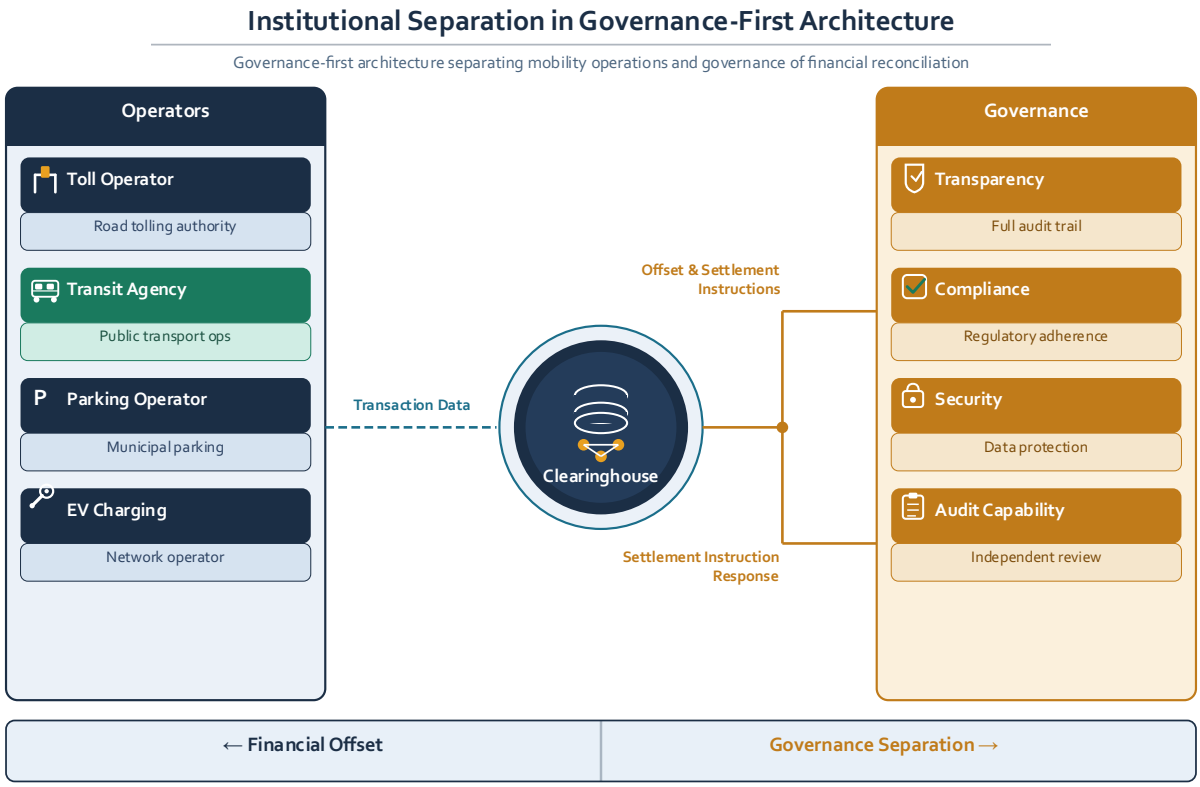

Diagram: Institutional Separation in Governance-First Architecture

Caption:
Institutional coordination is achieved by preserving authority control over execution, enabling orchestration without ownership, and establishing settlement as neutral shared infrastructure.

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8. Centralized Platforms vs Governance-First Architecture

Mobility systems can be structured using different architectural approaches, depending on scale, governance structure, and institutional alignment. Two common models are centralized platform architectures and governance-first, federated architectures.

Centralized platforms integrate user experience, infrastructure logic, and financial flows within a single system. This approach can simplify implementation in environments governed by a single authority or within limited, controlled deployments.

Such models are effective in single-city systems, pilot programs, or ecosystems with tightly aligned governance. In these contexts, centralized coordination reduces integration complexity and accelerates rollout.

However, as systems expand across multiple independent authorities, centralized models encounter structural limitations. Integrating pricing policies, operational rules, and financial flows within a single platform introduces dependencies that are difficult to sustain.

When centralized systems begin to influence pricing, revenue allocation, or policy enforcement, they absorb decision rights that authorities must retain. This creates conflicts over control, accountability, and regulatory responsibility, limiting scalability across distributed governance environments.

The limitations of centralized mobility platforms extend beyond scalability and governance alignment. When evaluated against legal, financial, and audit requirements, integrated models introduce structural risks that cannot be resolved through technical design alone.

Centralized systems often combine multiple functions, including pricing logic, transaction processing, financial reconciliation, and user interaction within a single platform. This consolidation creates ambiguity in authority, making it difficult to determine the legal basis for charges, the ownership of revenue, and the allocation of accountability.

From an audit perspective, such systems weaken the separation between measurement, billing, collection, and reconciliation, increasing the risk of opaque calculations and inconsistent financial records. From a regulatory perspective, they may violate principles of revenue segregation, procurement neutrality, and institutional independence.

These constraints explain why centralized models, while effective in limited environments, struggle to scale across multi-authority ecosystems. The challenge is not one of integration capability, but of governance compatibility. Systems that do not align with legal and financial structures encounter resistance, fragmentation, and long-term instability.

Governance-First Architecture addresses these limitations by separating coordination, execution, and financial settlement into interoperable layers. This enables systems to scale across authorities without consolidating control. The differences between these approaches can be summarized as follows:

Feature	**Centralized Platform**	**Governance-First Architecture**
Control	Platform-centric	Authority-sovereign
Scalability	Fast launch, limited multi-authority scale	Moderate launch, ecosystem-scale
Revenue Risk	Concentrated within the platform	Distributed across authorities
Interoperability	Proprietary integration	Federated coordination
Regulatory alignment	Challenging across jurisdictions	Preserved by design
Implementation complexity	Low initially, increasing with the number of authorities	Moderate initially, stable at scale

Feature	Centralized Platform	Governance-First Architecture
Time to value	Fast in single-authority contexts	Longer onboarding, durable at scale
Customer ownership	Concentrated in platform	Distributed across authorities

The choice between these approaches depends on the institutional context. Centralized architectures are effective in controlled environments, while governance-first models provide a more sustainable foundation for multi-authority ecosystems.

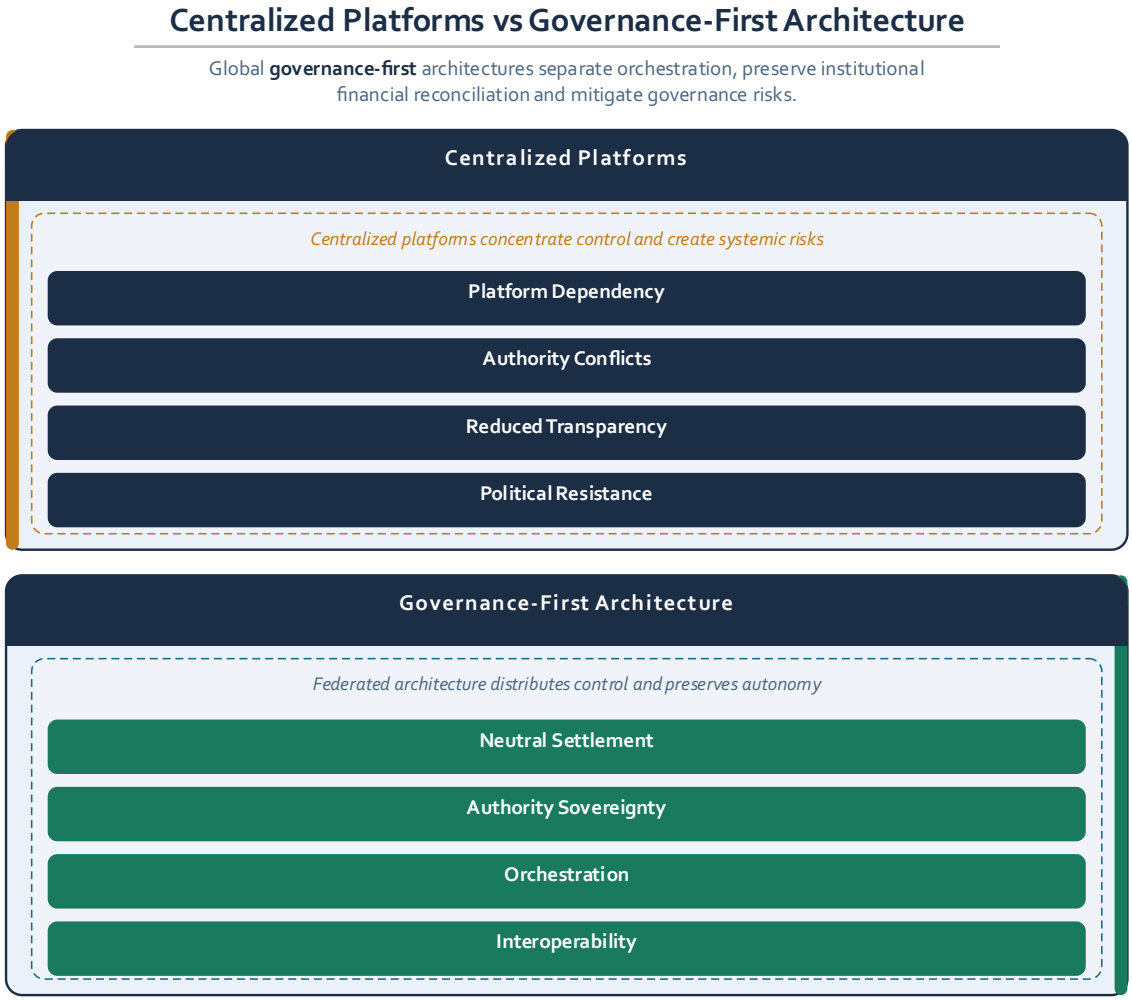

Diagram: Centralized vs Governance-First Architecture

Caption:
Centralized mobility platforms concentrate institutional authority, while Governance-First architecture distributes responsibilities across independent participants.

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9. Platform Implementation Stack

The Governance-First Architecture can be implemented through a layered design that aligns technical components with institutional responsibilities. Rather than consolidating functionality into a single platform, the stack separates concerns across distinct layers, each corresponding to a specific role. This ensures coordination does not alter authority control, financial accountability, or governance boundaries.

Traveler Interface Layer
This layer includes applications and interfaces through which users interact with mobility services. It supports journey discovery, access, and payment initiation across systems, providing a unified experience without embedding infrastructure-specific logic or policy decisions.

Orchestration Layer
The orchestration layer coordinates interactions across services, managing journey sequencing, request routing, and interaction state management across services.

Authority Systems Layer
Authority systems operate independently while participating in coordinated journeys, interfacing with the orchestration and financial layers through defined integration points.

Financial Interoperability Layer
This layer supports the financial lifecycle across systems, including transaction recording, clearing, settlement, reconciliation, and dispute handling. It ensures financial outcomes are consistently derived from operational events and remain visible, traceable, and auditable across participants.

Governance and Oversight Layer
This layer provides the institutional framework for coordination across participants, including:

- Participation rules and onboarding requirements
- Commercial agreements and settlement terms
- Dispute escalation and resolution frameworks
- Compliance monitoring and regulatory reporting
- Audit mechanisms and oversight controls

The governance layer operates across all other layers, ensuring interactions adhere to agreed rules without centralizing operational control. The implementation stack aligned with governance-first principles is illustrated below.

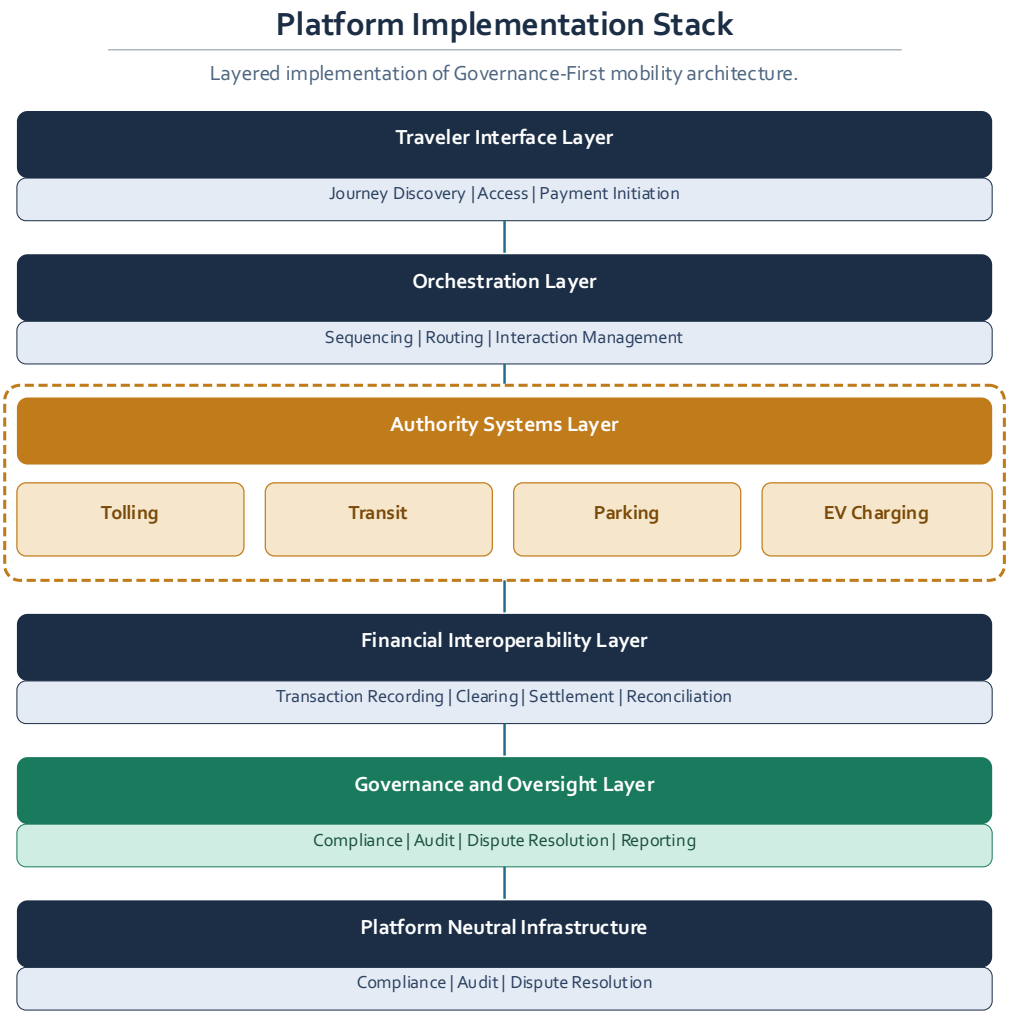

Diagram: Platform Implementation Stack

Caption:
Technology platforms implement Governance-First architecture while infrastructure authorities retain operational control of infrastructure systems.

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10. Case Studies: The Proof of Federated Success

The principles of governance-first architecture are reflected in several real-world mobility systems. While these implementations differ in scope, geography, and institutional structure, they demonstrate how coordination across institutional participants can be achieved without consolidating authority.

These systems are not complete implementations of multimodal mobility architecture. Rather, they illustrate specific patterns of interoperability, financial coordination, and institutional separation that are relevant to broader mobility ecosystems. Three examples provide useful reference points:

- **FASTag (India)** — a national tolling system demonstrating issuer-led interoperability and shared financial infrastructure across operators
- **European Electronic Toll Service (EETS)** — a cross-border framework enabling interoperability across sovereign jurisdictions while preserving national authority
- **Texas Tolling Interoperability** — a regional model where multiple authorities coordinate through shared account recognition and settlement arrangements

Each operates within a defined domain—primarily tolling—but reveals a consistent architectural pattern:

- Infrastructure authorities retain control over pricing, operations, and policy enforcement
- Financial coordination is achieved through shared mechanisms rather than centralized ownership
- Interoperability is enabled through structured interfaces between participants, not system consolidation

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11. Case Study 1: FASTag: National Interoperable Tolling (India)

26 certified issuer banks | 12 certified acquirer banks | 1,150+ toll plazas | ~10.6 million daily transactions | 98% of toll collections

FASTag is an electronic toll collection system that enables interoperable payments across toll plazas on national highways in India. It provides a practical example of how coordination across multiple participants can be achieved within a single mobility domain. The system operates through a federated structure with distinct institutional roles:

- **Issuer Banks** — provide FASTag-linked accounts and manage customer relationships
- **Acquirer Banks** — connect toll plazas to the network and facilitate transaction processing
- **NPCI NETC Infrastructure** — operates switching and clearing for transaction routing and reconciliation
- **Toll Operators** — manage infrastructure, determine pricing, and validate vehicle passage

No single entity controls the end-to-end system. Each participant performs a defined role aligned with its institutional responsibilities. When a vehicle passes through a toll plaza, the transaction is validated by the toll operator and routed through the network. Financial positions are determined through clearing and settled between banks based on recorded events. This reflects a separation between execution and financial coordination:

- **Execution** — remains with toll operators, controlling pricing, validation, and policy enforcement

- **Financial coordination** is enabled through shared infrastructure, ensuring consistent routing, reconciliation, and settlement

FASTag demonstrates that interoperability can scale nationally without consolidating authority over infrastructure operations or customer relationships. Coordination is achieved through shared financial and technical infrastructure, while decision rights remain distributed.

However, FASTag is limited to tolling and does not extend to multimodal mobility services such as transit, parking, or integrated journey orchestration. Its significance lies in the governance pattern it illustrates that interoperability can be achieved by separating execution, financial coordination, and participant roles, rather than consolidating them within a single system. The institutional structure of FASTag is illustrated below.

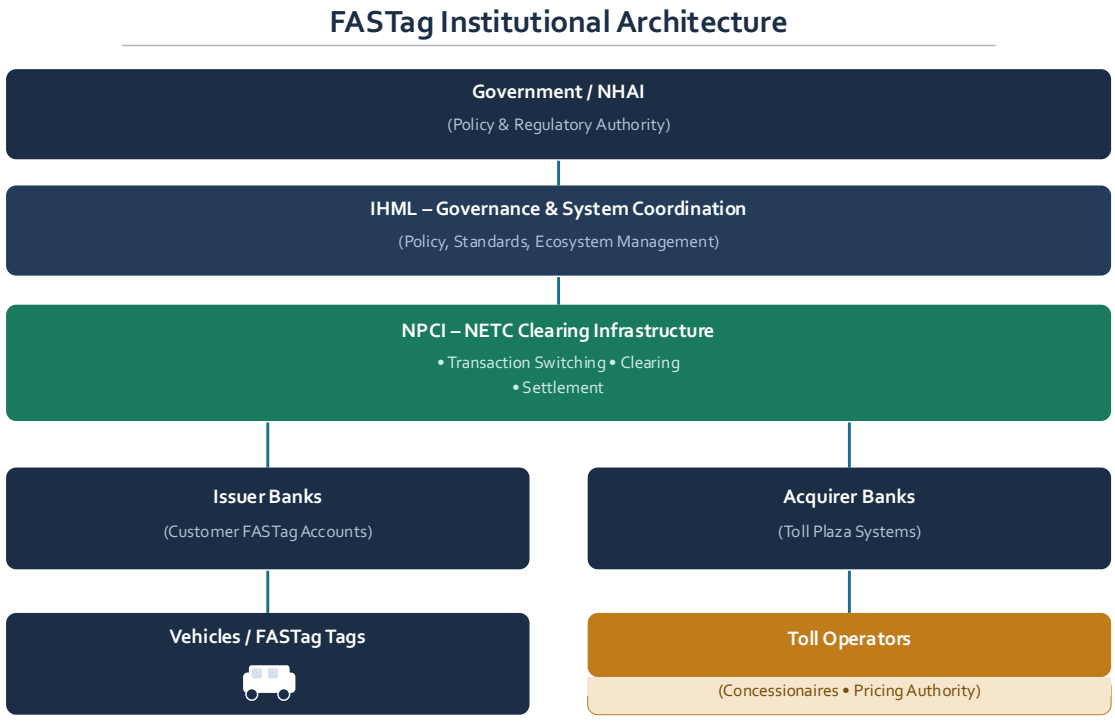

Exhibit A — FASTag Architecture

Caption:
FASTag separates infrastructure ownership, financial settlement, and governance across multiple institutions.

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12. Case Study 2: EETS — Cross-Border Sovereignty (Europe)

100+ independent national tolling systems across the EU | 140+ separate companies and government agencies | 2 active EETS providers enabling cross-border access

The European Electronic Toll Service (EETS) enables vehicles to access toll roads across multiple European countries through a single contractual relationship with an authorized service provider. It illustrates how interoperability can be achieved across sovereign jurisdictions with independent regulatory frameworks. The model operates through defined participants:

- **Member States** — retain authority over tolling policies, pricing, and regulatory frameworks
- **Toll Chargers** — operate infrastructure and validate road usage within national systems
- **EETS Providers** — enable user access across toll domains through a single interface and contractual relationship

Each country maintains full control over its tolling systems, including pricing, enforcement, and operational rules. EETS does not standardize these policies; it provides a framework that enables interoperability across them.

When vehicles use toll infrastructure across countries, transactions are validated locally by toll chargers. EETS providers coordinate access and facilitate financial and operational integration through defined interfaces and agreements. This reflects a separation between coordination and authority:

- **Coordination** — performed by EETS providers, enabling cross-border access and interaction
- **Execution** — remains with toll chargers and national systems, enforcing pricing, validation, and policy rules

EETS demonstrates that interoperability can be achieved across sovereign systems without harmonizing policies or centralizing control. Coordination operates through structured interfaces and agreements, while decision-making remains distributed.

However, the model is domain-specific and involves significant regulatory and operational complexity. It does not extend to multimodal mobility services and requires alignment across legal and institutional frameworks. Cross-border interoperability is achieved when coordination mechanisms operate alongside, rather than in place of, sovereign authority. The cross-border interoperability model of EETS is illustrated below.

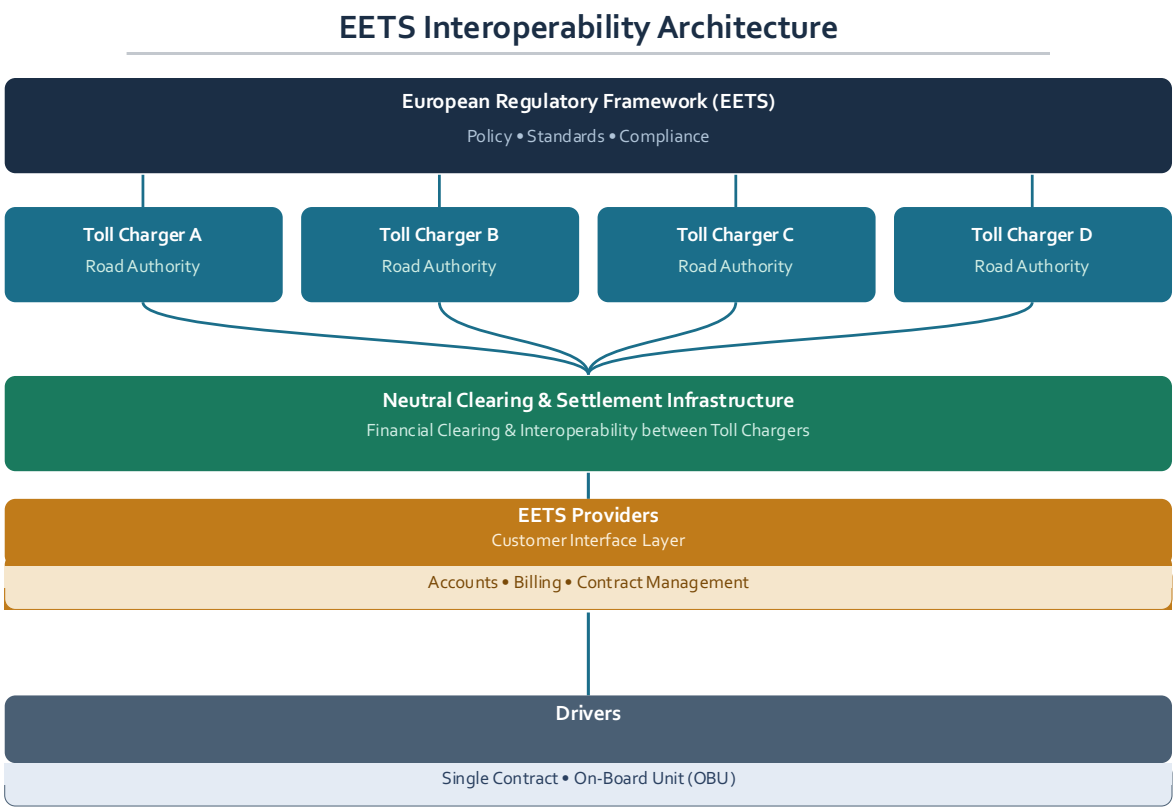

Exhibit B — EETS Architecture

Caption:
EETS enables cross-border interoperability while preserving authority with infrastructure operators.

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13. Case Study 3: The Texas Model — Regional Interoperability Hubs

3 primary independent toll authorities: TxDOT, NTTA, HCTRA | Single toll tag recognized across Texas, Oklahoma, Kansas, Colorado, and Florida

In Texas, multiple toll authorities operate independent tolling systems while enabling interoperability through coordinated account recognition and settlement arrangements. This model illustrates regional federation across infrastructure operators without centralized system control.

The ecosystem consists of multiple toll authorities, each responsible for its own infrastructure, pricing policies, and operations. Interoperability is enabled through agreements that allow users to access multiple toll roads using a single transponder or account. The model operates through:

- **Toll Authorities** — retain control over infrastructure, pricing, validation, and policy enforcement

- **Customer Accounts** — maintained by individual authorities but recognized across systems
- **Interoperability and Settlement Mechanisms** — enable transaction recognition, clearing, and financial settlement between authorities

When users travel across toll roads operated by different authorities, transactions are validated locally by each operator. Charges are attributed to the customer's home account, and settlement occurs between authorities based on recorded usage. This reflects a separation between execution and financial coordination:

- **Execution** — remains with each authority, governing pricing, validation, and policy rules
- **Financial coordination** — achieved through shared account recognition and structured settlement processes

Unlike orchestration layers that coordinate multi-service journeys, this model focuses on interoperability through account recognition and financial settlement within a specific domain.

It demonstrates that coordination can be achieved through federated agreements and shared settlement mechanisms, without requiring centralized control over infrastructure systems.

However, the Texas model is regionally scoped and primarily limited to tolling. It does not extend to multimodal mobility services and relies on bilateral and multilateral agreements between authorities.

Its significance lies in the governance pattern it illustrates that interoperability can scale across independent authorities through shared financial coordination and mutual recognition, while operational control remains distributed. The federated interoperability model across regional authorities is illustrated below.

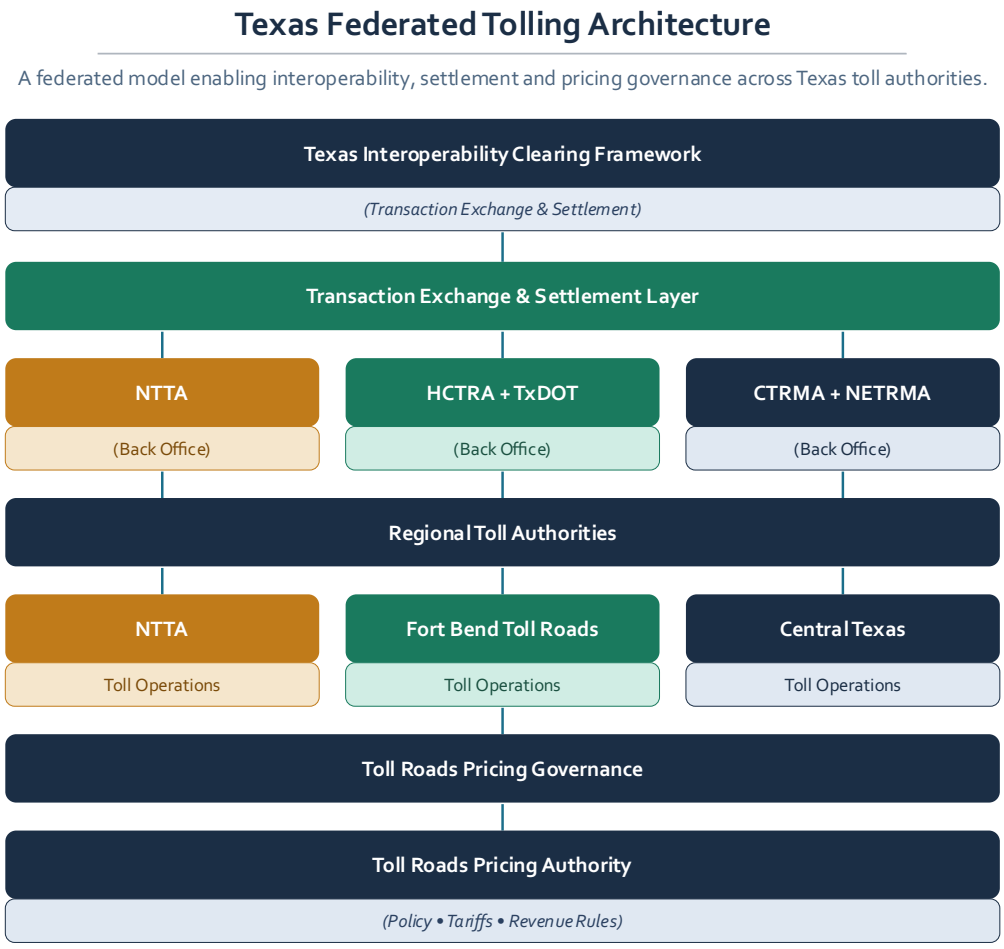

Exhibit C — Texas Federated Tolling Architecture

Caption:
Texas toll interoperability operates through federated authorities rather than a centralized toll system.

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14. Lessons from Global Implementations

The case studies illustrate how interoperability can be achieved across independently governed mobility systems without consolidating authority. Despite differences in geography, regulation, and implementation, a consistent set of principles emerges. These define the structural requirements for scalable, multi-authority ecosystems:

Authority Retains Control Over Policy and Pricing
All three implementations — FASTag, EETS, and Texas — demonstrate that interoperability does not require authorities to surrender pricing or policy control. This validates the Execution layer boundary defined in Section 7. These responsibilities remain with authorities rather than a central platform.

Customer Relationships Remain Distributed
User accounts, payment instruments, and interfaces are managed by multiple entities, including banks, service providers, and authorities. No single participant owns the full customer lifecycle.

Interoperability Requires Transparent Financial Reconciliation
Effective coordination depends on consistent reconciliation across systems. Financial outcomes must be derived from shared, verifiable representations of operational events.

Settlement Operates as Neutral Shared Infrastructure
In all three implementations, financial coordination was achieved through shared settlement mechanisms — NPCI NETC in FASTag, bilateral agreements in EETS, and interoperability arrangements in Texas — without any single entity owning or controlling the settlement function. This confirms that settlement can operate as neutral infrastructure, ensuring consistency and auditability without influencing pricing, policy, or execution.

Governance Separation Enables Ecosystem Scale
FASTag scaled to national coverage across hundreds of toll operators; EETS extended interoperability across sovereign jurisdictions; Texas achieved regional coordination across independent authorities — all without centralizing institutional control. In each case, the ability to scale depended on keeping coordination, execution, and settlement in separate hands, as defined in Section 7. Systems that attempted consolidation encountered resistance and fragmentation instead.

These principles reinforce that scalable mobility systems depend on structured coordination across institutional participants, rather than consolidation.

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15. Future Mobility Infrastructure

Mobility systems are expanding beyond traditional tolling and transit into broader use cases requiring coordination across multiple authorities and domains. These include congestion pricing, road usage charging, EV charging networks, multimodal journey passes, and urban curb management. Each introduces new interactions between infrastructure systems, financial flows, and policy frameworks. For example:

- **Congestion pricing** — Dynamic pricing logic remains with the authority (execution); orchestration presents real-time pricing to the traveler; settlement reconciles variable-rate charges across a journey.
- **Road usage charging (RUC)** — Distance-based billing requires jurisdiction-specific pricing rules at the execution layer, with settlement aggregating cross-border mileage into a consistent financial record.
- **EV charging networks** — Utilities and charging operators retain pricing authority; settlement coordinates billing between the traveler's home account and each operator.

- **Multimodal journey passes** — Pass issuers operate at the orchestration layer, presenting a unified access credential; each transit, tolling, and parking authority retains fare and pricing control at the execution layer; settlement distributes revenue across authorities based on recorded usage events.
- **Urban curb management** — Municipal authorities retain enforcement and pricing rules at the execution layer; orchestration coordinates real-time availability and booking across providers; settlement reconciles charges and penalties across curb operators and payment systems.

As these systems evolve, the complexity of coordinating operational events and financial outcomes increases. Interoperability extends beyond interface connectivity to aligning pricing logic, revenue attribution, policy enforcement, and financial reconciliation across institutional participants.

In this context, centralized approaches that combine coordination, execution, and financial control become increasingly difficult to sustain. Differences in regulatory frameworks, operational mandates, and financial accountability introduce constraints that integration alone cannot resolve.

Governance-First Architecture provides a structural foundation for addressing this complexity. By separating orchestration, execution, and settlement, new services can be integrated without altering institutional roles. Future mobility infrastructure will depend on architectures that support:

- Coordination across distributed authority systems without centralizing decision-making
- Event-linked financial visibility to ensure consistent outcomes across participants
- Clear allocation of responsibility for pricing, policy enforcement, and customer interaction
- Scalable settlement mechanisms across services, jurisdictions, and operators

As mobility ecosystems expand, aligning operational events with financial accountability across institutions will become a defining requirement. Future systems will be defined not by how many services are integrated, but by how effectively they coordinate governance, execution, and financial outcomes.

Governance-First Architecture introduces its own implementation challenges. Federated models require multilateral agreement on settlement standards, onboarding protocols, and dispute resolution frameworks, coordination overhead that centralized systems avoid. The value of this approach increases with the number of authorities and jurisdictions involved, making it more appropriate for large-scale, multi-operator ecosystems than for early-stage, single-city deployments.

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16. Conclusion: The Mandate for a Federated Future

Mobility systems are evolving toward integrated, multi-service journeys that span independently governed infrastructure. While digital platforms can coordinate user experiences, the underlying systems remain distributed across authorities with distinct responsibilities and mandates.

As this complexity increases, the limitations of centralized approaches become more evident. Integrating services across multiple authorities requires coordination mechanisms that do not alter institutional roles or concentrate control within a single system.

The Governance-First Architecture presented in this paper aligns system design with institutional realities. As mobility ecosystems expand across services and jurisdictions, the ability to coordinate operational events with financial accountability will become increasingly critical. Systems that embed this separation will scale, while those that attempt to consolidate control will encounter structural limitations.

Interoperability in mobility systems is therefore achieved not through system consolidation, but through structured coordination across institutional participants. In this context, neutral settlement infrastructure is not a back-office function—it is part of the governing architecture.

Governance-first architectures are not an alternative design choice; they are a structural requirement for any mobility system operating across multiple authorities. The question facing transport authorities, regulators, and platform architects is therefore not whether to adopt this separation, but how quickly the absence of it will limit the systems they are building today. Those who treat governance as a precondition for interoperability design will build systems that scale. Those who treat it as an afterthought will rebuild them.

17. Glossary of Key Terms

Orchestration
Coordination of user journeys across multiple services without controlling pricing, policy, or execution of those services.

Execution
Operation of infrastructure systems by authorities, including pricing, validation, and policy enforcement within their domain.

Settlement
The process of deriving, reconciling, and executing financial outcomes between participants based on operational events and agreed-upon rules.

Clearing
Determination of financial obligations between parties before settlement.

Federation
A governance model in which independent systems coordinate through shared standards, identity, and rules, while retaining control over their respective domains.

Authority
An institutional entity responsible for infrastructure operation, pricing, policy enforcement, and revenue ownership within a defined domain.

Issuer
An entity that provides user-facing accounts or payment instruments and manages the customer relationship.

Acquirer

An entity that connects infrastructure systems to financial networks and facilitates transaction processing.

Data Trusteeship

The principle that data generated within public infrastructure systems is governed by authorities, with controlled access based on role, consent, and purpose.