Comments for reviewers

Response to Review 3:
We thank you for the constructive and valuable feedback. We have revised the abstract to better reflect the practical implications of our governance framework and added concrete examples to clarify the relevance of governance for real-world PI challenges.

We fully acknowledge the importance of points 3 and 4. However, due to the strict 10-page limit of the IPIC conference and the fact that our paper already reaches this maximum, we are unfortunately unable to further elaborate on the limitations of the DI-PI analogy or include a discussion on implementation barriers at this stage. That said, we consider both points highly relevant and will integrate them into an extended version of the paper for submission to a journal.

Response to Review 4:
Thank you very much for your thoughtful and encouraging feedback. We appreciate your recognition of the paper's conceptual contribution.

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Governing the Physical Internet: Insights from Internet Governance and Future Research Directions

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Abstract: *Despite growing technical maturity, implementation of the Physical Internet remains limited. A key reason is that while operational mechanisms such as routing protocols and modular containers are well-researched, governance remains insufficiently addressed. This study explores how governance structures for the Physical Internet can be conceptualized, drawing on lessons from Physical Internet, horizontal logistics collaboration, and the evolution of governance in the Digital Internet. We conduct a systematic literature review and identify a gap in the consideration of collective-choice and constitutional governance, including rulemaking, stakeholder participation, and conflict resolution. To address this, we propose a conceptual framework grounded in Ostrom's Institutional Analysis and Development framework and inspired by the decentralized governance trajectory of the Digital Internet. The governance framework distinguishes between operational, collective-choice, and constitutional rule levels, offering a structure for coordinating logistics actors without centralized control supporting aligned operations for service providers and adaptive rulemaking for policymakers.*

Keywords: *Governance; Horizontal Logistics Collaboration; Physical Internet; Institutional Analysis and Development*

Physical Internet (PI) Roadmap Fitness*: Select the most relevant area(s) for your paper according to the PI roadmaps adopted in Europe and Japan:* ☐ *PI Nodes (Customer Interfaces, Logistic Hubs, Deployment Centers, Factories),* ☐ *Transportation Equipment,* ☐ *PI Networks,* ☐ *System of Logistics Networks,* ☐ *Vertical Supply Consolidation,* ☐ *Horizontal Supply Chain Alignment,* ☐ *Logistics/Commercial Data Platform,* ☐ *Access and Adoption,* ☒ *Governance.*

Targeted Delivery Mode-s*:* ☒ *Paper,* ☐ *Poster,* ☐ *Flash Video,* ☒ *In-Person presentation*

1 Introduction

The Physical Internet (PI) presents a transformative vision for the future of logistics, promising to enhance efficiency, interoperability, and sustainability by enabling logistics systems to function as an open, interconnected network of networks (Montreuil, 2011). Drawing inspiration from the Digital Internet (DI), the PI aims to move goods with modularity, flexibility, and scalability similar to how data packets travers digital networks. Rather than relying on a single provider for end-to-end delivery, the PI envisions shipments being dynamically routed, consolidated, and processed by a distributed network of independent logistics service providers (LSPs).

While technical innovations such as modular containers and routing protocols have received considerable academic attention (Achamrah et al., 2024; Briand et al., 2022; Sarraj, Ballot, Pan,

Hakimi, et al., 2014), the governance dimension of the PI remains significantly underexplored. Yet, governance is crucial if the PI is to enable collaboration among autonomous logistics actors, integrate across regulatory regimes, and operate in competitive markets where data sharing and coordination amongst others pose major challenges, for example, resolving liability in multi-actor shipment delays, or managing data ownership across international hubs.

Existing work on Horizontal Logistics Collaboration (HLC) and the PI often assumes the need for a neutral governing entity to enforce collaboration and manage conflicts (Cruijssen, 2012; Frisk et al., 2010). However, empirical studies such as Sternberg et al. (2022) challenge this assumption, showing that external facilitation can undermine trust and deter participation. Drawing a parallel to the DI, which was initially governed by government and academic institutions under the DARPA umbrella, it gradually evolved into a decentralized system shaped by voluntary stakeholder-based standards-setting bodies such as the Internet Engineering Task Force (IETF). This trajectory suggests that PI governance may also evolve from initial coordination toward distributed, adaptive forms.

Understanding how such an evolution might unfold in the PI requires moving beyond individual coordination tools to consider how they are embedded within a broader governance architecture. While previous studies have analyzed how routing, auction mechanisms, and optimization tools can enhance operational efficiency, they often overlook the broader governance structures needed to support such mechanisms in a decentralized system. The analogy with the DI underscores the importance of layered, flexible governance rather than fixed top-down structures. At the same time, key differences between digital and physical networks, such as the high cost of shipment loss or redirection, the high variability in costs and schedules, and capacity constraints, require governance models that are specifically tailored to the logistical, environmental, and institutional complexities of physical distribution systems.

To address these gaps, we first analyze the governance mechanisms and approaches in existing PI and HLC literature. Building on this foundation, we outline a conceptual governance framework for the PI, informed by lessons from HLC, the evolution of the DI, and the Institutional Analysis and Development (IAD) framework. The remainder of the paper is structured as follows: Section 2 introduces the theoretical background. Section 3 reviews governance-related literature in PI and HLC and maps findings using the IAD framework. Section 4 outlines a conceptual framework and discusses implications for future research.

2 Theoretical and Conceptual Background

2.1 Development of the Digital Internet

The PI draws on the architecture and principles of the DI, making it essential to briefly revisit how the DI evolved and where the analogy meets its limits. The origins of the DI date back to the 1960s, when DARPA initiated research into decentralized communication systems, leading to the creation of ARPANET, the first packet-switching network that connected selected research institutions (Kahn et al., 1997; Leiner et al., 2009). The successful transmission of data in 1969 laid the foundation for what would become the global Internet. A major development followed in 1974, when Cerf and Kahn introduced the Transmission Control Protocol (TCP), which was later split into TCP and IP to support scalable communication across heterogeneous networks (Cerf & Kahn, 1974). The formal adoption of the TCP/IP protocol in 1983 is widely considered the start of the modern Internet (Cerf, 1993; Leiner et al., 2009).

Initially, governance was managed by academic and governmental institutions such as DARPA and the National Science Foundation. Over time, this shifted toward a more decentralized model, with the Internet Engineering Task Force (IETF), established in 1986, becoming central

to defining technical standards and ensuring interoperability (Kurose & Ross, 2017). This shift from centralized control to stakeholder-driven governance provides relevant insights for the PI, where coordination will similarly involve distributed actors.

Nevertheless, important differences must be acknowledged. In the DI, data packets are transmitted within seconds and can be retransmitted at negligible cost if lost. In contrast, physical shipments may take days or weeks to arrive, cannot be duplicated easily, and involve significant costs and constraints in case of rerouting, delay, or disruption (Dong & Franklin, 2021). These differences call for governance mechanisms that are adapted specifically to the realities of physical logistics networks.

2.2 Mapping the PI Landscape: Themes and Gaps

The conceptual development of the PI has been strongly shaped by the Alliance for Logistics Innovation through Collaboration in Europe (ALICE). They have led the coordination of industry, policy, and research, positioning the PI as a pillar of sustainable freight transport and introduced a PI roadmap in 2020 (ALICE, 2020). Projects like MODULUSHCA, SENSE, ICONET, and NEXTRUST have advanced this vision by piloting modular containers, data-sharing platforms, and digital infrastructures (ICONET, 2018; Nextrust, 2020; Wu et al., 2025). The ALICE Roadmap outlines governance as a critical enabler for the PI, focusing on the development of rules, trust mechanisms, and coordination structures across logistics nodes, networks, and networks of networks. Building on Montreuil's foundational vision, academic research has developed in several directions. Münch et al. (2023) identify eight major communities, which we group into three themes: 1. *strategic foundations and actor roles*, 2. *technological enablers and infrastructure,* and 3. *application contexts and operational control*.[1]

Strategic foundations and actor roles: Our first theme includes three of Münch's communities. The first community addresses the benefits of the PI over conventional logistics and the challenges of its operationalization. Simulation studies highlight gains in cost, lead time, and distance (Ambra et al., 2021; Zheng et al., 2019), while others explore managerial incentives (Plasch et al., 2021) and the modularity of container as a success factor for operationalization (H. S. Sternberg & Denizel, 2021). The second community, dealing with research on actor roles, examines open hub structures, pricing, and behavioral aspects (Pan et al., 2015; Qiao et al., 2019), while the third community focusing on foundational work, defines PI principles and Internet analogies (Montreuil et al., 2013; Sarraj, Ballot, Pan, Hakimi, et al., 2014).

Technological enablers and infrastructure: This theme also includes three of Münch's communities. The fourth community explores product-service systems and emerging business models, including the use of PI principles in smart manufacturing with IoT and big data (Pan et al., 2019; Y. Zhang et al., 2016). The sixth focuses on ICT foundations such as IoT-based frameworks and smart containers for real-time data exchange (Sallez et al., 2016; Tran-Dang & Kim, 2018), for enabling PI operations. The seventh community centers on modular containers as enablers of interoperability, covering design and volume optimization models (Landschützer et al., 2015; Lin et al., 2014; Meller et al., 2012).

Application contexts and operational control: Our third theme includes the final two communities identified by Münch. The fifth community connects the PI to city logistics concepts, introducing hyperconnected city logistics (Crainic & Montreuil, 2016), collaborative planning and resource sharing (Crainic et al., 2020), and urban system architectures (Kim et al.,

[1] Note that we maintain Münch's numbering scheme for the communities identified to ensure easy cross-referencing.

2021). The eighth community focuses on PI hub control, including disruption-resilient scheduling (Chargui et al., 2020), intermodal control architectures (Vo et al., 2018), and port integration requirements (Fahim et al., 2021).

A recently emerging area of research is the Cyber-Physical Internet, which adds a cyber layer to the PI for real-time sensing, analytics, and autonomous coordination (Wu et al., 2025). Closer to the architecture of the digital Internet, the CPI adopts layered protocols and decentralized control. Recent studies highlight simulation-based planning (Wu et al., 2025), digital twin coordination frameworks (Wu et al., 2024), routing protocols (Qu et al., 2024), and pricing mechanisms (He et al., 2024), showcasing Cyber-Physical Internet's potential for scalable and intelligent logistics networks.

While the research discussed demonstrates the PI's emphasis on openness, interoperability, and collaboration, there is limited research into how such systems are governed, how rules are set, enforced, and adapted in open, decentralized environments. Wu et al. (2025) and Münch et al. (2023) both note that current contributions pay little attention to institutional mechanisms, decision rights, compliance frameworks, or platform-level coordination. This persistent omission points to the need for a dedicated research stream on PI governance.

2.3 Structuring Governance: Theories and Frameworks

Governance plays a central role in inter-organizational collaboration by structuring interactions, enabling coordination, and mitigating opportunism in the absence of hierarchical control. It comprises the structures, rules, and processes through which partners jointly manage responsibilities and resolve conflicts across organizational boundaries (Bryson et al., 2006; Emerson et al., 2012).

A common distinction in the literature is between contractual and relational governance (Poppo & Zenger, 2002; Prakash et al., 2021). In HLC, these are sometimes referred to as formal and informal governance (Lotfi & Larmour, 2021; Sheffi et al., 2019). For consistency, we use the terms contractual and relational governance. Contractual governance relies on formal agreements to specify roles, rights, and enforcement mechanisms, grounded in transaction cost economics (Poppo & Zenger, 2002; Williamson, 1979). Relational governance emphasizes trust, shared norms, and mutual commitment, drawing on relational and social exchange theories (Cao & Lumineau, 2015; Dyer & Singh, 1998; Raue & Wieland, 2015). The relevance of each logic varies by collaboration context, though they often complement one another.

Originally developed within the field of institutional economics and political science, Ostrom's IAD framework offers a valuable theoretical foundation for analyzing governance systems in decentralized and multi-actor contexts. It conceptualizes institutions as formal and informal rules, norms, and shared strategies that structure decision-making and interaction among multiple actors (Ostrom, 2009). Although originally developed to examine how communities self-organize around common-pool resources, the framework is well suited for inter-organizational collaboration, as both settings involve distributed authority, collective rulemaking, and the coordination of shared activities.

A foundational element of the IAD framework is its distinction between three institutional rule levels: operational, collective-choice, and constitutional. Operational rules govern day-to-day activities, e.g., routing protocols or scheduling tools in PI networks. Collective-choice rules define how operational rules are set and revised, through, for instance, stakeholder platforms or collaborative planning bodies. Constitutional rules determine who sets collective-choice arrangements, addressing foundational questions like actor eligibility, alliance formation, or

standard-setting authority. Examples include membership rules in logistics alliances or federated platform charters.

By distinguishing these three levels, the IAD framework provides a structured lens for analyzing governance in collaborative logistics. It moves beyond technical coordination and draws attention to questions of authority, legitimacy, and participation. It also offers a conceptual basis for assessing gaps in existing research and designing governance structures tailored to the complexity of systems such as the PI.

3 Governance Research Landscape in PI and HLC

3.1 Uncovering Governance Mechanisms in PI and HLC: A Systematic Literature Review

To ensure methodological rigor and transparency, we followed the guidelines proposed by vom Brocke et al. (2009), who emphasize the importance of systematically documenting the literature search process. A structured and replicable search strategy not only enables the identification of relevant studies but also strengthens the credibility and cumulative value of a review. The summary of our literature search and selection process is presented in Figure 1.

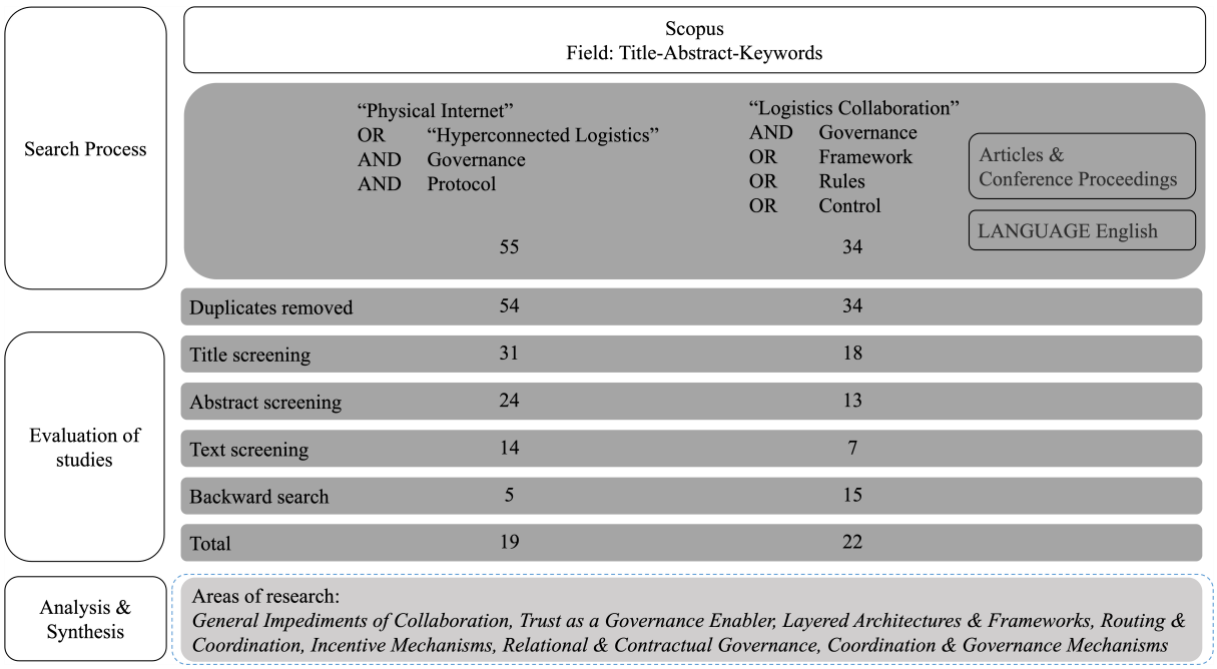

Figure 1: Literature Review Search Process

While governance is rarely addressed explicitly in the PI literature, many contributions propose coordination mechanisms, such as routing protocols, auction mechanisms, and layered architectures, that serve governance functions implicitly. These mechanisms structure behavior in distributed networks and address trust, interoperability, and authority distribution. In parallel, HLC research provides valuable insights into incentive alignment, facilitation, and trust dynamics. Together, these bodies of work form a fragmented but increasingly relevant basis for governance design in the PI.

General Impediments of Collaboration: To understand the foundations of governance design in logistics collaboration, it is essential to first consider the barriers that inhibit cooperation. Cruijssen et al. (2007) identify benefit allocation, cross-boundary coordination, and strategic autonomy concerns as central obstacles to HLC. These concerns are echoed in Fawcett et al.

(2015), who emphasize the role of structural misalignment and low trust as root causes of underperformance. Larsson et al. (2024) add a digital perspective, pointing to platform neutrality, legal safeguards, and data governance as prerequisites for collaboration These findings underscore that effective collaboration requires not just technical solutions, but governance mechanisms that address actor incentives, trust, and coordination roles.

Trust as a Governance Enabler: Building on these challenges, a growing body of work investigates the role of trust in enabling logistics collaboration. Prakash et al. (2021) show its mitigating effect on conflict, especially under uncertainty. Daudi et al. (2017b) and Sitadewi et al. (2020) demonstrate how trust evolves over time and is shaped by transparency, data accuracy, and benefit-sharing mechanisms. While not a governance tool in itself, trust supports both contractual and relational control systems.

Layered Architectures and Frameworks: A key stream of research explores how collaboration in the PI can be structured through layered architectures and formal frameworks. Montreuil et al. (2013) introduce eight core principles like modularity and interconnectivity, while the OLI and NOLI models (Colin et al., 2016; Montreuil et al., 2012) define layered architectures for logistics networks based on the seven layer OSI model. Later work aligns more closely with the TCP/IP model, emphasizing protocol layering as a basis for decentralized operations (Dong & Franklin, 2021; Wu et al., 2025). Studies by Kaup et al. (2021) and Qu et al. (2024) translate Internet-inspired logic into routing and coordination models. Hofman (2015) proposes a federated platform for logistics coordination, while Fahim et al. (2021) develop a layered framework for PI port integration that includes governance at the node level. While not always framed as governance research, these works offer key building blocks for structuring decentralized logistics systems.

While earlier contributions focus on coordination through protocol architectures and system-level design, the HLC literature shifts attention to the relational foundations of collaboration. Audy et al. (2012) develop a model for multi-party collaboration focusing on leadership and fairness. Daudi et al. (2017) map trust dynamics across strategic and operational levels, while Pomponi et al. (2015) link governance maturity to collaboration evolution. Sheffi et al. (2019) offer a layered framework combining contractual, relational, and informational governance in logistics clusters. Collectively, these studies illustrate how governance design spans both system-level architecture and relational coordination structures.

Routing and Coordination: Routing protocols represent one of the most developed operational governance areas. Sarraj, Ballot, Pan, and Montreuil (2014), Sarraj, Ballot, Pan, Hakimi, et al. (2014), and Gontara et al. (2018) demonstrate modular routing models inspired by the DI. Boysen et al. (2025) formalize this into optimization procedures grounded in PI logic. Achamrah et al. (2024), W. Zhang et al. (2020), and Q. Zhang et al. (2022) explore real-time decentralized coordination, while Sun et al. (2024) address trust and privacy concerns in protocol design. These studies exemplify how routing can embed governance by defining rules, authority, and coordination processes.

Incentive Mechanisms: Incentive alignment is another core governance function explored through profit-sharing and auction mechanisms. Yea et al. (2022) develop a cooperative game-theoretic profit-sharing model, while Briand et al. (2022) introduce auction-based routing with integrated payments. Van Duin et al. (2021) and van Heeswijk (2020) show how bidding systems and smart containers can self-organize last-mile delivery, though overarching governance is needed to ensure fairness and system coherence. These models provide technical solutions for coordination but also reveal the importance of meta-governance to ensure compliance, fairness, and stability in open systems.

Relational and Contractual Governance: Several studies explicitly compare governance mechanisms. Wallenburg and Raue (2011) argue that relational governance supports conflict resolution more effectively than contracts, while Schmoltzi and Wallenburg (2012) and Raue and Wieland (2015) emphasize their complementarity in dynamic settings. Lotfi et al. (2021) and Ramjaun et al. (2023) show how governance must evolve over time, from informal trust-based structures to more formalized hybrid models. These findings reinforce the view that governance must balance structure with flexibility and adapt to the life cycle of collaboration.

Coordination and Governance Mechanisms: Finally, a cluster of studies examines facilitation and coordination structures as implicit governance mechanisms. Ciprés and de la Cruz (2019) and Schultz et al. (2021) emphasize the role of neutral facilitation and transparent rules, while practice-oriented research by Ramjaun et al. (2024) and Hingley et al. (2011) show how coordination models vary based on actor maturity and perceived legitimacy. In contrast, Sternberg et al. (2022) caution that systematic facilitation can erode trust and autonomy. These studies reveal that facilitation is not one-size-fits-all but must align with actor preferences, power dynamics, and governance needs.

3.2 Mapping Governance Research through the IAD Lens

To assess the depth and orientation of governance research in the PI and HLC, we mapped the reviewed literature against the previously introduced three institutional levels defined in Ostrom's IAD framework: operational, collective-choice, and constitutional rules (Figure 2). This framework helps differentiate between the mechanisms used to execute coordination, the processes through which those mechanisms are negotiated and maintained, and the foundational structures that define governance itself.

Most of the studies concentrate on governance at the operational level. Studies in this category primarily focus on coordination mechanisms such as routing protocols, auction-based assignment systems, and trust-building practices. These include research on DI-inspired logistics protocols (Boysen et al., 2025; Gontara et al., 2018; Sarraj, Ballot, Pan, Hakimi, et al., 2014), decentralized optimization models (Achamrah et al., 2024; Q. Zhang et al., 2022; W. Zhang et al., 2020), and incentive-compatible auction schemes (Briand et al., 2022; van Duin et al., 2021). While these contributions do not always frame their findings in governance terms, they directly shape how decisions are made and responsibilities are allocated in decentralized networks, aligning closely with operational rule design.

The literature also addresses governance at the collective-choice level, particularly in the HLC domain. Studies in this area consider how collaborative arrangements are negotiated, sustained, and institutionalized. For example, Ramjaun et al. (2024) and Hingley et al. (2011) investigate facilitation models such as lead firms or third-party coordinators; Raue and Wieland (2015) and Schmoltzi and Wallenburg (2012) explore the interplay between relational and contractual mechanisms; and Sheffi et al. (2019) propose a layered governance framework for logistics clusters. These works highlight the importance of shared rule-setting, mutual adjustment, and platform governance, but often stop short of explicitly theorizing how such rules evolve or who participates in their development.

In contrast, constitutional-level governance remains largely underexplored. Only a few studies engage with questions of rulemaking legitimacy, actor inclusion, and meta-level authority. Fahim et al. (2021) introduce a governance layer within their PI port framework but limit their analysis to node-level concerns. Sheffi et al. (2019) also briefly touch on foundational design choices in logistics clusters. Sternberg et al. (2022), while critical of systematic facilitation, highlight the need for governance models that safeguard self-determination and reflect participant expectations. Their critique shifts attention from how collaboration is managed to

how it is initially framed and who holds authority to define its structure. This reveals a gap in understanding how governance in collaborative logistics is constituted and legitimated.

IAD Level	Coverage in Literature	Examples	Gaps identified
Operational	Significant	Routing, auctions, optimization, trust mechanisms, benefit-sharing	Little reflection on how these mechanisms are negotiated or changed over time
Collective-Choice	Moderate	Coordination models, relational vs. contractual, platform governance	Limited insight into rule-making process, accountability, and dispute handling
Constitutional	Minimal	Cluster design, Critique of facilitation	Missing framework for rule-making legitimacy, actor inclusion, and authority, local-, regional-, global governance

Figure 2: IAD Analysis

Taken together, this mapping shows that research in PI and HLC is heavily concentrated at the operational level, with some attention to coordination and facilitation at the collective-choice level. However, little is known about how governance structures are established and legitimized at the constitutional level. The IAD framework thus highlights not only the areas where governance thinking has been most developed but also where further conceptual and empirical work is needed.

4 Bridging Gaps: Governance and Future Research for the PI

Although individual aspects of governance in the context of HLC and PI such as routing, coordination mechanisms, or incentive structures have been studied in detail an integrated approach that systematically links these elements is still lacking. A comprehensive governance framework for the PI that brings together these dimensions and considers their interdependencies has yet to be developed.

In the beginning we emphasized that the evolution of the DI offers important lessons for the governance of the PI, while also highlighting the need to adapt these lessons to the distinct realities of physical logistics networks. The DI did not begin as a decentralized system. Early stages of development were coordinated by government and academic institutions, such as DARPA and the National Science Foundation, which provided the structural foundation for protocol development, interoperability, and stakeholder experimentation. Over time, as the system matured, governance transitioned toward stakeholder-driven models such as the IETF, which enabled decentralized rule-setting and consensus-building without centralized control.

This trajectory suggests that governance systems in large-scale, open networks like the PI do not need to be fully decentralized from the outset. Instead, they can evolve iteratively. Early governance structures may initially require coordination, oversight, and strong technical guidance to build interoperability and trust. Over time, these structures can give way to more decentralized, actor-driven models as participants gain experience and mechanisms for distributed coordination are institutionalized.

At the same time, significant differences between digital and physical infrastructures must be considered. Unlike digital data, physical goods cannot be re-sent at negligible cost, are subject to greater temporal and spatial constraints, and operate under more intense competitive pressures. These characteristics create governance requirements that go beyond protocol design

and technical coordination: they demand attention to trust-building, liability, incentive compatibility, and multi-level decision-making.

The literature review confirms these needs and identifies several important research gaps. First, most existing studies focus on operational mechanisms such as routing protocols, optimization models, and auction systems, while governance structures at higher institutional levels, such as rule-setting processes, stakeholder representation, and meta-level authority, remain underexplored. Second, current contributions rarely consider multi-level governance. There is little discussion on how governance should be structured across local, regional, and global levels, or how rulemaking authority should be distributed and coordinated across scales. Third, many studies frame governance primarily as a technical optimization problem. Yet the DI demonstrates that governance systems do not evolve through optimization alone, but through pragmatic solutions, stakeholder negotiation, and institutional layering over time. The PI will similarly need adaptive, inclusive, and legitimacy-focused governance structures that can operate effectively under real-world constraints.

To address these needs, we propose a governance framework for the PI that integrates insights from the IAD framework, DI governance, and the literature on HLC (Figure 3). The framework is structured along two dimensions: institutional layers (operational, collective-choice, and constitutional) and spatial scales (local, regional, and global). This structure allows us to address both the content of governance (what rules are needed and how they are made) and the scope of governance (where and at what scale governance takes place).

In addition to distinguishing governance levels, it is important to differentiate the underlying governance logic at each level. Drawing on the distinction between contractual and relational governance, we argue that different layers may rely on different mechanisms. At the operational level, governance tends to follow a contractual logic, emphasizing protocols, agreements, and performance control. At the collective-choice level, relational mechanisms such as trust, mutual adjustment, and consensus gain importance for resolving disputes and adapting rules to evolving needs. At the constitutional level, legitimacy and inclusion are central, and both contractual structures (e.g., formal eligibility criteria) and relational processes (e.g., long-term partnerships or shared values) play a role. The table below summarizes these elements:

	Local Level	Regional Level	Global Level
Operational Rules	Definition of local coordination practices and service standards; alignment of actor responsibilities; data exchange within nodes.	Harmonization of processes across nodes; development of shared infrastructure use protocols; oversight of corridor-level operations.	Establishment of global interoperability principles; creation of universally accepted technical standards and compliance mechanisms.
Collective-Choice Rules	Design of inclusive decision-making structures for local actors; local mechanisms for adapting operational rules and resolving disputes.	Regional coordination and planning forums; negotiation structures for cross-node rule adaptation and benefit allocation.	Institutions for cross-regional representation, rule convergence, and adaptive standard governance.
Constitutional Rules	Criteria for actor inclusion and participation; assignment of rights and responsibilities; local rulemaking legitimacy.	Definition of authority structures within regional alliances; frameworks for stakeholder representation and institutional alignment.	Foundational principles for the governance of the global system, including openness, neutrality, and institutional legitimacy.

Figure 3: Conceptual Governance Framework Elements

To operationalize this framework as a research agenda, we propose a set of guiding questions for each level of governance across spatial scales. These questions are intended to direct future research.

Operational Governance

Local: How can routing protocols be standardized within PI nodes while preserving local autonomy? What safeguards are needed for last-mile data sharing?

Regional: How should interoperability standards be developed across jurisdictions? What monitoring systems are feasible at the regional level?

Global: What minimum technical standards are required for interoperability? How can cross-border routing protocols integrate with regional constraints?

Collective-Choice Governance

Local: What voting rights and accountability structures are effective at the node level? How can stakeholders revise local rules fairly?

Regional: What coordination bodies are needed for regional planning? How should disputes and benefits be negotiated among actors?

Global: What federated decision-making models preserve local flexibility while enabling global alignment? How can diverse actors be represented equitably?

Constitutional Governance

Local: What inclusion rules and access rights define node-level governance? How is data ownership governed among local actors?

Regional: What legitimacy frameworks support regional rulemaking? How should authority be distributed in regional networks?

Global: What institutional design supports global meta-governance? How can openness and neutrality be ensured across regions?

These research questions emphasize the importance of systematically addressing how governance at different institutional levels, operational, collective-choice, and constitutional, can be effectively designed, negotiated, and legitimated across spatial scales. Together, they highlight that governance in the PI is not a monolithic construct but a layered and evolving system that must be tailored to the complexities of real-world logistics networks.

Building on this foundation, future research should pursue three interconnected directions. First, it should translate these guiding questions into concrete governance mechanisms, with particular emphasis on the currently underdeveloped collective-choice and constitutional levels. Second, empirical investigations are needed to evaluate governance models in early PI pilots, examining how coordination unfolds under practical constraints and which design choices promote legitimacy, adaptability, and adoption. Third, theoretical work should refine principles of modularity, subsidiarity, and meta-governance that support dynamic scaling across local, regional, and global layers.

By moving beyond technical coordination and engaging with the deeper institutional structures that enable trust, inclusion, and accountability, governance research can play a central role in making the PI vision operational. Rather than being defined by a static blueprint, governance must be approached as a flexible architecture, capable of evolving with the network it is meant to sustain.

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