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Virtual Port Coordination as a Cross-Border Governance Mechanism for Seaport–Dry Port Multimodal Transport Systems: Evidence from Ningbo–Zhoushan and Tashkent

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Annotation: The growing dependence on cross-border multimodal transport corridors has exacerbated coordination difficulties between seaports and dry ports, particularly in contexts characterized by deep-seated institutional fragmentation and insufficient physical connectivity. The available literature on port-hinterland integration and smart ports focuses more on infrastructure investment along with technology adoption, but not on the organizational and governance processes through which coordination within international borders can be facilitated. The research fills the gap of this phenomenon by looking at Virtual Port Coordination (VPC) as a form of cross-border governance that enables functionality integration within Seaport–Dry Port. Based on a qualitative case study of the Ningbo–Zhoushan Seaport, and the Tashkent Dry Port on the Maritime Silk Road Framework, the research uses process tracing to explain how the causal mechanisms of VPC work. The empirical data were collected using 32 semistructured interviews that were complemented with policy documents, operation logs and archive files.

Keywords: Virtual Port Coordination; Seaport–Dry Port; Cross-Border Multimodal Transport Corridors; Multimodal Transport System; Port–Hinterland Integration; Double-landlocked Country; Four-Port Linkage.

DENGIZ PORTI-QURUQ PORT MULTIMODAL TRANSPORT TIZIMLARI UCHUN CHEGARALARARO BOSHQARUV MEXANIZMI SIFATIDA VIRTUAL PORTNI MUVOFIQLASHTIRISH: NINGBO-ZHOUSHAN VA TOSHKENTDAN OLINGAN DALILLAR

Annotatsiya: Chegaralararo multimodal transport yo'laklariga tobora ortib borayotgan qaramlik dengiz portlari va quruq portlar o'rtasidagi muvofiqlashtirishdagi qiyinchiliklarni kuchaytirdi, ayniqsa chuqur institutsional parchalanish va jismoniy aloqaning yetarli emasligi bilan tavsiflangan sharoitlarda. Port-ichki hudud integratsiyasi va aqlli portlar bo'yicha mavjud adabiyotlar ko'proq texnologiyalarni joriy etish bilan birga infratuzilma investitsiyalariga qaratilgan, ammo xalqaro chegaralar ichida muvofiqlashtirishni osonlashtirish mumkin bo'lgan tashkiliy va boshqaruv jarayonlariga emas. Tadqiqot ushbu hodisaning bo'shlig'ini Virtual Port Muvofiqlashtirish (VPK) ni Dengiz porti-Quruq porti ichida funktsional integratsiyani ta'minlaydigan chegaralararo boshqaruv shakli sifatida ko'rib chiqish orqali to'ldiradi. Ningbo-Zhoushan dengiz porti va Dengiz Ipak yo'li doirasidagi Toshkent quruq portining sifatli holatini o'rganish asosida tadqiqot VPKning sabab-oqibat mexanizmlari qanday ishlatilishini tushuntirish uchun jarayonlarni kuzatishdan foydalanadi. Empirik ma'lumotlar siyosat hujjatlari, operatsiya jurnallari va arxiv fayllari bilan to'ldirilgan 32 ta yarim tuzilgan intervyular yordamida to'plangan.

Kalit so'zlar: Virtual port muvofiqlashtirish; Dengiz porti-Quruq port; Chegaraviy multimodal transport yo'laklari; Multimodal transport tizimi; Port-ichki hudud integratsiyasi; Ikki dengizga chiqish imkoniyati bo'lmagan mamlakat; To'rt portli bog'lanish.

ВИРТУАЛЬНАЯ КООРДИНАЦИЯ ПОРТОВ КАК МЕХАНИЗМ ТРАНСГРАНИЧНОГО УПРАВЛЕНИЯ МУЛЬТИМОДАЛЬНЫМИ ТРАНСПОРТНЫМИ СИСТЕМАМИ МОРСКИХ И СУХИХ ПОРТОВ: ДАННЫЕ ИЗ НИНБО-ЧЖОУШАНЬ И ТАШКЕНТА

Аннотация: Растущая зависимость от трансграничных мультимодальных транспортных коридоров усугубила трудности координации между морскими и сухими портами, особенно в условиях глубоко укоренившейся институциональной фрагментации и недостаточной физической связности. Имеющаяся литература по интеграции портов и внутренних районов, а также по «умным» портам, больше фокусируется на инвестициях в инфраструктуру и внедрении технологий, но не на организационных и управленческих процессах, посредством которых может быть облегчена координация в международных границах. Данное исследование восполняет этот пробел, рассматривая виртуальную координацию портов (VPC) как форму трансграничного управления, которая обеспечивает функциональную интеграцию в рамках морских и сухих портов. На основе качественного тематического исследования морского порта Нинбо-Чжоушань и сухого порта Ташкента в рамках Морского Шелкового пути, исследование использует метод прослеживания процессов для объяснения того, как работают причинно-следственные механизмы VPC. Эмпирические данные были собраны с помощью 32 полуструктурированных интервью, дополненных политическими документами, операционными журналами и архивными файлами.

Ключевые слова: Виртуальная координация порта; Морской порт – Сухой порт; Трансграничные мультимодальные транспортные коридоры; мультимодальная транспортная система; интеграция портов и внутренних районов; страна, не имеющая выхода к морю; связь четырех портов.

1. Introduction

1.1 Research Background and Problem Statement

In the face of growing globalization in supply chain reorganization, multimodal transport has become both an important organizational structure for improving logistics performance and a means to decrease transport costs overall system wide. Especially a double-landlocked one, not connected directly to any sea and completely enclosed by other landlocked states, finds structural mediation of access to maritime transport through various jurisdictions, transport modalities, and institutional interfaces. Consequently, dry port take on a central role in the context of accessing worldwide shipping networks, but their successful functioning is becoming dependent more on the ability to coordinate than the mere extension of infrastructure.

The problem of coordination of double-landlocked countries is represented by Uzbekistan. Much of its international trade relies on long-distance rail-sea routes which span across several states and regularly cause a lot of friction between institutions as well as operations borders (e.g. borders, break of gauges, unavailability of documentary evidence, lack of uniformity in information systems). In spite of continued investment in the corridor infrastructure, persistent delays and breakdowns in coordination suggest that performance limits increasingly arise due to intra-organizational and cross-border governance issues, not only physical bottlenecks (Rodrigue & Notteboom, 2020). The current situation gives Uzbekistan analytical significance as the place to study how the coordination potential created through digitalized platforms and combined governance

schemes could enhance corridor reliability and efficiency amidst extreme geographical and institutional limitations.

1.2 Research Gaps and Analytical Motivation

The current literature on port regionalization, dry port development, and multimodal transport corridors governance has offered some useful ideas regarding port-hinterland integration. Nevertheless, there are still three major gaps that restrict its explanatory strength in cross-border settings:

First, in most studies, it is implicitly assumed that the coordination context is domestic in nature, and that regulatory frameworks, standards and information systems are relatively consistent with each other. The assumption makes little contribution to the explanation of how seaport and dry port can attain some level of functional integration across countries' borders, which are characterized by institutions fragmentation, asymmetric power relationships.

Second, despite the growing acknowledgment of digital platforms as facilitators of port coordination, they tend just to be placed as a kind of technical infrastructure in the background instead of being taken as critical organizational skills that directly impact the result of coordination. As a result, there are no exact theoretical explanations of how platform-enabled coordination leads to actual performance improvements.

Third, the empirical studies do not often examine the complex micro-level processes through which coordination arrangements create observable performance gains. Most importantly, the key middleman position of coordination quality, including information transparency, decision alignment and

process synchronization among actors, has not been widely researched in crossborder intermodal contexts.

In order to fill these gaps, the research in this paper extends the idea of Virtual Port Coordination (VPC) as a cross-border collaboration capability, which facilitates dry port acting as real extensions of seaport by means of a digital platform, common information architecture and virtual dispatching system. Inspired by the operational rationale behind China's Four-Port Linkage Smart Logistics Platform, We conceptualize VPC as a multi-dimensional coordination mechanism including information coordination, management coordination, operational coordination, and strategic coordination.

1.3 Research Questions

This study covers three interrelated research questions:

RQ1 (Conceptual): What is considered to be Virtual Port Coordination (VPC) in terms of cross-border collaborative capacity between the seaport and dry port and what are the ways of making these dimensions operational?

RQ2 (Mechanistic): What are the causal mechanisms that allow VPC to improve the quality of coordination in the information, decision making and operational processes, and what is the evidence supporting these mechanisms?

RQ3 (Performance): In what ways can better coordination quality be reflected by observable performances, particularly with respect to system reliability, efficiency, utilization and resilience in the context of double landlocking?

This paper will help answer some of those issues to achieve theoretical insights on trans-border port cooperation and also practical insights on how to

enhance logistics performance in landlocked environments.

2. Literature Review and Analytical Positioning

2.1 Port–Hinterland Integration and Port Regionalization

Port and hinterland linkages have been the main focus of attention in port and transport geography for many years. Initial research viewed port-hinterland relations mainly as spatial manifestations of port power with a primary focus on cargo flow, market coverage, and connectivity of infrastructure. Under the growing globalization of supply chains and intensified competition among ports, this vision slowly developed towards the idea of port regionalization, which implies considering the functional connectivity of ports and inland logistic centers beyond the limits of the immediate port (Notteboom & Rodrigue, 2005).

As recent literature suggests, this is not just a process of physical expansion but also organizational and institutional. Research has indicated that inland terminals, logistics parks, and dry ports have begun to act as a component of the seaport system, allowing ports to obtain cargo bases, stabilize throughput, and improve service reliability. Nonetheless, most empirical contributions into this stream implicitly adopt a domestic or a single-jurisdiction setting in which regulatory systems, operating principles, and informational networks are fairly synchronized.

Nonetheless, despite the usefulness of the port hinterland integration theory as a basis for understanding connections between seaport and dry port, the framework cannot explain much in terms of cross-border environments with the characteristics of institutional

fragmentation, heterogeneous governance structures and unequal power dynamics among the players. The problem is especially acute in the case of doubly-landlocked regions, when the inland access to maritime infrastructure requires coordination within several national systems.

2.2 Dry port and cross-border multimodal transport system

The dry port has become a significant point on the global logistics network, especially in areas that want an enhanced hinterland connection and mitigate congestion problems at seaport. The dry port idea could be used in many forms of facilities, including as a simple rail terminal or even a complex integrated logistics terminal with customs clearance function, storage and other value-added services (Roso et al., 2009). A more recent literature conceptualizes the seaport–dry port network as a smart and agile system that is part of a sophisticated industrial paradigm (Rekabi et al., 2025). Other research has shown the feasibility of dry ports to increase intermodal efficiency, lower transport costs, and help regional economic growth.

The dry port has an increasingly important strategic position in the cross-border multimodal transport system, serving as a gateway between landlocked areas and maritime trade routes. The role of cross-border multimodal transport system has been studied to reveal that infrastructure continuity, service rate, and regulatory facilitation are important. Nevertheless, empirical studies indicate that investments in infrastructure are not adequate to address the ongoing coordination problems in cross-border logistics networks, especially when instant multi-modal risk management tools are poorly developed (Ouedraogo et

al., 2026).

There is a growing scholarly consensus that the effectiveness of cross-border multimodal transport systems relies on the capability of various agents to make decisions and operations across different organizational boundaries and borders of countries. The actors are the railways, freight forwarders, cargo owners, customs authorities, and seaport. Even though this is identified, the current works have a tendency to view corridor performance based on overall performance. They present limited insights into how micro-level coordination processes occur to ensure dry port function effectively as intermodal hubs for distant seaport.

2.3 Digitalization, Port Community Systems, and Platform-Based Coordination

The digitalization of maritime logistics is accelerating at an alarming rate, leading to an increasing amount of literature on smart ports, port community system (PCS), and digital platforms. Port community systems are often considered as major facilitators of information exchange between stakeholders in the port and help to exchange documents, provide visibility into operations, and create uniform processes. Some more recent works are extending this interest to newer digital technologies like blockchain, digital twins, and artificial intelligence (Caldeirinha et al., 2020; Iida & Watanabe, 2023).

Although this literature contributes much to explaining how digital technologies could enhance port effectiveness and transparency, there are two shortcomings. In the first place, the phenomenon of digitalization is considered as a technical measure but not as an organizational ability that is part of

the governance and coordination arrangements. Secondly, empirical studies have focused on the port-centric application, with less focus on how the digital platform facilitates long-term coordination between seaport and land-based nodes (Inkinen et al., 2021; Molavi et al., 2020; Triska et al., 2024).

Nevertheless, the cause-effect relationship between digital platforms and performance results is often assumed rather than shown. In particular, there is no detailed empirical analysis of how platform-based coordination mechanisms work in reality, how such mechanisms are changing the decision-making process among non-homogeneous actors, as well as in what circumstances these mechanisms are leading to quantifiable improvements in system performance.

analysis of how platform-based coordination mechanisms work in reality, how such mechanisms are changing the decision-making process among non-homogeneous actors, as well as in what circumstances these mechanisms are leading to quantifiable improvements in system performance.

2.4 Coordination Quality and Performance Mechanisms in Multimodal Transport System

Another strand of literature investigates coordination and governance in transport and supply chains. Research on collective governance, network coordination and institutional harmony indicates that the enhancement of performance depends not just on the presence of resources but also on how well coordinated they are among the players.

The concept of coordination quality has been seen as an important intermediary factor between governance structure and performance results. It tends

to have reflection on informational clarity, uniformity in decision making, and harmonization in terms of processes involved.

Nevertheless, the concept of coordinated action is infrequent within the framework of ports and multimodal transport. Rather than being a direct analysis construct, it can be incorporated indirectly into a set of overall governance typology or performance indicators. Furthermore, empirical research often fails to follow through on the particular coordination mechanism that can lead to increased reliability, efficiency or resilience, especially when working in the complicated environment of cross-border interactions (Jia & Cui, 2021).

It is particularly conspicuous in the case of the so-called double-landlocked situations, where coordination breakdowns have more severe implications due to heterogeneity of regulations, increased distance of transportation, and increased sensitivity to external shocks. Knowing how the quality of coordination can be created, preserved and utilized in these environments has not been explored enough as a field of research.

2.5 Synthesis and Analytical Positioning

Conclusively, the available literature has shown three interconnected gaps that exist. The first gap is that although the concept of port-hinterland integration and dry port study recognises the significant role played by linkages between inland and seaport nodes, it gives little insight into the mechanism involved in achieving functional integration across national boundaries. The second gap is that the digitalization studies focus on the opportunities offered by platforms and port community systems but lack the

theories that support their existence as organizational and managerial coordination mechanisms. Thirdly, coordination quality is a point of emphasis in governance-related research, though this line of study seldom disassembles coordination arrangements-performance outcomes relationships in cross-border multimodal transport systems.

In order to overcome such gaps, it is proposed in this research to adopt the concept of Virtual Port Coordination (VPC) as a conceptual framework that views cross-border cooperation between seaports and dry ports as something with multi-dimensional capability, not merely a technical fix. Through process tracing, the paper aims at providing an insight into how the mechanism of platform-facilitated coordination can enhance coordination quality and produce measurable performance effects in the context of double-landlocked circumstances by bringing together the findings of port regionalization, dry port development, digital platform studies, and coordination theory (Caldeirinha et al., 2020; Triska et al., 2024).

3. Conceptualization of Virtual Port Coordination

3.1 From Port-Hinterland Integration to Virtual Port Coordination

The idea behind port-hinterland integration has existed as an underlying paradigm of understanding spatial and functional extension of seaports to inland regions. In traditional research, the focus is placed on the connectivity of infrastructure, shifts in modal transportation, and organizational coordination in the national context. However, in the case of border regions, especially in the case of doubly landlocked nations, the simple physical

closeness and administrative cohesion are not sufficient explanations of successful port-dry port cooperation.

Under those conditions, dry port is unable to exploit merely geographical connectivity or the development of corridors to link to maritime networks. On the contrary, they are more and more based on the extent to which the remote seaport may provide the operational, managerial, and informational services across the physical barriers separating them. Conceptualizing these extensions in the form of a phenomenon that should not be seen as spatial but functional and organizational change and referring to this as Virtual Port Coordination (VPC) is the core of the presented study. Virtual Port Coordination is different from other digital coordination ideas because it focuses on cross-border functional integration and governance possibilities instead of systems that focus on ports.

Virtual Port Coordination can be defined as a form of cross-border cooperation under which the function of the dry port becomes an extension of the ports of seas via digital channels, mutual information structures, and virtual dispatching technologies. In contrast to traditional port information systems, VPC is part of the regular procedures and decision-making practices, allowing joint planning, implementation and control of cross-border operations regardless of national and modal borders.

3.2 Dimensions of Virtual Port Coordination

Based on the working principle of the Four-ports linkage smart logistics platform of China, this paper conceptualizes Virtual Port Coordination as a multi-dimensional collaborative ability which involves the following four inter-related dimensions: information

coordination, management coordination, operation coordination and strategic coordination.

Information coordination is real-time sharing and integration of information on seaports, dry ports, railway operators, freight companies and owners of cargos regarding logistics data. It also comprises cargo condition, availability of containers, transport timetable, clearance at customs, as well as the situation along the corridor. The concept can minimize uncertainty and alleviate information asymmetries in cross-border multimodal transport.

Management coordination is based on online assignment of resources and cross-border movement supported by digital channels. Centralized and federated scheduling facilities allow seaports to be participants in the intra-national plans and dry ports to coordinate their actions considering the port capacity and service circumstances in the seaport. Coordination management converts a disconnected pattern of choice making into an integrated process of system optimization (Nguyen et al., 2026).

The operational coordination is centered on integration of processes among different modes of transportation and jurisdictions, which include common documentation, uniform timing, and similar operation regulations. Single-bill operations and interoperable workflow systems are examples of ways that decrease transaction costs and increase efficiency in intermodal transfer.

Strategic coordination refers to organizational alignment and policy alignment to ensure that long-term cooperation takes place. Such a dimension also consists of joint developmental strategies, regulation harmonization, green transport projects, and coordinated

response to an emergency. There is strategic coordination which will make virtual integration possible by having sound governance structures and sustainable goals behind this phenomenon.

3.3 Theoretical Foundations of Virtual Port Coordination

As is possible to see, Virtual Port Coordination may be theoretically located at the crossing point of three research streams, namely, port-hinterland integration, dynamic capability, and collaborative governance theories.

According to the dynamic capabilities theory (Teece, 2007), VPC is a higher-level organizational capability that allows port enterprises to detect the presence of coordination possibilities across organizational boundaries, take these opportunities by committing resources, and rearrange operating processes in order to obtain sustained performance gains. VPC as a dynamic capability changes over time with the organizational learning process and adaptive changes in response to the changing environment of the institution and competition.

According to the theory of collaborative governance (Ansell and Gash, 2008), VPC can be defined as an institutional arrangement and interaction mechanism that permits diverse agents with various interests and operational logics to collaborate over a long time. The actors comprise ports, railways, customs agencies, freight forwarders and owners of cargo. The four dimensions of VPC are related to major facets of collaborative governance. Coordinating information creates common bases of shared knowledge. Coordinating management allows co-decision making. Coordinating operations allows the implementation of

collective action. Coordinating strategies provides the alignment of institutions.

Theoretical positioning that sets VPC apart from purely technical concepts like smart ports or digital twins is that it has rather an organisational and managerial attribute that is built into the governance structure and decision-making routines (Molavi et al., 2020; Triska et al., 2024; Zhu et al., 2025). Although digital technologies may be used as a basis of the VPC, the effectiveness of this technology will depend upon how it is applied through organizational processes and relational dynamics.

3.4 Conceptual Framework

Cross-border coordination capabilities enable functional integration between seaport and dry port in cases of institutional fragmentation. The conceptual framework used to describe this relationship is illustrated in Figure 1 as Virtual Port Coordination (VPC). The framework conceptualises Virtual Port Coordination as a multi-dimensional coordination capability with four interrelated dimensions of information coordination, management coordination, operational coordination, and strategic coordination. Instead of functioning in isolation, these dimensions act as mutually reinforcing elements that collectively shape the dynamics of interaction among geographically dispersed and institutionally diverse actors traversing cross-border multimodal transport corridors.

Coordination quality is at the centre of the framework, acting as the mediator between the level of coordination abilities and performance results (Caldeirinha et al., 2020; Surucu-

Balci et al., 2024). Coordination quality encompasses alignments in processes across organizations and is measured by the improved transparency of information, synchronisation of decisions, and good management of resources. The fact is explicitly stated that there is no straight and linear connection between the organizational coordination setups and the results of actions as it is supposed to occur in a way of improvement in the quality of the coordination process only through the translation of such organizational capability.

Performance outcomes in this framework relate to performance outcomes in the form of observable changes in system-level operation, such as more reliability, less variability, better efficiency and higher use of intermodal services. The results are perceived as emergent properties of coordinated action and not the result of an automatic consequence of the expansion of infrastructures or application of technologies (Chang et al., 2025; Zhu et al., 2025).

The model also acknowledges that the efficiency of Virtual Port Coordination will depend on a series of situational factors. There are included moderating factors, including institutional environment, digital infrastructure maturity and interorganizational trust, which define the extent and robustness of coordination mechanisms. This set of conditions affects the manner in which coordination capabilities are implemented in practice, and it is the reason why such capabilities can be implemented in different ways in each cross-border context.

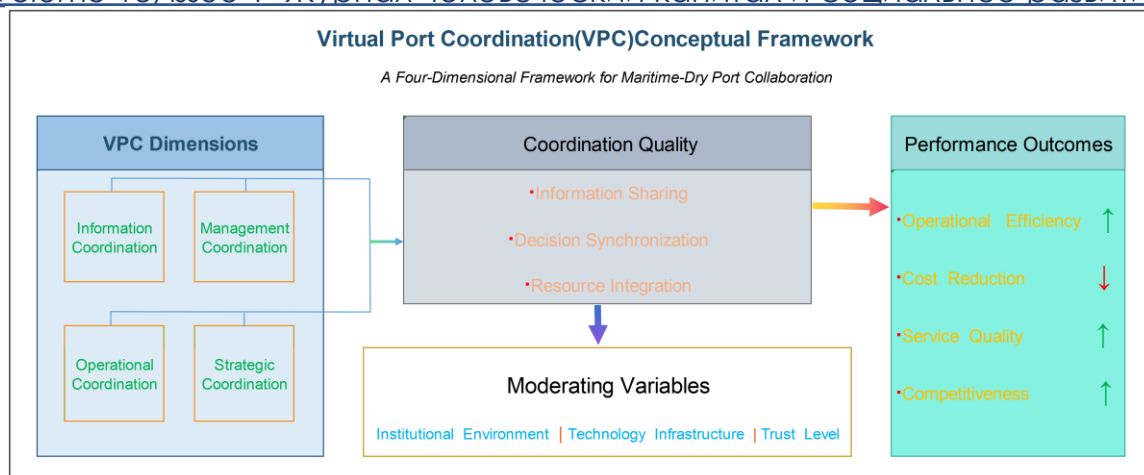


Figure 1 Conceptual Framework of Virtual Port Coordination

Integration abilities, quality control of coordination, as well as contextual variables can be synthesized into a unified analytical framework that enables a mechanism-orientation-based explanation of the port-hinterland integration phenomenon within trans-border intermodal schemes. Theoretically speaking, it gives a theoretical foundation of how further analysis is made based on empirical studies (it is explained by how they relate) to investigate causal links behind Virtual Ports Coordination - performance results through the use of a

process tracing approach.

This framework has been developed to be used in the analysis process to determine mechanisms instead of a formative model.

Virtual Port Coordination is executed by four related aspects, including information-based management, management-oriented planning and operations and strategy-focused coordination. Table 1 has a summary of what the four dimensions are and what each one means, in addition to its indicators.

**Table 1:
Dimensions, Mechanisms, and Performance Implications of Virtual Port Coordination**

VPC Dimension	Core Mechanism	Operational Manifestation	Related Performance Outcomes
Information Coordination	Cross-border data sharing and real-time visibility	Shared cargo status, container availability, transport schedules, and customs progress	Improved reliability, reduced waiting time, enhanced transparency
Management Coordination	Virtual dispatching and coordinated planning	Alignment of rail dispatching, yard operations, and storage allocation	Higher resource utilization, stabilized throughput, reduced idle capacity
Operational Coordination	Process integration and workflow harmonization	Interoperable documentation, synchronized scheduling, single-bill operations	Lower transaction costs, increased intermodal transport share
Strategic Coordination	Institutional and policy alignment	Joint development strategies, green logistics initiatives, coordinated emergency response	Enhanced system resilience, improved safety and sustainability

4. Research Design and Process Tracing Methodology

4.1 Case Selection and Research Strategy

The research design used in this paper is an embedded single case; it emphasizes the interaction between Ningbo-Zhoushan Port and Tashkent. It meets three criteria analytically. Firstly, Ningbo - Zhoushan Port is an excellent example of a maritime hub with high-level digital coordination potential. Secondly, Tashkent Dry Port can be seen as an important gateway to the foreign

trade of Uzbekistan due to its double-landlocked situation. Thirdly, the nascent use of border-crossing coordination mechanisms in terms of digital coordination offers an unrivaled chance to watch the development and functioning of Virtual Port Coordination in reality. Both the cases have complementary structural and functional attributes in the area of cross-border corridor. Figure 2 is a comparison of the main features of the Ningbo - Zhoushan Seaport and the Tashkent Dry Port.

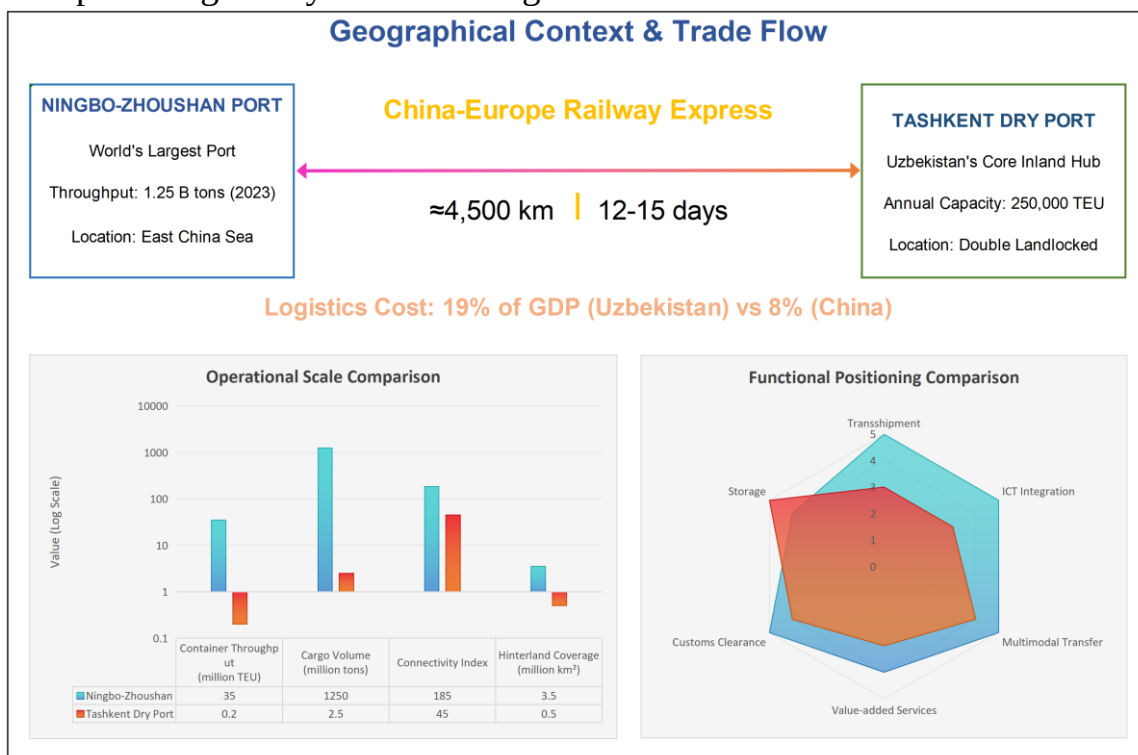


Figure 2 Cross-border complementarity between Ningbo–Zhoushan Seaport and Tashkent Dry Port.

The primary analytic tool used in the study is process tracing, which allows the researcher to unpack causal mechanisms, not just identify correlations. It is possible to consider this methodology to provide a systemic analysis of the ways in which particular coordination arrangements lead to intermediate results which add up to the improvement of performance.

4.2 Data Sources and Evidence

Base

Based on several types of evidence, such as policy documents, platform architecture specifications, operational history, and semi-structured interviews, the empirical analysis is made. Stakeholders included in the interviews were five different groups: government agencies, port authorities, railway operators, freight forwarders, and cargo owners. Such an approach of multiple

actors allows to perform triangulation of evidence and thus make the causal inference stronger.

The 32 semi-structured interviews were carried out in January 2025 - September 2025 to ensure that there was representation of multi-actors regarding cross-border maritime dry port coordination. The interviewees belonged to five major groups of stakeholders in the China-Uzbekistan multimodal transport corridors, which included government bodies (5 interviews with customs officers and representatives of the transport ministries), port authorities (8 interviews with the administrators of the Ningbo-Zhoushan SeaPort and the managers of the Tashkent Dry Port), railway companies (China Railway and Uzbekistan Railway, 6 interviews each), freight forwarders (multinational logistics companies and local freight agents, 7 interviews each), and cargo owners (6 interviews of importers and exporters utilizing the corridor actively).

The interviews generally took about 30-45 minutes and were held in either English or Chinese and, whenever required, there was a provision of professional interpretation assistance. In order to minimize the retroactive bias, the data collected through interviews has been triangulated against policy documents, operational logs, and material related to the platform gathered over the same time.

4.3 Data Analysis and Evidence Triangulation

After the data collection, a systematic qualitative analysis was performed to determine the means of coordination and follow the sequence of causal connections between Virtual Port Coordination and performance results. The analysis strategy was an integrative

use of theory-guided coding, evidence triangulation and temporal sequences, as recommended in the best practice guidelines on qualitative process tracing studies (Beach & Pedersen, 2019).

4.3.1 Hybrid Coding Approach

The paper uses both deductive and inductive methods of coding to analyze the transcripts of the interviews and documentary evidence in a systematic way to identify particular coordination procedures that underlie the concept of Virtual Port Coordination.

The conceptual framework of section 3 is used in deductive coding using the four dimensions of port multimodal coordination, i.e., information coordination, management coordination, operation coordination and strategy coordination. Such an approach leads to consistency between empirical investigations and theory postulations.

The method of inductive coding is the method to identify emergent practices not envisaged by the initial framework. Begin by performing open coding on the interview transcripts and documentary materials, labeling the text sections outlining coordination practices, decision-making processes, platform use, and organizational communication processes without any predefined categories. The inductive codes were then compared to the deductive structure by means of axial coding. In this iterative way, emergent themes either found their place in the already existing VPC dimensions or were discovered as complimentary sub-mechanisms which further clarified each dimension's conceptualization. As an example, particular instances of practice like adjustment of virtual schedules, exceptions handling across borders, and joint contingency planning were revealed, making abstract concepts of coordination

tangible.

Specific coding was then used to incorporate coded observations into logical causation storylines, taking special care of time order and actor attribution. At this stage, background conditions are discerned, triggering events are identified, and outcome-generating mechanisms are identified. No coding patterns were kept as credible causal process observations unless they could be backed up by more than one data source.

Through this hybrid methodology, it is possible to remain theoretically oriented but at the same time have some room to be flexible to the context-specific coordination dynamics of cross-border multimodal transport systems (Beach & Pedersen, 2019).

4.3.2 Evidence Triangulation

The current study uses evidence triangulation in three dimensions to enhance the believability of causal inferences, namely data sources, actors' perspectives, and time sequence.

The triangulation of data sources uses semi-structured interviews, policy documents, materials related to the platform, and operation records. The evidence provided by interviewees was examined in comparison with both documentary and operational evidence to ensure that the information is factually consistent and does not depend on self-reported information. Only in the case the given observation was backed up by at least two independent data sources, was it considered reliable.

Actor triangulation involves the dynamics of coordination between stakeholders by taking various points of view into consideration. The interviewees comprised five different categories, i.e., government institutions, port agents, railway agents, freight forwarder agents,

and cargo owners. All groups were in different locations in the cross-border intermodal scheme. Across these groups, convergence of accounts was considered a stronger indicator of underlying coordination mechanisms, whereas discrepancies suggested additional consideration of context or position aspects.

The notion of temporal triangulation is related to causal ordering evaluation. It had been decided to study evidence at various times in order to see if variations in the coordination arrangements have led to the observed performance results. In such a time series, this is what will separate valid causations and false associations, especially involving dynamic multilateral settings.

The process of triangulation was closely incorporated into the hybrid coding process throughout the analysis. The coding patterns that were impossible to confirm through triangulation were not included in the list of causal claims. This systematic plan improves internal validity and helps in establishing valid causal observation processes (Beach & Pedersen, 2019).

4.3.3 Analytical Validation and Reliability Checks

In order to enhance the level of analytical rigor even more, several validation methods are included in this study.

Analytical memos have been consistently kept during the whole process of coding and triangulation with documentation of category definitions, coding decisions, and interpretative judgment in writing. Memos like these give an explicit audit trail that connects the raw empirical data to more advanced levels of analytical structure, which increases both transparency and

replicability.

The consistency tests were carried out between coding iterations. The previous coded pieces are reviewed as coding advances through open, axial and selective stages to evaluate whether category assignment is stable and coherent. Changes were only done whenever fresh evidence or clarified conceptual understanding warranted recoding, and thus minimized the possibility of ad hoc interpretation.

The negative case analysis found that there were observations that deviated from the dominant coordination patterns. The situations when coordination outcomes have not improved in spite of the existing Virtual Port Coordination arrangements were specifically investigated to fine-tune causal explanation and prevent its overgeneralization.

Interpretive credibility was measured by using cross-validation of interviewees' role positions and institutional surroundings. Fact consistency of observations was not simply considered in evaluating the observations but also whether suggested mechanisms were plausible regarding the power of actors, their incentives, and working duties. Such validation is a guarantee that the mechanisms under consideration are institutionally and organizationally reliable.

4.4 Process-Tracing Tests and Evaluation of Rival Explanations

This is an empirical research which builds upon the verified coding and triangulation processes and implements formal process-tracing assessments to test the strength of causal statements.

Initial straw-in-the-wind tests evaluated whether there was a general resemblance between the observed

coordination practices and the suggested mechanisms. The data included greater inter-boundary visibility, increased frequency of joint planning interactions, and virtual changes in operation which offered some support, albeit not enough to confirm causation.

The hoop tests then tested the presence of conditions that are needed to activate mechanisms. Particularly, the fact that there is a commonality of digital platforms, institutionally defined coordination routines and minimal requirements of inter-organizational trust was considered as a necessary condition. These conditions were missing in other cases that did not have sustained improvements in quality of coordination, thus confirming the causal importance of Virtual Port Coordination.

The smoking-gun tests were performed in selective situations in which particular evidence played a significant role in supporting some of the specific causal mechanisms. In example, recorded instances where the collective decision-making efforts between port, railway, and customs players caused directly stopping the cascade delays may be regarded as determinative evidence connecting the coordination strategies to the result of their implementation in performances.

Three competing hypotheses were systematically reviewed: expansion of physical infrastructure, changes in external demand, unilateral facilitation of policy. The two factors considered, temporal sequencing and actor attribution, show that there are no single reasons that explain why the identified improvements were recorded. Coordination failures would frequently precede infrastructure investments. Performance gains were not always associated with demand growth. Unilateral measures failed to gain cross-

actor acceptance.

All things considered, the process-tracing tests offer converging evidence to the proposition that the Virtual Port Coordination mechanisms cause the improvement of the quality of coordination rather than the other possible explanations. The conjunction between temporal sequencing, actor attribution, and negative case analysis minimises the possibility of retrospective rationalisation.

5. Process Tracing Findings: Mechanisms of Virtual Port Coordination

Virtual Port Coordination is investigated by using a process-tracing strategy in order to understand the underlying causes of the mechanism. Key coordination mechanisms and their subsequent interactions are illustrated in Figure 3.

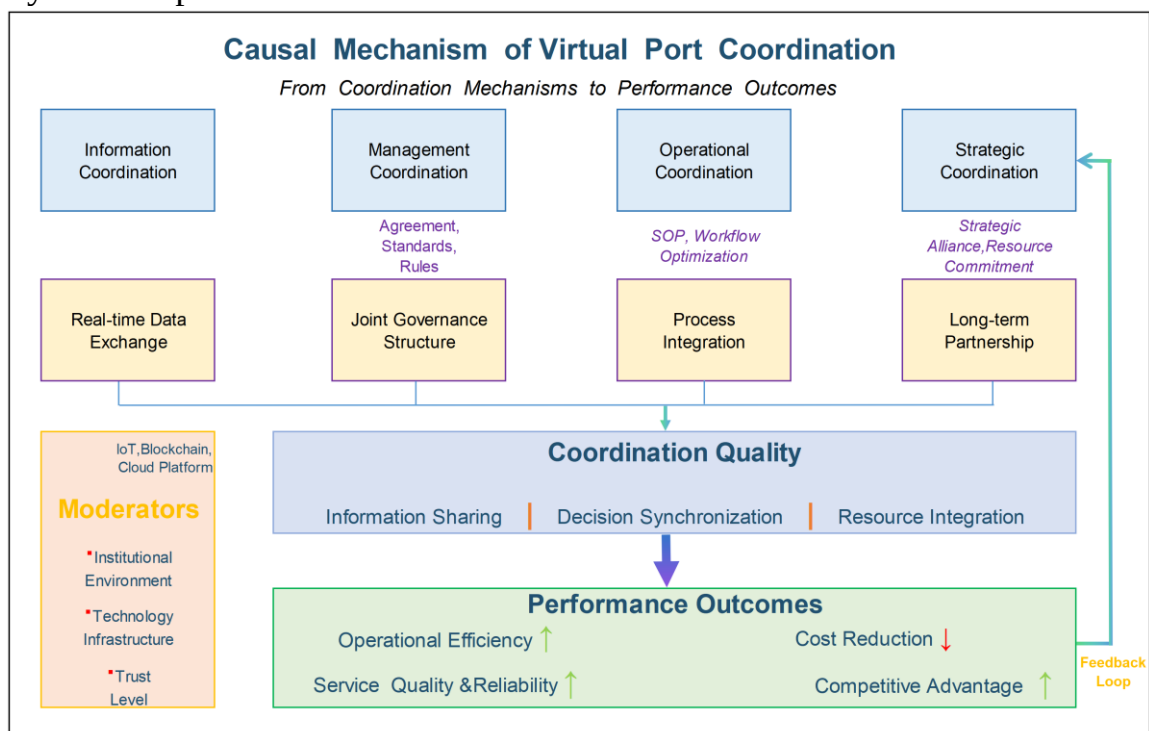


Figure 3 Causal Mechanisms of Virtual Port Coordination

5.1 Information Coordination and Reliability Improvement

Process-tracing analysis reveals the initial causal mechanism as information coordination. Before introducing the idea of virtual arrangements to coordinate, the stakeholders stated that they experienced broken streams of information, slow information on their standing, and lack of visibility at the interface between rail and sea transport modes. The result of this was uncertainty in scheduling and restricted the possibility of inland operators to fit their plan according to maritime port operations.

With the widening of digital functions of platforms based on the Four-Port Linkage Smart Logistics Platform, there was great improvement of visibility among the corridor through real-time exchange of information concerning the condition of consignment, box availability as well as transportation schedules, which enhanced the corridor-level resiliency during congested and disruption periods (Chang et al., 2025). Such information coordination allowed the faster detection of breakdowns and allowed making active changes earlier, leading to higher reliability and shorter waiting times at crucial transfer points.

This mechanism is supported by the evidence obtained through interviews:

(a) One of a freight forwarder said: Pre-platform, it was common that we had no idea when there would be delays until there were already containers sitting on the border. We now receive notifications 48 hours before, and can either re-route or reschedule.

(b) One railway operator said: With real-time visibility on the current situation, we have decreased our average reaction time to disruptions by 72 hours to 12 hours.

(c) Port authority data revealed that it took on average 35% less time to spend on containers at the terminal at the Tashkent Dry Port after implementation of the platform.

5.2 Management Coordination and Resource Allocation Optimization

A second causal mechanism uncovered by the process tracing is virtual dispatching, which enables management coordination. Before the implementation of the concept of virtual port coordination, the activities in Dry Ports did not necessarily involve the planning related to the capacity of the Seaports. The inland node scheduling choices tended to be reactive because they depended on late information about the arrival of vessels, containers, and the condition of congestion in the port.

The introduction of management coordination mechanisms made it possible for the Dry Port to have a virtual presence in the upstream planning process. With common planning periods as well as synchronized scheduling systems, Tashkent Dry Port matched up rail dispatches, yard works and storage spaces to Ningbo-Zhoushan Port operation paces.

The new virtual alignment

changed the disjointed decision-making into consistent utilization of resources. The stakeholders pointed out better use of storage space and less idle time of containers, as well as increased predictability of rail-sea transfers.

Key evidence includes:

(a) The utilization of storage in Tashkent Dry Port has risen by 68% to 89% after the introduction of joint scheduling times

(b) The mean container idle time went down by 4.2 days to 1.8 days

(c) A port manager said: Currently, we receive early notification of the Estimated Time of Arrival (ETA) of the vessels two weeks in advance, and that allows us to optimize the yard planning and rail dispatching activities to a large extent.

5.3 Operational Coordination and Transaction Cost Reduction

The third mechanism involves operational coordination via process integration, in particular harmonization of documentation, scheduling and operational processes. Prior to the implementation of virtual coordination systems, cross-border rail-sea carriage saw several handover situations and duplicated verification of the information, which was associated with increased transaction costs and coordination time.

The emphasis of operational coordination within the context of the VPC framework was on workflow integration in contrast to the standardization of physical infrastructure. The implementation of synchronized schedules, interoperable information interfaces and phased deployment of unbilled operations helped curb administrative redundancy and increase the efficiency of handing over.

Process tracing documentation

shows that in those functional changes, coordination costs were decreased and the appeal of multimodal transportation solutions to the owner of cargoes became higher.

Documented improvements include:

(a) Decrease in average documentation processing duration by 72 hours to 18 hours

(b) Decrease in administrative costs per container from \$180 to \$95

(c) Increasing the percentage of multimodal transport share in total corridor volume by 23%-41%

(d) A cargo owner stated: The one-bill system has made our operations very easy. We are dealing with one platform which we were previously engaging with five different agencies.

5.4 Strategic Coordination, Resilience, and Sustainability Outcomes

Strategic coordination constitutes the last mechanism that will be addressed in this discussion, which offers institutional and organizational security for long-term partnerships. The concept of strategy coordination includes alignment of policies, joint aims of development, programs on green transport, and plans on emergency responses.

Based on information obtained through interviews, it can be concluded that placing virtual coordination systems into wider strategic approaches promoted the strength of the systems. The fact that organized action made it easier to react and recover during times of disruption, i.e. temporary congestion, regulatory changeovers, etc helped increase responsiveness and recovery rate. Besides, the compatibility with green logistics goals helped in promoting energy-saving transportation services and

enhancing ecological measurements of excellence.

Interview and documentary data also indicate that corridor resilience improved during disruptions due to the insertion of the virtual coordination mechanisms into a wider context of the strategic partnership. The stakeholders always reported on faster collective sense-making and coordinated recovery efforts whenever the change in border procedures was applied or any form of temporary congestion existed. Although there is no available data that reports rerouting statistics exactly on a corridor-by-corridor basis in the accessible railway operational records, various participants mentioned the documented instances where the reallocation of rail-slots or temporary storage was undertaken quickly through cooperative decision-making, or other measures to manage the rail flow. Moreover, there were various players associating the notion of strategic coordination with newer green logistics agendas such as encouraging load factors to rise and discouraging blank repositioning. The research makes no attempt to report an exact carbon-reduction rate level along the corridors as a result of access-to-information restrictions, but rather uses decarbonization as an objective of governance that only becomes operational once standardization of standards, incentives, and evaluation of performance have been achieved among the participants.

6. Discussion

6.1 Virtual Port Coordination and the Reconfiguration of Port-Hinterland Integration Theory

The presented paper builds upon the theory of the integration between the port and hinterland through the fact that

functional integration within cross-border multimodal transport systems is increasingly led by the ability to coordinate, instead of being physical or controlled by ownership.

Although port regionalization theory was originally focused on spatial scale and organization consolidation in relatively homogenous institutional environments, results indicate that these mechanisms do not work in situations of institutional fragmentation and multiplicity of jurisdictions. Virtual Port Coordination becomes a possible way of achieving functional integration of the dry port into maritime logistics networks in the case of double-landlocked contexts where centralized governance is not feasible.

Through conceptualization of integration as a capability-driven process and not a spatial result, this research redefines port-hinterland integration as a continuous act of coordination. This reorientation is also expanding current theories in that it points out how functional integration can be realized without territorial continuity, or a formal hierarchy.

6.2 Digital Platforms as Coordination and Governance Capabilities

In this research paper, the contribution to the body of knowledge on port digitalization is made by going beyond technological explanations but instead redefining digital platforms as a form of governance and coordination ability.

The findings in question support the idea that, instead of seeing platforms as neutral infrastructure which has a passive role in facilitating the exchange of information, they can play an active role in structuring coordination through

creating visibility, decision rights and operational flexibility. Digital platforms are a mediator of inter-organizational relations and redistribution of coordination power among participants via shared architectural models, virtual scheduling, or joint decision protocol (Caldeirinha et al., 2020; Surucu-Balci et al., 2024).

Such an angle allows explaining how comparable digital technologies can produce different effects in various contexts. The efficiency of digital platforms is not based merely on their technical sophistication but on the ways they are integrated into coordination mechanisms and governance systems. Through this framing of this capability-focused standpoint, the paper contributes to the literature on digitalization, port governance as well as inter-modal coordination.

6.3 Coordination Quality as a Causal Mechanism

One of the most important theoretical contributions of this research is that it establishes coordination quality as a causality between coordination schemes and performance results in cross-border multimodal transport systems.

In most of the past research focusing on governance, it is believed that coordination activities and performance enhancement are directly correlated. Instead, the results indicate that coordination agreements would only impact the outputs when they lead to better coordination quality, which would manifest itself through higher information transparency, decision synchronization, and resource integration (Liu et al., 2025; Nguyen et al., 2026).

The investigation can offer a process level explanation of how coordination functions in practice by

unpacking this mediating mechanism. This emphasizes causal mechanisms over mere correlations, highlighting how pivotal intermediate organizational processes illuminate performance variation.

6.4 Implications for double-landlocked countries

The trade performance of double-landlocked nations can be constrained structurally because they do not have access to the global transportation web of water transportation, thus, coordination quality may be an important condition. The evidence points out to the fact that there can be higher returns on coordination capability investments in addition to the sole fact that expanding more infrastructure could do that. They consist of platform-based governance, shared-decision-making norms and online operational synchronisation.

Virtual Port Coordination could be considered as an efficient solution to dry port challenges due to the structural drawbacks in terms of organizational and institutional creativity. It is very relevant to the development policies of landlocked areas, in which financial and geographic factors restrict the possibility of carrying out extensive infrastructure initiatives.

6.5 Limitations and Future Research

Virtual Port Coordination is not intended as a context-sensitive solution, but rather as a way of viewing how coordination abilities can replace physical integration in situations of fragmented governance. In spite of these contributions, the current paper does have limitations. The discussion will focus on a particular China-Central Asia corridor that could limit generalizability. Future studies might look into whether or not Virtual Port Coordination could work in

more than two corridors, or incorporate both qualitative and quantitative methods in order to test the scalability of the proposed framework. Although the empirical environment is limited, the coordination processes that were observed are likely to be applicable to other cross-border multimodal transport environments where institutional fragmentation is present.

(a) Restrictions on Digital Infrastructure: The involvement of a number of actors does not lead to any significant change in synergistic effects, but creates dependencies between VPC mechanisms instead because the participating actors may not have sufficient digital infrastructure or technical skills.

(b) Geopolitical Tension: Political relations are worsening, which in turn can lead to a breakdown of cross-border flows of information and coordination processes, thus affecting the VPC efficiency.

(c) Severe Capacity Constraints: In cases where transport capacity is extremely constrained (e.g. rail bottlenecks), the coordination improvements will not make up for physical constraints.

(d) Power asymmetries: In cases where there have been very high power imbalances between the parties involved, trust and information sharing can be undermined and this in turn may affect their effectiveness in implementing VPCs.

These drawbacks indicate the directions that might be taken through further study, such as comparative case investigation, use of mixed approaches, and studying the forms of failure in VPC and its limit conditions.

7. Conclusion

The aim of this investigation was to explore the issue of seaport and dry port attaining effective cross-border integration in institutional fragmentation environments with low connectivity. The article tackled one of the most pressing voids in the literature on port-hinterland integration by considering the interaction between Ningbo-Zhoushan Seaport and Tashkent Dry Port. Despite significant literature gaps in the field, the study of infrastructure investments and technologies as the focus of port-hinterland integration has taken place much longer than that of inter-state mechanisms of coordination on ports functioning.

Theoretically, it can be noted that the research presents Virtual Port Coordination as a form of governance capacity that allows achieving functional integration of seaport and dry ports, without any formal organizational integration or physical proximity. The results are based on the process-tracing method whereby it is indicated that Virtual Port Coordination involves four interlinked dimensions, namely informational, managerial, operational, and strategic coordination. Quality of coordination is the mediator that connects these dimensions with intermodal performance results, especially in digital synchronization contexts, when just-in-time coordination is very important as a measure of ensuring performance stability.

This study theoretically contributes to the research field of port-hinterland integration by changing analytical emphasis from explaining the phenomenon based on infrastructure-centric accounts into coordination-focused mechanisms. By so doing, it adds

to previous works done on smart ports and digitalization literature by illustrating how information systems and digital platforms are effective due to the fact that they have been integrated into other areas of coordinated governance and coordination as opposed to the technological complexity alone.

Taking into consideration the practical aspect of the issue, the results provide some useful recommendations to policymakers, port authorities and the stakeholders of the corridors that participate in the process of cross-border intermodal development. Instead of focusing on the increase of the scale of infrastructure, stakeholders can obtain significant gains in performance as they invest in coordination skills that can improve the level of information clarity, alignment of decisions, and collaboration in solving problems within and between organizations, as well as across national borders. The meaning of this implication is especially applicable to landlocked and double-landlocked countries, where geographical restrictions on physical connectivity make coordination mechanisms particularly valuable.

Finally, this paper also has numerous weaknesses, and the following are some of them. The analysis relies on the use of only one in-depth case study, thereby limiting the possibility that the results will generalize directly. However, the research focus is analytical but not statistical generalization. Other future studies may adopt the idea of the Virtual Port Coordination framework in other cross-border corridors or use comparative case designs or combine quantitative methods to extend, test, and develop the mechanisms described in this study.

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