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Anticipatory Regionalization of Busan's Emerging Gateway Region: A Conceptual Framework for Sustainable Gateway Development

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Abstract

Gateway regions contain operating ports, planned airports and logistics districts with different delivery horizons. This article develops anticipatory gateway regionalization as a conditional framework for the formation of complementary capabilities before all assets operate. The scholarly synthesis covers 60 works selected through reference-led screening and a dated six-query targeted discovery search. A nine-record official-document analysis, 2023–2025 port throughput baseline and structured Singapore–Dubai comparison provide bounded context. Four mechanisms—temporal alignment, functional complementarity, spatial and urban embedding, and institutional orchestration—organize six untested propositions. Existing systematic reviews limit claims of novelty and document competing interpretations. The records identify port growth, asynchronous project plans, a 2024 environmental-scoping notice, earlier port consultations and a 2026 airport-project coordination meeting. They do not establish a binding cross-modal coordination mechanism or its effects. A proposition-specific challenge audit distinguishes observed precursors from rival explanations and unavailable outcomes. The operational/developmental hinterland distinction and service-specific stranded adjacency identify conceptual boundaries. An operating baseline and a dimensionless financial illustration provide descriptive and conditional appraisal evidence. Firm-level routing, additional regional value, post-opening services and causal effects remain unmeasured. The contribution is a bounded conceptual and documentary analysis, not an empirical validation of all six propositions.

Keywords: port regionalization; infrastructure asynchrony; sustainable gateway development; institutional orchestration; port–airport integration; regional value capture; stranded adjacency; gateway region; business ecosystem; Busan–Jinhae–Gadeok

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1. Introduction

Ports are no longer adequately understood as bounded transport facilities whose competitiveness is determined only by nautical access, quay capacity and terminal productivity. Their performance increasingly depends on inland corridors, logistics districts, digital platforms, industrial clusters, producer services and urban labour markets [1–4]. Port regionalization theory explains how maritime gateways extend inland through terminals, corridors and logistics platforms [5,6]. Although much of this work examines established flows, later research also recognizes strategic agency and institutional change. Sequencing

becomes consequential when interdependent assets must be planned before their joint flows become observable.

Operating cargo flows provide only part of the explanation for gateway regions in which major infrastructure assets are planned and delivered at different speeds. Authorities must reserve corridors, allocate logistics land, attract firms, organize data systems and prepare labour markets before the relevant flows become observable. Early commitments may lock scarce land and capital into inappropriate uses; late commitments may create missing links, operational bottlenecks and forgone investment. The question therefore concerns how a future gateway system acquires complementary capabilities under uncertainty [7,8].

Busan–Jinhae–Gadeok provides an illustrative setting. Busan New Port is an operating maritime anchor, and Jinhae New Port is a capacity extension within the wider Busan Port system. Gadeokdo New Airport remains pre-operational. A March 2026 announcement initiated its basic-design process and stated a target opening in the second half of 2035 [9]. On 7 September 2026 the Ministry of Land, Infrastructure and Transport reported receipt of the airport site-formation basic-design submission [10]; on 18 September it reported the first meeting of an airport-project coordination body comprising the ministry, Busan Metropolitan City and the airport construction corporation [11]. These are documentary procedural observations, not proof of airport construction completion, effective cross-modal integration or commercial demand. Existing port hinterland districts, free economic zones, manufacturing cities and metropolitan labour markets surround these assets. Their proximity alone does not establish an integrated commercial system.

According to Busan Port Authority (BPA), Busan New Port handled 17.880 million twenty-foot equivalent units (TEU) in 2024 and 18.638 million TEU in 2025, representing 73.3% and 74.9% of Busan Port's respective container throughput [12]. A construction notice published in September 2025 lists April 2024–November 2028 for the first-phase southern breakwater and April 2025–May 2030 for the first container-terminal works package at Jinhae [13]. These are reported works periods rather than independently observed start or completion dates. Completion of a works package is also distinct from commercial opening.

The Physical Artificial Intelligence (AI) Port Strategy, posted on 22 July 2026 for announcement on 23 July, identifies Jinhae's first phase in 2032 and second phase in 2040 as policy horizons. It proposes links between existing terminals and maritime, land and air logistics data [14]. These targets differ in scope from the works-package dates in [13]. Neither source demonstrates an operating port–airport service, and the airport opening date in [9] is likewise a target rather than an observed outcome.

The sequencing problem is also a sustainability problem. Economically, mistimed commitments can leave terminals, corridors or logistics land idle, and gateway growth can coexist with weak value retention in the host region. Socially, the benefits of gateway employment depend on accessible jobs and on community acceptance of construction and operational burdens. Environmentally, early allocation of land to road-dependent uses and uncoordinated construction can lock in emissions and land consumption that later integration cannot reverse [15,16]. The framework therefore speaks to Sustainable Development Goal (SDG) 9 on resilient infrastructure, SDG 11 on sustainable cities and communities and SDG 13 on climate action [17].

Three questions organize the analysis. First, how should port regionalization theory be extended when key gateway infrastructures are not simultaneously operational? Second, which mechanisms convert spatial proximity among ports, airports, logistics districts and hinterland cities into commercial complementarity? Third, how can the resulting framework be made observable and testable during the transition from planning to operation?

The contribution is an explicitly bounded theoretical recombination [18] of four alignment mechanisms, analytically distinct operational and developmental hinterland functions,

and a narrowly diagnosed failure state. Six falsifiable but untested propositions organize the comparison of competing explanations. The nine official records document heterogeneous project horizons and some pre-operational administrative coordination, without demonstrating either regionalization effects or failure. The service-specific challenge matrix in Section 5.5 and Table A4 identifies what the sources support, what contradicts stronger claims and which observations remain unavailable. Figure 1 summarizes the documented operating base and the different dates and statuses of source-reported milestones.

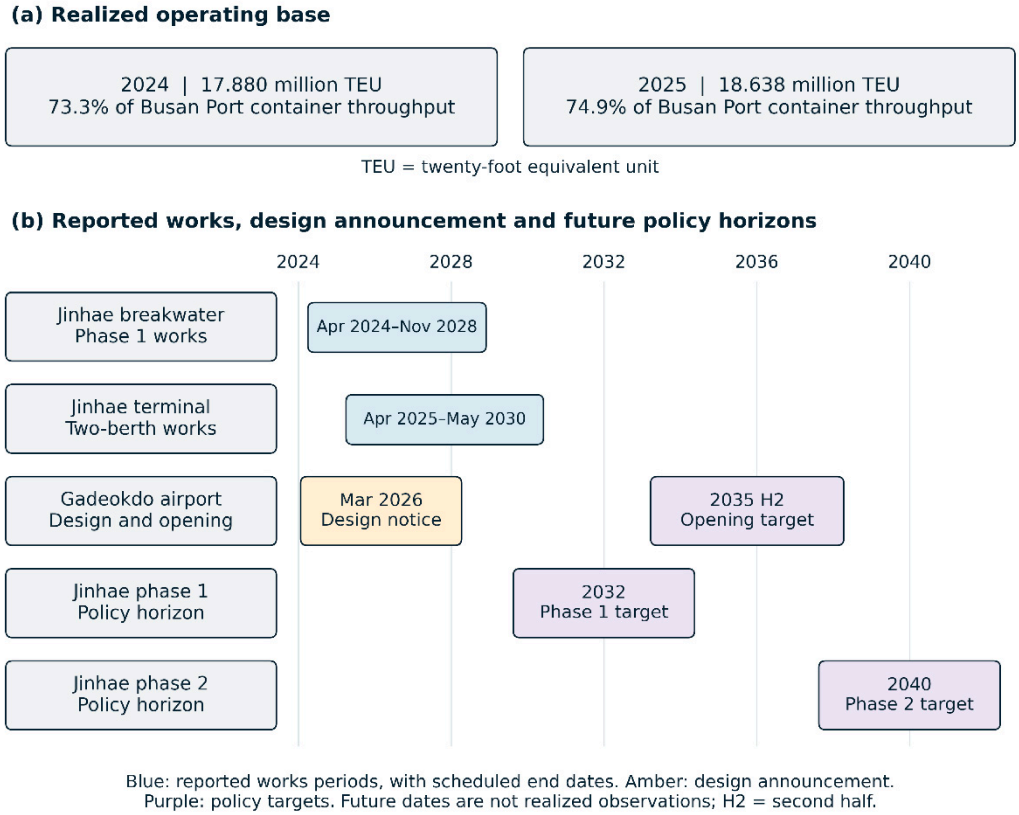


Figure 1. Operating results and source-reported development horizons. (**a**) Realized container throughput at Busan New Port in 2024 and 2025. (**b**) Reported works periods, the airport design announcement and future policy horizons. Blue bars show reported works periods with scheduled end dates; amber denotes a design announcement; purple denotes policy targets. The two-berth works package ending in 2030 differs in scope from the broader 2032 first-phase policy horizon. Future dates are not observations. Sources: airport announcement [9], throughput [12], works notice [13] and national strategy [14]. Prepared with AI assistance as described in Section 2.4; the final conceptual content and graphical representation were reviewed, revised, and approved by the authors.

2. Materials and Methods

The research combines a purposive, reference-led theory synthesis informed by integrative-review principles [18–20] with a bounded, status-coded analysis of official documents. This is neither a registered systematic review nor a causal process-tracing study. Its analytic outputs are construct definitions, conditional propositions, transparent source-to-claim mapping and specifications for observations that could contradict the framework. Descriptive source statements are kept separate from the authors' interpretation, prospective measures and candidate policy instruments.

The analysis integrates three components: (i) source-level scholarly discovery and eligibility coding (Appendix E); (ii) extraction of contemporaneously dated operating values and official administrative records (Appendix C); and (iii) an adversarial evidence

audit organized by proposition and rival explanation (Table A4). Only the third is a limited within-case challenge exercise; the records are insufficient for causal process-tracing identification. Evidence terms are used consistently: "observed" for published throughput or a reported dated administrative act, "reported" for works periods, "target" for future policy dates, "proposition" for unestimated relationships and "pilot candidate" for an unapproved intervention.

2.1. Literature Scope and Selection Transparency

The scholarly inventory contains 60 purposively retained works. Fifty-seven were identified through reference-led selection: 39 substantive studies, nine critical or rival-explanation studies, six comparative studies and three methodological works (Appendix B). The scholarly literature was compiled between July and October 2026; within this period, a targeted search of publicly indexed academic sources in October 2026 identified three further publications concerning port–hinterland governance, integration mechanisms and stated preferences for a proposed sea–air service [21–23]. The 57-work reference-led selection has no complete dated database export, candidate retrieval list, duplicate-screening record or candidate-level exclusion log. Appendix E documents the executed search queries, access limitations and inclusion decisions for the three search-identified publications. Since ranked web-search results do not constitute an exhaustive or stable bibliographic database corpus, the search is described as targeted scholarly discovery rather than a systematic review. Eligible sources address gateway development, hinterland governance, multi-port relations, port–city integration, ecosystems or infrastructure sequencing with a relevant logistics, regional, governance or strategic decision dimension. Titles, publication records and DOIs were checked where available. The inventory supports traceable interpretive synthesis but does not establish search completeness, saturation, independent duplicate coding or a formal risk-of-bias assessment.

2.2. Interpretive Mapping and Synthesis

For each of 60 included scholarly sources, the mapping records five categories: the relevant claim, analytical role (input, qualification, rival explanation, method or comparison), proposed construct, mechanism, and proposition linkage (Appendix B). We first juxtaposed the six literature streams in Table 1, then identified four distinct dependencies—asset timing, independently justified joint-service value, regional production/labour links and decisions across autonomous actors. We formulated P1–P6 only after separating mechanisms from outcomes (Section 4). Section 4.6 records rival pathways and potentially weakening observations for each proposition. The mapping is qualitative argument reconstruction, not a count of positive empirical findings or a reproducible database screen. It was not independently duplicate-coded; no intercoder-reliability estimate can be reported.

Table 1. Interpretive synthesis from six literature streams to mechanisms and propositions. The scope statements describe the emphasis relevant to the analysis, not universal assumptions of each literature.

Literature Stream	Established Insight	Scope Relevant to the Synthesis	Proposed Construct	Mechanism	Proposition Links
Port regionalization	Gateway functions extend through corridors and inland nodes	Flows, strategy and actors are already recognized	Critical-interface exposure	Temporal alignment	P1, P2
Multi-port gateway regions	Ports compete, concentrate and cooperate	Main focus is seaport relations; timing varies	Cross-node service capability	Functional complementarity	P3

Table 1. *Cont.*

Literature Stream	Established Insight	Scope Relevant to the Synthesis	Proposed Construct	Mechanism	Proposition Links
Port–city and cluster research	Urban and supplier relations shape regional development	Includes institutions and regional change	Overlapping hinterland functions	Spatial and urban embedding	P4
Port governance	Decisions depend on authority, ownership, coordination and legitimacy	Includes planning, reform and institutional agency	Coordination across asset dependencies	Institutional orchestration	P5, P6
Business ecosystems	Interdependent complements enable a value proposition	Includes alignment before realization	Recurrent joint-service formation	Functional complementarity	P3
Megaproject and lock-in research	Uncertainty and irreversibility affect commitment	Findings require contextual transfer to an asset portfolio	Net option value; continuity under contested development	Temporal alignment; institutional orchestration	P2, P6

For example, regionalization and megaproject research jointly motivate the question of whether preserving options can reduce adaptation costs (P1–P2). Multi-port and ecosystem research motivates an independently measured complementarity pathway (P3). Port–city, cluster and production-network research motivates regional capability and value-capture questions (P4). Governance and megaproject research motivates conditional coordination and legitimacy relationships (P5–P6). These are the authors' deductions; the cited studies do not test the newly combined framework. Existing research on agency, institutional plasticity and port ecosystems also limits the novelty claimed in Section 3.4.

2.3. Documentary Layer

The official-document corpus contains nine purposively selected records [9–14,24–26] covering port throughput, reported construction periods, future policy horizons, airport design and pre-operational institutional activities and environmental-scoping consultation. Three kinds of dates are distinguished. The documentary event cutoff, 28 October 2026, applies only to the documentary and empirical evidence (official records and operating data); later events are not considered. All nine records were accessed on 28 October 2026. The cutoff does not apply to the scholarly literature, which was compiled between July and October 2026, including a targeted search in October 2026; these dates are reported separately in Section 2.1 and Appendix E. Records from 2019 to 2021 are retrospective entries in a published BPA chronology, not contemporaneous recovered minutes. Appendix C identifies source, date, extraction locator, purpose and limitation. The extraction unit is an attributable passage or dated entry. Coding distinguishes realized outcome, reported activity, scheduled milestone and policy target; it also distinguishes explicit action, stated intention and information absent from the selected record. Each coordination episode is tagged by institutional remit (port project, airport project or an established cross-modal interface). The authors did not obtain an independently coded archive, interview corroboration or a longitudinal administrative-decision panel. Absence of a statement in a short announcement is not evidence of institutional absence.

2.4. Use of Generative AI

ChatGPT and Codex (GPT-6 Astra; OpenAI, San Francisco, CA, USA) were used for language editing, grammar correction, conceptual figure preparation, and image generation. AI assistance included suggestions for refining construct definitions and the selection and

representation of hypothesized relationships, together with graphical implementation, including layout, labels, and connectors. The authors evaluated these suggestions against the cited literature and documentary evidence and selected and revised the final constructs, relationships, and graphical representations. The figures prepared with AI assistance are identified in their respective captions. AI-generated suggestions were not treated as documentary evidence or empirical validation of the proposed framework. All model output was reviewed, verified, and edited by the authors. The authors retain full responsibility for the content, accuracy, and integrity of the publication.

3. Results of the Theoretical Synthesis

3.1. Port Regionalization and Infrastructure Timing

Port regionalization explains the functional extension of maritime gateways into inland space through corridors, inland terminals and distribution platforms [5,27–29]. Dry ports can relocate customs, storage and modal-transfer functions inland and may reduce road congestion where cargo density and rail services are viable, although dry-port projects also contain interdependent risk dimensions [6,30]. Later studies showed that these processes are not automatic. Institutional barriers and mismatched strategies among ports, carriers, inland terminals and public authorities can prevent effective integration [31–33].

These studies explain flows, strategic agency and institutional constraints, including planning and pre-operational action [7,31–33]. Anticipatory gateway regionalization combines the relative timing of interdependent assets with commercial and urban capability formation. The contribution lies in this analytical recombination rather than in identifying anticipatory agency as a previously unrecognized process.

3.2. From Operational Hinterland to Developmental Hinterland

Port–city research demonstrates that the relocation of terminals does not remove urban dependence. Ports continue to draw on specialized labour, engineering, finance, logistics services, research institutions and metropolitan accessibility [34–36]. Seaport cluster performance likewise depends on relationships among firms and institutions rather than simple co-location, and on the quality of regional production, knowledge and proximity relations [37–40]. Recent evidence on port–city synergy reinforces the importance of transport networks, industrial structure and regional policy in converting port development into wider economic effects [41].

Operational and developmental hinterlands denote two analytical functions. The operational hinterland provides cargo-handling and circulation capabilities through terminals, corridors, customs, warehouses and data interfaces. The developmental hinterland supplies firms, labour, knowledge, housing, professional services and capacities for environmental management and participation. These functions overlap spatially and organizationally; a logistics firm may contribute to both. Throughput growth can coexist with external procurement or commuting leakage, but such outcomes require measurement rather than inference from the functional distinction.

3.3. Ecosystems, Orchestration and Infrastructure Lock-In

Business ecosystem theory holds that value depends on aligned activities undertaken by interdependent actors and on capabilities that permit adaptation over time [42–45]. A port authority cannot independently deliver an integrated gateway service because shipping lines, terminals, customs agencies, road and rail operators, logistics firms, manufacturers and technology suppliers control essential complements. Port governance studies similarly show that coordination problems arise because no single actor controls the hinterland chain and because reforms operate through diverse institutional settings [46–50].

Recent work further emphasizes uncertainty, digital integration and resilience at the port-ecosystem level [51,52].

Megaproject research adds a temporal warning [53]. Sunk costs, political commitments and premature design closure can lock projects into weak trajectories [54,55]. For gateway regions, lock-in can occur outside the terminal: land can be allocated to road-dependent tenants, corridors can be duplicated and incompatible data systems can become embedded. An adequate theory must therefore treat the port, airport, corridors, logistics land and urban capabilities as an interdependent investment portfolio.

3.4. Positioning Against the Related Literature

Anticipatory gateway regionalization overlaps with established work. Windows-of-opportunity and path-dependence research recognizes purposeful change [7,8]; multi-port research recognizes cooperation and institutional impediments [28,33]; port–city research connects urban capabilities with development [35,41]; and ecosystem theory addresses the alignment of complements before and after a value proposition is realized [42,44,45]. The framework organizes these insights around an interdependent portfolio of gateways, connections, land and urban capabilities with different delivery dates (Table 2). The dual-hinterland distinction is a heuristic, and stranded adjacency is a bounded diagnostic category whose additional explanatory value requires evaluation.

Table 2. Positioning of anticipatory gateway regionalization against the related literature.

Literature	Unit	Timing	Change Mechanism	Pre-Operational Relevance	Analytical Emphasis
Windows of opportunity and path dependence [7,8]	Port system or region	Evolution over time	Purposeful institutional and strategic change	Agency and future paths already recognized	Joint timing of several interdependent asset types
Multi-port gateway regions [28,33]	Related seaports	Development and operation	Competition and cooperation	Planning and cooperation are possible	Commercially justified cross-modal dependencies
Port–city and cluster research [35,41]	Port and urban economy	Urban and regional evolution	Labour, supplier and policy relations	Capability preparation is compatible with this work	Circulation and regional capability distinguished analytically
Business ecosystems [42,44,45]	Actors around a value proposition	Before and after realization	Alignment of interdependent complements	Central to ecosystem strategy	Asset timing, land and urban interfaces made explicit
Anticipatory gateway regionalization	Asset portfolio	Before all required assets operate	Conditional alignment of timing and capabilities	Explicit organizing focus	Combined propositions and a bounded diagnostic category; added value untested

4. Anticipatory Gateway Regionalization

Anticipatory gateway regionalization is the deliberate formation of connective, commercial, urban and institutional capabilities around interdependent gateway assets before all nodes required for a proposed service become operational (Figure 2a). It applies where at least one critical asset is incomplete, autonomous actors control complementary resources, and sequencing affects feasible responses to uncertain demand. Interdependence requires

evidence beyond geographical proximity. The six propositions are deductions from the theoretical synthesis and remain untested.

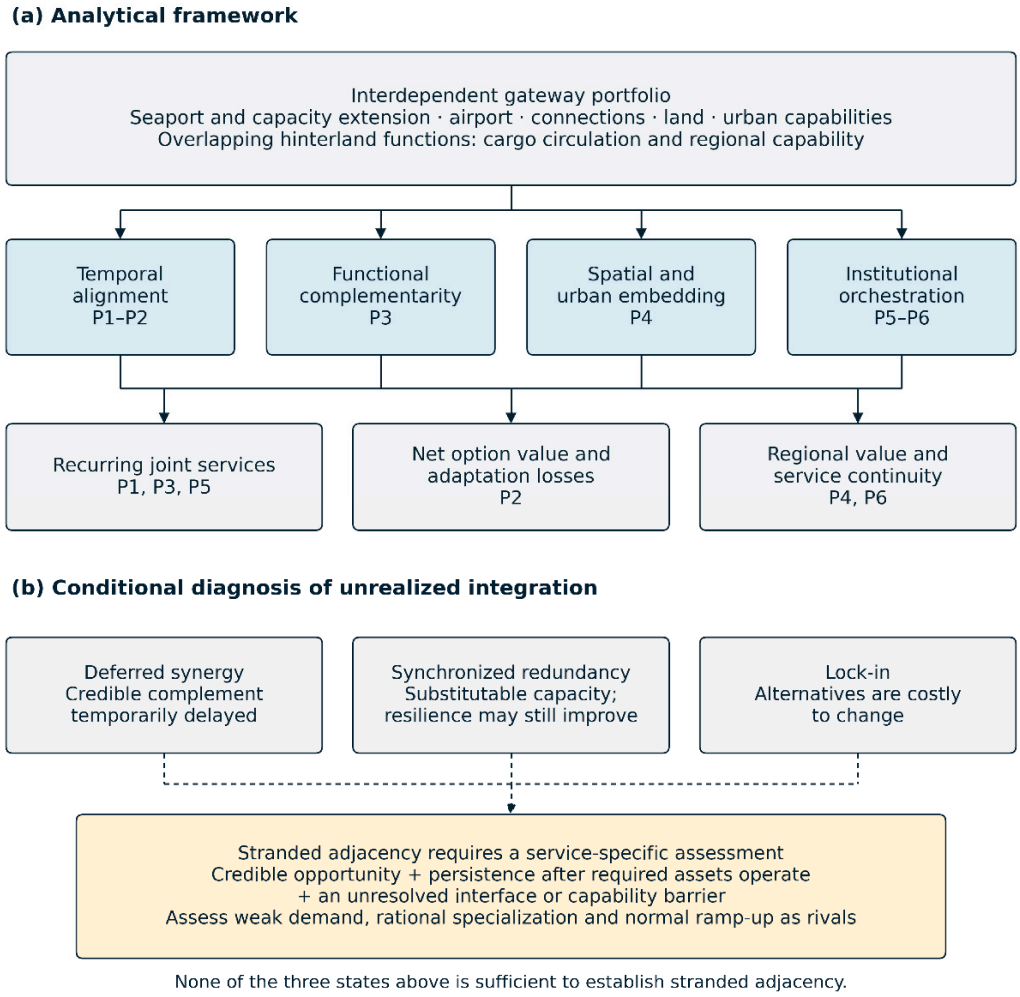


Figure 2. Analytical framework and conditional diagnosis. (**a**) Interdependent assets, overlapping hinterland functions, four alignment mechanisms and prospective outcomes. The aggregate connections organize the framework; Figure 3 specifies the proposition-level relationships. (**b**) Deferred synergy, synchronized redundancy and lock-in motivate service-specific assessment but are not sufficient conditions for stranded adjacency. Diagnosis requires an independently credible service opportunity, persistence after all required assets operate and evidence of an unresolved barrier, with rival explanations assessed. Arrows do not represent observed transitions. P denotes proposition. Source: authors' elaboration. Prepared with AI assistance as described in Section 2.4; the final conceptual content and graphical representation were reviewed, revised, and approved by the authors.

Table 3 separates constructs from their measurement proxies. Gateway ecosystem formation concerns recurrent joint services and transactions. Functional complementarity concerns the independently assessed benefit of combining capabilities, rather than transaction volume itself. Option value concerns the incremental value of flexibility relative to a fixed commitment; a staged land-release ratio is only a process proxy. Hinterland integration is measured through supplier and labour links, while regional value capture requires value-added or income evidence. These distinctions prevent a mediator and its outcome from being defined by the same indicator.

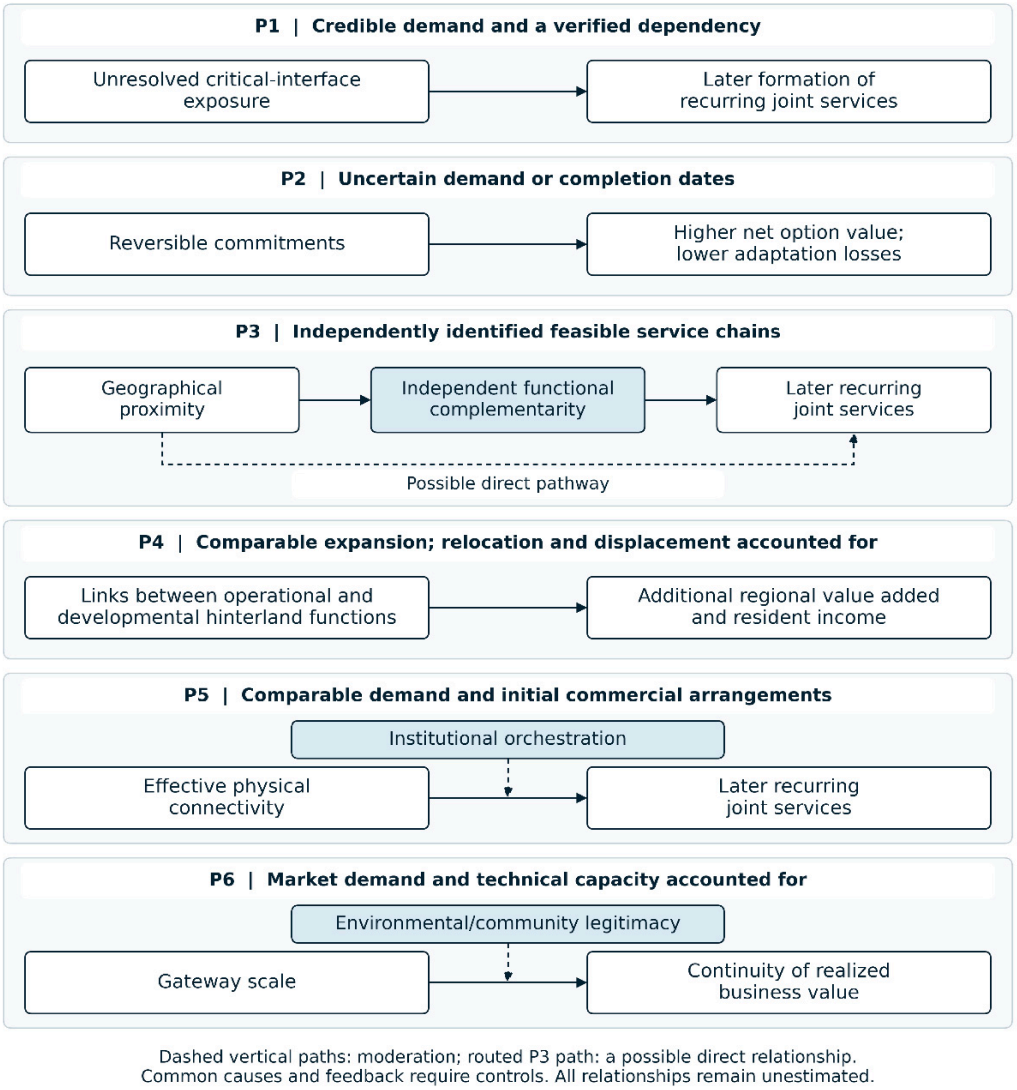


Figure 3. Hypothesized relationships in P1–P6. P denotes proposition. Explanatory variables, the independently measured P3 mediator and subsequent outcomes are distinguished. Dashed vertical arrows indicate moderation of relationships; the routed dashed P3 path denotes a possible direct proximity relationship. Demand, initial capabilities, ownership and regulation are potential common causes, and outcomes may feed back into coordination. All relationships remain unestimated. Source: authors' elaboration. Prepared with AI assistance as described in Section 2.4; the final conceptual content and graphical representation were reviewed, revised, and approved by the authors.

Table 3. Definitions and indicators of the constructs.

Construct	Definition	Prospective Measure or Proxy in Section 6
Critical-interface exposure	A required complement is unavailable when a specified service or commitment needs it	Required-versus-available date; schedule and realized records kept separate
Temporal alignment	Ability to sequence interdependent commitments and retain feasible alternatives	Interface exposure; conditional land release as a process proxy
Net option value	Incremental expected present value of a flexible rather than fixed commitment, net of staging and waiting costs	Scenario-specific value difference; realized adaptation cost as a separate outcome
Functional complementarity	Incremental service capability or generalized-cost advantage of combining nodes against a feasible alternative	Independent service-capability assessment before measuring joint transactions

Table 3. *Cont.*

Construct	Definition	Prospective Measure or Proxy in Section 6
Gateway ecosystem formation	Emergence and continuation of recurrent joint services among independent actors	Repeat joint-service transactions; multi-node customer share as a supporting proxy
Spatial and urban embedding	Links between gateway activities and regional labour, suppliers and other urban capabilities	Regional procurement and worker access; not assumed from distance
Hinterland integration	Operational activities draw measurable capabilities from developmental-hinterland functions	Supplier and labour links; functions can overlap within one firm or place
Institutional orchestration	Alignment of interdependent decisions through public, private or mixed arrangements	Documented decision rights, due-issue closure and tested data exchange
Legitimacy	Sustained, procedurally credible acceptance by affected communities and regulators	Acceptance and grievance evidence alongside permit compliance
Regional value capture	Regional production and resident-income benefits attributable to gateway activity	Regional value-added share and net additional value added; procurement reported separately
Stranded adjacency	Persistent non-realization of an independently credible joint service after its required assets operate	Service-specific follow-up and barrier evidence; no diagnosis from low volume alone

4.1. Infrastructure Asynchrony and Temporal Alignment

Infrastructure asynchrony is a mismatch among the dates when gateway assets, connections, land and urban support functions are required and become available. Differences in completion dates are not inherently harmful. Exposure arises only when an independently specified service or investment depends on an unavailable complement. Scheduled exposure and realized delay must be recorded separately; neither can be inferred solely from two projects having different opening dates.

Temporal alignment is the capability to sequence interdependent commitments while retaining feasible responses to new information. Candidate instruments include protected interfaces, modular facilities, conditional land release and contingencies. They may also impose carrying, coordination and waiting costs. The relevant comparison is the net value of flexibility against an explicit fixed-commitment alternative, not simultaneous completion or staging for its own sake.

Proposition 1. *Conditional on credible demand and a verified dependency, greater unresolved critical-interface exposure is associated with later formation of recurrent cross-node services, relative to otherwise comparable service chains with the required complements available.*

Proposition 2. *Under uncertain demand or completion schedules, commitments that remain reversible until independently specified information arrives yield higher net option value and lower irreversible adaptation losses than otherwise comparable fixed commitments.*

4.2. Functional Complementarity

Functional complementarity exists when the capability of one node raises the value of another. It differs from specialization, because specialized facilities may remain commercially unrelated. Complementarity may arise through cargo type, service speed, vessel or aircraft requirements, technology, customs arrangements, manufacturing links or resilience functions.

New capacity may substitute for existing activity rather than create additional value. Port–airport proximity is therefore an insufficient basis for an integration claim. Sea–air

services require a feasible combination of commodity characteristics, handling reliability, customs arrangements, schedules and end-to-end generalized cost. The comparison must include viable all-sea, all-air or other routing alternatives. Positive throughput at two nearby facilities does not establish complementarity.

Proposition 3. *For independently identified feasible service chains, functional complementarity partly mediates the relationship between geographical proximity and subsequent gateway ecosystem formation; proximity alone need not produce joint services.*

4.3. Spatial and Urban Embedding

Spatial and urban embedding connects gateway activity to regional suppliers, labour, research, housing and environmental systems. Accessibility alone is insufficient. An automated terminal may reduce some manual tasks while increasing demand for software, equipment maintenance, systems integration and cybersecurity. If these capabilities are sourced externally, terminal productivity may rise without equivalent regional value capture.

Operational hinterland functions enable cargo circulation, while developmental hinterland functions connect that activity to regional suppliers and workers. Procurement and labour links are intermediate relationships rather than evidence of net regional benefit. Proposition 4 therefore requires regional value-added evidence, a fixed spatial boundary and adjustment for relocation and displacement.

Proposition 4. *For comparable capacity expansion and after accounting for displacement, stronger links between operational and developmental hinterland functions are associated with greater additional regional value added and resident income than capacity expansion with weaker regional links.*

4.4. Institutional Orchestration and Legitimacy

Institutional orchestration is the capacity to align interdependent decisions through compatible milestones, information rights, cost and risk allocation, and conflict resolution. It need not involve organizational merger or public leadership. Carriers, operators and private platforms can supply coordination. Its net contribution should be assessed against coordination costs, institutional rigidity and the strength of existing commercial arrangements.

Legitimacy denotes procedurally credible and sustained acceptance by affected communities and regulators. Permit compliance is necessary but does not by itself establish that acceptance. Environmental burdens and uneven benefits can affect implementation [15,16], while consultation can reveal unresolved or conflicting preferences. Independent participation, grievance and acceptance evidence is therefore required alongside compliance records.

Proposition 5. *For comparable service demand and initial commercial arrangements, the association between effective physical connectivity and subsequent ecosystem formation is stronger where cross-actor decision rights and interfaces are explicitly coordinated; this difference is expected to be greater under jurisdictional fragmentation.*

Proposition 6. *The association between gateway scale and continuity of realized business value is stronger under sustained environmental and community legitimacy, conditional on market demand and technical capacity; this relationship may be more consequential where approvals span several jurisdictions.*

4.5. Stranded Adjacency

Stranded adjacency is the persistent non-realization of an ex ante specified, commercially credible cross-node service after all assets required for that service become operational, despite their geographical proximity. It is a proposed subset of co-location without

integration, not a label for every unconnected pair of facilities. Its diagnosis requires an independently documented service opportunity, an explicit follow-up horizon and evidence of an unresolved interface or capability barrier. Rational specialization, inadequate demand and ordinary ramp-up remain alternative explanations. No such diagnosis is made for Busan–Jinhae–Gadeok.

Deferred synergy concerns a temporary delay to a credible complement; synchronized redundancy concerns substitutable capacity; and lock-in concerns costly irreversibility, which does not require proximity (Table 4; Figure 2b). None necessarily ends in stranded adjacency. Future studies should prespecify a service-specific follow-up horizon and report sensitivity to shorter and longer horizons. Low sea–air volume or low regional procurement alone cannot identify the construct. Regional value capture and cross-node commercial integration are separate outcomes, and unavailable observations must be recorded as missing rather than zero.

Table 4. Stranded adjacency and related concepts.

Concept	Proximity Required	Relationship	Time Condition	Reversibility	Diagnostic Evidence
Co-location without integration	Yes	Joint services absent	Any	Varies	Nearby assets operate independently; commercial rationale may be absent
Deferred synergy	Context	Credible complement delayed	Temporary	Depends on the delayed complement	Documented service opportunity and recoverable missing interface
Synchronized redundancy	No	Capacity is substitutable	Any	Varies	Overlapping services and demand; redundancy may add resilience
Lock-in	No	Alternatives costly to change	Path dependent	Costly or limited	Irreversible contracts, land uses, designs or standards
Stranded adjacency	Yes	Credible joint service unrealized	Persistent after required assets operate	Varies; not a defining condition	Pre-specified opportunity and horizon; unresolved barrier; rival demand explanation assessed

4.6. Causal Structure and Measurement of the Propositions

Figure 3 distinguishes proposed relationships and measurement roles. Functional complementarity is measured independently of subsequent joint transactions in P3; institutional orchestration moderates the connectivity relationship in P5; and legitimacy moderates the scale relationship in P6. Temporal ordering, demand controls and the possibility that successful integration attracts coordination require explicit treatment before mediation or moderation estimates can support causal interpretation.

Table 5 specifies each proposition's unit of analysis, boundary conditions, rival explanation and potentially weakening observation. These are prospective tests; the documentary corpus supplies contextual evidence.

Table 5. Proposition-to-measurement matrix.

Proposition and Rival	Distinct Measures	Unit and Time	Boundary	Pattern Weakening the Relationship	Prospective Method
P1; harmless timing differences	Interface exposure before service; subsequent recurring services	Service chain; dated milestones	Credible demand and verified dependency	Comparable chains form services despite unresolved critical exposure	Process tracing; event history with demand and initial-capability controls
P2; staging adds avoidable delay	Incremental flexible-versus-fixed value; adaptation and waiting costs	Parcel or investment package; decisions before outcomes	Uncertain demand or dates; comparable alternatives	Flexibility has non-positive incremental value or no lower irreversible losses	Decision-cohort comparison and audited scenario appraisal
P3; demand or common ownership explains joint use	Travel time → independent service advantage → later repeat transactions	Firm/service pair; temporally ordered measures	Feasible joint-service opportunity; relevant nodes observable	No incremental indirect pathway after demand, initial capability and ownership controls	Longitudinal routing study; mediation only with identification assumptions
P4; redistribution rather than additional benefit	Supplier/labour links → additional regional value added and resident income	Fixed region and linked establishments; before/after	Comparable expansion; displacement tracked	Apparent gain disappears after relocation, leakage or counterfactual adjustment	Supplier-network and regional accounts study with a comparison region
P5; carriers coordinate without added public intervention	Effective connectivity × independently recorded coordination → later services	Interfaces/regions; governance measured first	Variation in fragmentation and coordination cost	No incremental interaction; market arrangements explain services equally well	Comparative process tracing; moderation with endogeneity checks
P6; demand and technology explain continuity	Scale × prior acceptance and compliance → continuity and realized value	Projects and affected groups; repeated observations	Market demand and technical capacity accounted for	Acceptance has no incremental association with continuity or realized value	Approval and grievance tracing; repeated stakeholder and outcome data

5. Documentary Application to Busan–Jinhae–Gadeok

5.1. Source-Reported Milestones and Documentary Scope

The milestone panel establishes different development horizons and observable pre-operational administrative actions, rather than a completed integrated gateway or a harmful effect of asynchrony. Table 6 separates realized operating results, announcements, reported works periods, scheduled milestones and policy targets; Table 7 codes the institutional scope of actions and intentions. The airport basic-design submission reported on 7 September 2026 and the first meeting of an airport-project consultative body on 18 September are dated procedural observations [10,11]. A construction-period label is not a site observation, and the 2030 works package and 2032 policy phase concern different scopes. The nine-record source register and retrospective institutional entries appear in Appendix C.

Table 6. Evidence tiers of the 2024–2026 documentary panel.

Evidence Status	Event or Horizon	Asset/System	Source-Reported Item	Source and Locator
Realized result	2024	Busan New Port	17.880 million TEU; 73.3% of Busan Port. Published import/export and transshipment components: 6.704 million and 11.176 million TEU.	[12], New Port and total-port rows
Realized result	2025	Busan New Port	18.638 million TEU; 74.9% of Busan Port. Shares are calculated from the published total-port denominator.	[12], 2025 rows
Reported activity	Notice dated 8 September 2025	Jinhae southern breakwater, phase 1	Notice lists a works period of April 2024–November 2028. This does not independently verify the physical start date.	[13], Hyundai works package
Reported activity	Notice dated 8 September 2025	Jinhae container terminal, phase 1-1 first section	Notice lists two berths and a works period of April 2025–May 2030.	[13], first terminal package
Announced design procedure	5 March 2026	Gadeokdo New Airport	Site briefing scheduled for 9 March 2026, followed by basic design. Announcement is distinct from verified construction progress.	[9,25], announcement and subtitle
Scheduled milestone	November 2028	Jinhae breakwater package	Reported end of the stated works period; not a realized completion.	[13]
Scheduled milestone	May 2030	Jinhae first terminal package	Reported end of a two-berth works package; not the opening date of the entire port phase.	[13]
Policy target	2032; 2040	Jinhae first and second phases	First-phase Physical AI model and later expansion. Scope differs from the works package above.	[14], strategy 2
Policy target	Second half of 2035	Gadeokdo New Airport	Opening target stated in the March announcement.	[9], subtitle
Reported submission	7 September 2026	Gadeokdo airport site formation	Ministry reports receipt of contractor basic-design documents; design review and contract procedures follow; physical completion not observed.	[10], official release
Reported meeting	18 September 2026	Airport-project coordination	First meeting of MOLIT, Busan City and airport construction corporation; construction cost and project execution issues discussed; announced quarterly meetings. Not a port–airport integration body.	[11], official release

TEU = twenty-foot equivalent unit. Reported works periods and future milestones do not establish realized completion or commercial opening.

A minimal published operating baseline can nevertheless be reproduced. BPA reports New Port throughput of 16.309, 17.880 and 18.638 million TEU in 2023, 2024 and 2025, respectively, and Busan Port totals of 23.154, 24.402 and 24.882 million TEU [12]. New Port's within-port shares are therefore 70.44%, 73.27% and 74.91%, and annual New Port growth is 9.63% in 2024 and 4.24% in 2025 (Table A5). These are arithmetic descriptions of an

already operating asset, not baseline estimates of future sea–air integration, public-policy impact or regional welfare. The environmental-scoping portal additionally records an airport public-comment window from 29 April to 13 May 2024 [26]; this demonstrates an opportunity for procedural input, not stakeholder acceptance, environmental compliance or community legitimacy. The nine-source official layer is bounded to accessible evidence and must not be treated as an exhaustive archive.

Table 7. Bounded documentary coding. "Explicit" identifies a source-reported action or entry, "intended" identifies a stated future measure, and "not specified" means only that the selected document does not establish the matter. None denotes demonstrated effectiveness.

Record	Temporal Alignment	Functional Complementarity	Spatial and Urban Embedding	Institutional Orchestration and Legitimacy
Physical AI strategy [14]	Intended: phased technology deployment; 2032 and 2040 horizons	Intended: real-time links across sea, land and air logistics; no demonstrated joint service	Intended: cluster, supplier support and training	Intended: standards, certification and stakeholder dialogue; implementation and acceptance unmeasured
Jinhae works notice [13]	Explicit: dated works periods and packages	Explicit: terminal works; cross-modal commercial interfaces not specified	Not specified in this safety and construction notice	Explicit: package contractors; cross-sector decision rights and effectiveness not established
Airport announcements [9,25]	Explicit: procurement/design procedure; future opening target	Cross-node service demand not established	[9] reports consortium participation; this is not realized regional value added	[25] proposes a project-promotion consultative arrangement; a proposal is not evidence of operation
BPA development record [24]	Explicit retrospective entries: appraisal/reappraisal and later implementation period	Port-capacity and technology purpose; commercial port–airport services not established	Port-development context; supplier and labour outcomes unmeasured	Explicit retrospective entry: public–private consultative activity from August 2019; authority, minutes and effects not supplied
Airport-project coordination [10,11]	Explicit: design materials received 7 September 2026; first coordination meeting 18 September 2026; future quarterly meetings intended	Port–airport joint-service demand, port participation and operational data interchange not specified	Airport hinterland regional-development agenda discussed; local value-added outcomes not measured	Explicit: MOLIT, Busan and construction corporation met on project execution and costs; remit is airport-project coordination, with effectiveness untested

AI = artificial intelligence; BPA = Busan Port Authority. Explicit, intended and not specified refer to the content of the selected records, not demonstrated effectiveness.

Table 7 classifies explicit actions and intentions in the selected documents. The national strategy proposes maritime–land–air data links and industrial capabilities [14]; it does not establish a working cross-modal platform. The construction, design and airport-delivery notices are narrower in institutional scope [9–11,13]. In particular, the airport consultative body reported in [11] demonstrates actual pre-operational inter-agency convening but not an authorized cross-modal data exchange, coordination benefit or port–airport commercial service. The BPA development record independently reports consultative activity from August 2019 and an appraisal sequence involving a non-passing result followed by a passing reappraisal in 2021 [24]. These documented events refute a claim that institutions were inactive before operation but cannot establish which actors changed a decision or by how much.

5.2. Provisional Functional Scenarios

The roles below are provisional scenarios. Each requires commercial and institutional evidence and must be compared with independent operation or alternative allocations. They are not established specializations or recommendations to reserve land.

Busan New Port could remain the maritime network anchor as Jinhae capacity enters service. Its realized 2024–2025 throughput establishes an operating base [12], but it does not predict future carrier choices or prove complementarity with another node. Carrier-network, transfer-cost and firm-routing evidence would be needed to evaluate this scenario.

Jinhae could add differentiated technology and capacity within the Busan Port system. The Physical AI strategy proposes supplier support, skills and a manufacturing–port–logistics cluster [14]. This is a policy scenario rather than evidence of regional supplier capture. Validation requires procurement origin, supplier capabilities, additional value added and a comparison with sourcing outside the region, including the costs and risks of technology adoption.

Gadeokdo could support selected time-sensitive chains, such as urgent industrial components, pharmaceuticals or perishables. These are candidate markets, not demonstrated demand. Ishihara et al. model sea–air routing through Japan and find route-specific potential [56]; their results neither estimate Gadeokdo demand nor establish observed conversion. Commodity-chain and routing studies must compare schedules, generalized cost, customs feasibility and handling reliability with viable alternatives before any dedicated sea–air facility is justified.

A regional capability scenario would examine how port hinterland districts and firms in Busan, Changwon and Gimhae contribute services, equipment, manufacturing knowledge and labour access. These are candidate relationships to investigate, not fixed city-level assignments. Establishment locations, supplier networks, worker residences and competing land uses are needed to assess them. A surrounding city's industrial profile alone cannot establish a gateway linkage.

5.3. Institutional Questions and Existing Pre-Operational Coordination

The records distinguish the institutions responsible for port development and airport project delivery [9–11,13,24,25]. They also contradict any assumption of an institutional vacuum: BPA records an earlier public–private consultative activity beginning in 2019 [24], and the September 2026 ministry release reports an actual airport-project coordination meeting involving the ministry, Busan City and the airport construction corporation [11]. The latter body focuses on airport construction, costs and associated regional-development questions. Neither source establishes a formally authorized port–airport joint-governance body, measured coordination effectiveness or commercial integration. The mandate, decision authority, minutes and consequences of these bodies require further documentary and interview evidence.

Three questions remain open. Who can authorize a change to a shared interface, finance it and settle disputes? Which commercial and personal data can be shared, with whose consent and under what security arrangements? Which land-release or procurement conditions can the relevant authorities lawfully apply? These questions follow from the framework and the limits of the available sources; they are not findings that separate planning, commercial confidentiality or appraisal practice has caused a coordination failure.

An institutional feasibility assessment would examine governing instruments, approved plans, budgets, contracts and inter-agency agreements and validate the interpretation with responsible authorities and affected groups. No full legal-mandate audit, stakeholder interview programme or policy-effectiveness evaluation was conducted. The available documents do not establish that a gateway-wide joint dependency register, cross-modal

shared data platform or conditional land allocation is already authorized, funded or acceptable. The airport-project body recorded in [11] cannot be assumed to possess those additional decision rights.

A dependency register is consequently a candidate pilot, not an implemented governance architecture. A pilot could list the interface, responsible bodies, decision rights, required dates, data permissions and contingency, while documenting unresolved conflicts. Its value should be judged against administrative cost and the performance of existing arrangements.

5.4. Four-Stage Implementation Pathway

The following pathway is an agenda for feasibility assessment and piloting. Progression between stages requires evidence and the relevant approvals; the sequence is not a validated implementation plan.

Stage 1—option appraisal: Identify credible interdependencies, environmental constraints and competing land uses. Compare the costs of reserving an interface with early commitment and with leaving the assets independent.

Stage 2—capability piloting: Subject to operator consent, access agreements and approvals, use existing facilities to test a bounded data exchange, supplier relationship or joint service. Record baseline performance, costs and failure criteria before the pilot starts.

Stage 3—conditional scaling: Consider additional land or facilities only after independent evidence establishes demand, interface readiness, environmental requirements and authority to act. The relevant triggers must be negotiated and tested; no trigger value is validated here.

Stage 4—evaluation after operation: Compare joint services, utilization, regional value added, emissions and distributional effects with the prespecified alternative. Scale, adapt or discontinue arrangements in light of observed benefits and costs.

Candidate participants include the maritime and transport ministries, BPA, the airport construction authority, the free economic zone authority, Busan Metropolitan City, Gyeongsangnam-do, relevant municipalities, customs, operators, suppliers, workers and affected communities. Naming them does not establish a shared statutory mandate or agreement. Before adoption, each proposed action requires a documented decision owner, applicable authority, budget or contract route, data permissions and stakeholder review.

5.5. Documentary Challenge Tests Against the Six Propositions

The documentary tests use two competing interpretations. H_A states that publicly documented pre-operational coordination plausibly conditions a later joint gateway service; H_B states that the same actions reflect independent port or airport project administration without a commercially authorized cross-modal interface. The records identify within-project consultation and scheduled or actual meetings, satisfying only the minimal existence-and-timing prerequisite for H_A. Neither minutes attributing a port–airport design or service decision to that coordination nor signed joint commitments and downstream transactions were identified in this bounded record set. Consequently, the currently observed traces are equally consistent with H_B. This is not evidence that coordination is absent: it is an evidentiary failure to discriminate causal explanations with available records. Table A3 sets out the known sequence and Table A4 explicitly identifies missing tests for each proposition.

Official documents do not directly test any of the six propositions; nevertheless, their implications can be challenged rather than merely illustrated. Table A4 separates an observed or reported trace, the strongest justified inference, an alternative explanation or contradictory implication, and the evidence required for adjudication. The 2019 port con-

sultation and September 2026 airport-project council contradict a categorical assertion that coordination never precedes operation. They do not confirm P5: the council's documented remit concerns airport delivery, and no independent comparison of service formation with and without coordination is available. Likewise, distinct asset schedules demonstrate temporal heterogeneity but do not establish harmful critical-interface exposure under P1. Neither unobserved post-opening service volumes nor unmeasured local value added is recoded as zero.

These restrictions change the interpretation of the Busan application. The documentary findings are limited to (i) an established maritime operating base, (ii) distinguishable construction and policy horizons, (iii) reported pre-operational port and airport decision activity, and (iv) the absence of accessible evidence in this corpus on realized cross-modal service effects, additional regional value, or tested governance benefits. The last item is an evidence gap, not evidence that the outcomes or institutions do not exist. The framework's increment over existing port and ecosystem accounts therefore remains a testable hypothesis rather than an established explanatory advantage.

6. Operationalization and Decision Logic

Table 8 specifies prospective measurements. Data holders are candidate custodians; access, coverage and linkage have not been secured. The first full 12 months of authorized collection would establish a baseline, supplemented by retrospective observations where records are recoverable. Measures that depend on an airport or joint service begin only when the relevant service becomes observable. Missing or inapplicable values must not be coded as zero. The illustrative regional boundary comprises Busan, Changwon and Gimhae and should be tested against a functional labour-market boundary. Policy thresholds, data-sharing agreements and pilot results remain to be established.

Table 8. Prospective measurement specification. All access and baselines remain to be established. Process proxies are distinguished from outcomes, and denominator coverage must accompany every ratio.

Dimension and Indicator	Definition, Timing and Evidence Requirement
Temporal alignment Critical-interface exposure	Record the month a specified service requires an interface and the month it becomes available. A positive difference denotes exposure in months. Keep forecasts separate from realized dates; observe quarterly. Candidate sources: project owners and operators. Published schedules alone do not establish a causal dependency.
Temporal alignment Conditional land-release share	Area allocated after a documented demand or readiness condition is met divided by total area allocated in the same annual cohort. Candidate sources: land authorities and BPA. Conditions, release records and forgone uses must be inspected; a high share is not proof of positive option value.
Temporal alignment Net option value and adaptation loss	Expected present value of a feasible flexible alternative minus that of a fixed alternative, including staging, waiting and residual risk. Record realized redesign, relocation and cancellation losses separately. Candidate sources: approved appraisals, contracts and audited project accounts; no estimates supplied.
Functional complementarity Independent joint-service advantage	For a fixed commodity, origin–destination pair and service requirement, compare generalized cost, time, reliability and handling feasibility of joint and viable alternative chains. Measure before later transactions; report components and valuation assumptions. Candidate sources: quotes, routing audits, customs and operators.
Ecosystem formation Recurring joint services and customers	Count repeat transactions and continuing joint-service contracts within a fixed observation window. Supporting share: eligible firms using the specified two-node service divided by all sampled eligible firms. Record sampling and nonresponse. Candidate sources: longitudinal firm panel and operators; baseline begins when service use is possible.

Table 8. *Cont.*

Dimension and Indicator	Definition, Timing and Evidence Requirement
Functional complementarity Sea–air transfer	Matched maritime–air consignments by tonnes, value, commodity and origin–destination, not TEU. Use identifiers and an explicit transfer window. Candidate sources: customs and cargo operators, subject to access and linkage permission. Pre-opening values are inapplicable, not zero.
Spatial embedding Regional procurement share	Eligible purchases from operating establishments inside the fixed region divided by all eligible purchases. Use establishment origin rather than headquarters address, report imported pass-through inputs, and retain a constant annual scope. Candidate sources: public contracts and private vendor records; access not secured.
Spatial embedding Worker access	Surveyed gateway employees able to travel between their usual residence and shift workplace within 45 min by public or employer transport divided by surveyed gateway employees. Test 30/45/60 min cutoffs; 45 min is an analytical convention, not a validated standard. Candidate sources: workers, employers and timetable/routing data.
Institutional orchestration Decision rights and due-issue closure	First record binding or agreed responsibility for each interface. Quarterly closure = registered issues due in that quarter resolved by their original deadline divided by all issues due in that quarter. Track severity, reopened issues and coordination cost. Requires a prospective register or existing equivalent; none obtained.
Institutional orchestration Tested data interoperability	Priority interface transactions successfully exchanged under agreed definitions, access and security rules divided by all priority interface transactions tested. Report test coverage and failures semiannually. Candidate sources: port, customs and future airport-system operators; no cross-modal agreement or test result supplied.
Legitimacy Compliance and acceptance	Report verified permit actions completed divided by actions due, with severity and overdue items. Separately repeat an affected-group survey and track unresolved grievances and appeal outcomes. Compliance cannot substitute for community acceptance. Candidate sources: permit authorities, project owners and independently sampled stakeholders.
Regional value capture Regional value-added share	Value added generated inside the fixed region by the defined gateway-linked establishments and suppliers divided by value added of the same observed activity network across all locations. Specify network coverage and avoid double counting intermediate purchases. This measures production location, not resident-income retention. Candidate sources: establishment accounts and linked regional input–output evidence.
Regional value capture Additional value and resident income	Estimate the change in regional value added and income accruing to resident workers/owners against a specified counterfactual. Track relocated firms, displaced activity and commuting/ownership leakage separately. Do not add gross procurement, wages and taxes to value added. Requires a supplier/firm panel and a credible comparison design.
Sustainability and durability Environmental burden and service continuity	Report absolute and shipment-normalized emissions, land conversion, permit conflicts, utilization and continuity of joint services over a prespecified horizon. Define cargo and system boundaries; report relocation and rebound. Candidate sources: environmental reports, operating records and affected groups; outcomes remain to be measured.

6.1. Decision-Relevant Cost–Benefit Logic

Financial appraisal requires an explicit decision-maker perspective and must be distinguished from social welfare assessment. Delay may affect the present value of net contribution, idle or duplicated investment, sourcing, redesign and temporary operation. Staging may also incur financing, coordination and waiting costs. External sourcing is not automatically a social loss, and procurement, wages and taxes must not be added as independent benefits when they overlap within value added. Environmental burdens and displacement require separate assessment.

The relevant comparison is a staged arrangement against a specified project-by-project or independently operating alternative. Cargo and employment benefits depend on net ad-

ditional activity after relocation, substitution and commuting leakage. Neither capacity nor proximity establishes such benefits. Section Algebraic Illustration of Partial Risk Reduction provides a financial break-even illustration rather than a social cost–benefit analysis or a Busan estimate.

Algebraic Illustration of Partial Risk Reduction

For a delay of d months, conditional exposure under alternative j is defined at a common present-value date, where $j = 0$ denotes the comparator and $j = 1$ the staged arrangement:

$$E_j(d) = R_{\text{delay,j}}(d) + C_{\text{dup,j}}(d) + C_{\text{ext,j}}(d) + C_{\text{redesign,j}}(d) \quad (1)$$

Here, $E_j(d)$ denotes conditional financial exposure; $R_{\text{delay,j}}(d)$ is the present-value loss from postponed or cancelled net contribution; $C_{\text{dup,j}}(d)$ is incremental duplication cost net of reuse or salvage; $C_{\text{ext,j}}(d)$ is an external-sourcing premium applied to a stated eligible purchase base; and $C_{\text{redesign,j}}(d)$ is redesign or temporary-operation cost. Components must be mutually exclusive, measured from the same decision-maker perspective and discounted consistently. A deferred receipt recovered later contributes only its timing loss unless a permanent loss is documented. The break-even condition is

$$S + W < p_0 E_0(d) - p_1 E_1(d) \quad (2)$$

In Equation (2), p_0 and p_1 denote the respective probabilities of the dependency event, S the incremental cost of the staging package and W the additional waiting and carrying cost not already included in exposure. Staging has a positive expected financial increment only when the reduction in expected exposure exceeds $S + W$. For illustration, assume equal probabilities p and an avoided fraction q of conditional exposure, so that $E_1(d) = (1 - -q)E_0(d)$. Under linear delay scaling, $E_0(d) = (d/24)E_0(24)$. The break-even ceiling for $(S+W)/E_0(24)$ is then $p \times q \times d/24$. Table 9 uses $q = 0.5$ to show the arithmetic. These inputs are chosen examples rather than probability bounds, calibrated parameters or estimates of policy feasibility. No monetary values or event probabilities are estimated for Busan.

Table 9. Algebraic break-even ceilings for $(S + W)/E_0(24)$, assuming $p_0 = p_1 = p$, 50% avoided exposure ($q = 0.5$) and linear delay scaling. Equality denotes break-even; a positive expected financial increment requires a lower cost ratio. The entries are dimensionless arithmetic examples, not Busan sensitivity estimates.

Illustrative Probability p	12-Month Delay	24-Month Delay	36-Month Delay
0.1	0.025	0.050	0.075
0.2	0.050	0.100	0.150
0.3	0.075	0.150	0.225
0.4	0.100	0.200	0.300
0.5	0.125	0.250	0.375

Under the illustrative assumptions, $p = 0.3$ and $d = 24$ yield a ceiling of 0.15. Setting $q = 0.25$ halves every displayed ceiling, whereas $q = 1$ doubles it. In an application, p may range from zero to one and exposure need not increase linearly with delay. Audited costs, residual risks, correlations, discounting and nonlinear schedules would be required. A positive financial increment alone cannot authorize land release or establish a net social or environmental benefit.

7. Discussion

7.1. Theoretical Contribution

The framework combines timing, commercial complementarity, regional capability and institutional coordination at the level of an interdependent asset portfolio. Its additional

explanatory value depends on whether this specification predicts outcomes beyond existing regionalization, ecosystem and governance accounts.

The dual-hinterland distinction separates circulation from regional capability as analytical functions. Stranded adjacency is a proposed diagnostic subset of unrealized integration, conditional on independently established commercial potential. Neither construct is established as a separate theory or an observed Busan outcome.

Transfer beyond Busan is conditional on demonstrable asset interdependence, incomplete complements and uncertainty that makes sequencing consequential. Singapore and Dubai provide secondary-source boundary illustrations, not independent validation cases.

7.2. Competing Explanations and Contrary Evidence

The critical literature qualifies several links. Carrier and shipper strategies provide a rival source of integration [57], so a public body's presence is not evidence of its marginal contribution (P5). Route-specific sea–air modelling [56] weakens generic proximity arguments (P3). Institutional plasticity [58] documents adaptation as well as inertia (P2/P5). Port reform and co-opetition scholarship [59,60] require coordination costs, competition and substitution to be examined. The September 2026 airport-project coordination body [11] supplies an additional documentary counter-instance to any conjecture that actors wait for full gateway operation before coordinating; however, it is not evidence that the proposed cross-modal mechanism improves services. The limited documentary challenge tests (Section 5.5; Table A4) also identify an observed pre-operational coordination episode that weakens any institutional-vacuum premise. None of these sources validates or falsifies the conditional P1–P6 relationships in Busan.

The remaining evidence also needs careful scope. Highway-based redistribution in [61] is an analogy for displacement, not a direct port-region estimate (P4). Reclamation and hinterland-environment studies identify reasons to measure land and transport burdens [62,63]. The automation study examines stakeholder attitudes rather than establishing local employment losses [64] (P6). These studies are not direct tests of P1–P6. Table 5 therefore pairs each proposition with a rival and a prospective discriminating observation. Stable services despite critical-interface exposure would weaken P1; non-positive net flexibility benefits would weaken P2; absent incremental complementarity would weaken P3; no additional regional value after displacement would weaken P4; market-led integration without a coordination interaction would weaken P5; and continuity unrelated to independently measured acceptance would weaken P6. Demand and temporal ordering must be considered before any such pattern is interpreted.

7.3. Structured Boundary Comparison with Singapore and Dubai

Singapore and Dubai are purposively selected, information-rich boundary illustrations because both combine maritime, aviation and logistics activities, and published research already compares their development [65–70]. Their governance arrangements provide contrasts, but both are prominent hub-development examples. This selection omits failed and weakly integrated regions and cannot identify necessary or sufficient conditions. Table 10 applies common descriptive dimensions linked to the four mechanisms. It combines historical scholarship with contemporary institutional descriptions, not matched observations or a harmonized dataset. Current operator claims are attributed as such; outcome equivalence and causality are not inferred.

The comparison suggests questions about sequencing interfaces, assigning capability-development responsibilities and making shared services operable. It does not show that either arrangement would work in Busan. City-state and emirate contexts differ from Korea in fiscal authority, planning, property, labour and approval systems, and Dubai itself

contains several distinct entities. Potential transfer must be examined instrument by instrument for authority, resources, commercial demand and environmental and distributional consequences. Neither case supplies a validated Korean governance template.

Table 10. Structured secondary-source boundary comparison. The entries describe selected arrangements at different historical dates; they do not rank performance, establish equivalent governance concentration or validate transfer to Korea.

Dimension	Singapore	Dubai	Busan–Jinhae–Gadeok	Mechanism
Governance	Specialized public agencies and firms in a city-state context [65,66]	Distinct government-linked port, free-zone, aviation and development bodies [67–70]	Distinct port and airport implementing bodies; existing pre-operational consultative record [24,25]	Institutional orchestration
Sequencing	Tuas formally opened in 2022; phased development toward the 2040s [71]	Historical port/free-zone development followed by additional airport and logistics capacity [67–70,72]	Operating maritime anchor, capacity extension and pre-operational airport; dates differ in scope [9,12–14]	Temporal alignment
Port–airport interface	Separate air-cargo/free-trade-zone services; this source does not measure joint port–airport flows [73]	Dubai South reports a bonded corridor to Jebel Ali and airport access [74]; realized volume not supplied	No Gadeokdo operating-service outcome can yet be observed; independent commercial feasibility untested	Functional complementarity
Industrial capability	JTC Corporation describes an innovation and manufacturing district; port supplier links not established by that page [75]	Jafza describes a port-adjacent free zone; occupancy is not a value-capture measure [76]	Hinterland and cluster intentions [14]; regional supplier effects not measured	Spatial and urban embedding
Data and service arrangements	Historical research describes trade/information coordination [65]; no common current coverage metric	Historical port/customs arrangements [67]; organizational concentration is not proof of technical interoperability	National data-link intentions [14]; no cross-modal access agreement or tested coverage supplied	Institutional orchestration
Transfer limit	City-state fiscal and planning context; separate commercial and environmental tests required	Emirate institutions and property/labour context; several entities remain distinct	Each instrument needs Korean authority, resources, data rights and stakeholder assessment	All four; no effect size transferred

Jafza = Jebel Ali Free Zone. Institutional and operator descriptions are not matched outcome observations or evidence of causal effectiveness.

7.4. Managerial Implications

Managers could use the framework to identify a small number of credible dependencies and evaluate whether a joint arrangement adds value beyond existing commercial coordination. Port authorities' involvement should follow the dependencies they can influence. Tenant appraisal could examine gateway links, adaptability and regional effects alongside commercial viability, subject to the rules governing allocation and procurement.

A bounded dependency-register pilot could provide an initial test. Each interface would identify a decision owner, deadline, authority, evidence source, permissions, contingency and review criterion. Agreement on these items has not been obtained. Evaluation should record coordination costs and unresolved disputes alongside service outcomes.

7.5. Prospective Validation, Research Agenda and Limitations

Recent systematic reviews provide important qualifications to the proposed theoretical contribution. Rahayu et al. systematically review 49 port–hinterland governance papers and show that governance changes with spatial and temporal context [21]. Zhang et al. synthesize 90 full-text port–hinterland studies and discuss weak causal identification for many integration levers [22]. These reviews directly disconfirm any assertion that governance dynamics, anticipatory actors or integration layers are unrecognized in prior research; the narrower proposed contribution is a service-specific portfolio of assets with distinct

operating dates and explicit evidence criteria. Eo and Choi's stated-preference analysis of the proposed Busan–Gadeokdo sea–air connection identifies service attributes in respondents' choices, but it is neither observed cargo conversion nor a calibrated forecast of airport demand [23]. The environmental-scoping portal records the 2024 public-notice window but no representative acceptance survey [26]. Treating these four sources as serious alternative evidence, rather than automatic support for P1–P6, further narrows the framework's empirical claims.

Validation can begin before the airport opens. A process study could follow BPA's 2019 consultation and 2021 appraisal/reappraisal entries [24], the 2026 airport design procedures [9,10], and the September 2026 airport coordination meeting [11] through minutes, contracts, option assessments and dated decisions. Archival collection should distinguish the authority that met from the authority that could change an interface; it should document alternatives considered, actor-specific positions, actual changes and dissent. Interviews with authorities, operators, firms, workers and affected communities could test rival accounts. The first authorized observation year would establish baselines; repeated firm-routing, supplier and worker observations would then follow formation of services as assets operate. Comparative sampling should include weak or failed integration, not only Singapore and Dubai. Mediation and moderation tests require temporally ordered, independently measured constructs and evaluation of selection, demand, ownership and reverse causality. Appendix D supplies a prospective protocol and Table A4 documents current evidentiary challenges; neither amounts to completed interviews, a reproducible systematic review, causal identification or populated baselines.

Several limitations constrain interpretation. The 60 retained scholarly works (57 reference-led and three identified by targeted search) are an auditable included-source inventory, not a systematic search yield; historical query exports, candidate-level screening, exhaustive coverage and independent coding are missing. The nine official records establish time-stamped announcements and selected institutional actions, but not continuous deliberation, stakeholder acceptance, validated legal authority or attributable impacts. The September 2026 airport-project council cannot be equated with effective cross-modal coordination. Singapore and Dubai are prominent, non-failure boundary illustrations without matched outcomes. Firm-level routing, supplier networks, land-release data, independent joint-service, supplier and community-acceptance baselines and pilots have not been obtained. Accordingly, P1–P6 remain untested. A full systematic review and longitudinal process study would be needed to evaluate the proposed relationships against broader evidence.

8. Conclusions

Busan–Jinhae–Gadeok illustrates a planning question: how should interdependent interfaces and capabilities be sequenced when an operating maritime gateway, its capacity extension and a pre-operational airport have different horizons? The nine official records establish those horizons, port consultation prior to full operation and a dated September 2026 airport-project council. They do not demonstrate realized port–airport integration, the marginal benefit of additional orchestration or causal effects on sustainable development.

Anticipatory gateway regionalization offers six untested propositions organized by four alignment mechanisms. Its contribution is a combined analytical specification, with explicit distinctions among timing, commercial complementarity, regional capability and legitimacy. The dual-hinterland distinction and stranded adjacency remain proposed analytical devices.

For sustainable gateway development, the framework identifies questions about reversible investment, net regional value added, emissions, land use and the distribution of benefits and burdens. Staging or coordination is desirable only where its incremental

benefits exceed its economic, environmental and social costs under the relevant institutions. These sustainability effects require empirical evaluation.

The executed targeted search improves visibility of critical new research but does not replace a database-complete systematic review. Public records permit a reproducible throughput baseline and limited testing of whether a procedural precondition was reported; they cannot identify the counterfactual marginal effect of coordination, port–airport transactions, additional regional value, emissions or ongoing community acceptance. The next empirical stage must obtain decision minutes, alternative investment packages, firm-routing and supplier data and eventually post-opening service observations. The six propositions, functional-role scenarios and candidate governance instruments remain conditional rather than verified. Infrastructure scale and throughput alone cannot establish sustainable gateway value.

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Abbreviations

Abbreviation	Definition
AI	Artificial intelligence
BPA	Busan Port Authority
Jafza	Jebel Ali Free Zone
MOF	Ministry of Oceans and Fisheries
MOLIT	Ministry of Land, Infrastructure and Transport
MPA	Maritime and Port Authority of Singapore
SDG	Sustainable Development Goal
TEU	Twenty-foot equivalent unit

Appendix A. Source Notes and Limits of the Boundary Comparison

The institutional sources below document selected infrastructure and service arrangements in Table 10. They are not independent evaluations of effectiveness. Historical studies [65–70] provide context at their publication dates and cannot verify present-day outcomes.

Appendix A.1. Singapore's Phased Consolidation and Differentiated Public Roles

The Maritime and Port Authority of Singapore (MPA) reports Tuas's formal opening in September 2022 and phased development toward the 2040s [71]. Changi Airport Group describes its air-cargo free-trade-zone services [73], while JTC Corporation describes an advanced-manufacturing innovation district [75]. These sources identify distinct organizational roles without establishing the performance of a unified port–airport chain or demonstrating that district firms supply the port.

Appendix A.2. Dubai's Port, Airport and Free Zone Arrangements

Jebel Ali Free Zone (Jafza) describes a port-adjacent free zone [76], Dubai Airports describes its cargo services [72], and Dubai South advertises access to Jebel Ali through a bonded logistics corridor [74]. These sources establish stated facilities and arrangements rather than sea–air volumes, regional benefits or cost savings. Historical studies describe government-linked development and the importance of its institutional setting [67–70].

Appendix B. Included Scholarly Sources and Their Interpretive Roles

Table A1 inventories 60 scholarly sources: 39 substantive, nine critical or rival-explanation, six comparative and three methodological works and three studies identified through a dated targeted search. Institutional sources are listed separately in the references. The mapping identifies each work's analytical role and relevant mechanism or proposition. It does not imply that the sources test the propositions or share a common temporal assumption.

Table A1. Included scholarly sources (60 records) and their interpretive roles. Mechanism labels and proposition links are the authors' mapping, not empirical support counts.

Study [Reference]	Role in Synthesis	Insight Used and Qualification	Mechanism and Proposition Link
Hesse and Rodrigue (2004) [2]	Port regionalization	Logistics integration reorganizes freight distribution around gateways, corridors and distribution centres	Spatial and urban embedding P4
Parola et al. (2017) [4]	Port regionalization	Port competitiveness depends on hinterland connectivity and cost as well as nautical access	Spatial and urban embedding P4
Notteboom and Rodrigue (2005) [5]	Port regionalization	Inland extension of port functions through corridors and terminals	Temporal alignment P1, P2
Roso, Woxenius and Lumsden (2009) [6]	Port regionalization	Dry ports relocate seaport functions inland where rail services and cargo volumes allow	Temporal alignment P1
Jacobs and Notteboom (2011) [7]	Port regionalization	Windows of opportunity and actors' strategies shape port-system evolution, including anticipatory agency	Temporal alignment P2
Rodrigue and Notteboom (2010) [27]	Port regionalization	Transshipment hubs integrate with the hinterlands of other ports through foreland-based regionalization	Functional complementarity P3

Table A1. *Cont.*

Study [Reference]	Role in Synthesis	Insight Used and Qualification	Mechanism and Proposition Link
Rodrigue and Notteboom (2010) [29]	Port regionalization	Gateways and corridors organize freight distribution differently across regional settings	Temporal alignment P1
Rodrigues et al. (2024) [30]	Port regionalization	Risk dimensions in dry-port projects are interdependent	Temporal alignment P1, P2
Monios and Wilmsmeier (2012) [31]	Port regionalization	Regionalization can be directed by inland and public actors, not only by ports	Institutional orchestration P5
Monios and Wilmsmeier (2013) [32]	Port regionalization	Regionalization depends on viable intermodal services and institutional arrangements	Institutional orchestration P5
Notteboom (2010) [28]	Multi-port gateway regions	Concentration and cooperation among neighbouring seaports	Functional complementarity P3
Notteboom, Knatz and Parola (2018) [33]	Multi-port gateway regions	Port co-operation varies by type, driver and impediment	Functional complementarity; institutional orchestration P3, P5
Ducruet and Lee (2006) [34]	Port–city and cluster research	Port–city relations evolve with the centrality and intermediacy of ports	Spatial and urban embedding P4
Hall and Jacobs (2012) [35]	Port–city and cluster research	Ports remain dependent on urban labour, services and knowledge	Spatial and urban embedding P4
Wiegmans and Louw (2011) [36]	Port–city and cluster research	Port–city interfaces are renegotiated as terminals relocate and land uses change	Spatial and urban embedding P4
de Langen (2004) [37]	Port–city and cluster research	Seaport cluster performance depends on governance relations among firms and institutions	Spatial and urban embedding P4
Coe et al. (2004) [38]	Port–city and cluster research	Regional development depends on strategic coupling with global production networks and on value capture	Spatial and urban embedding P4
Boschma (2005) [39]	Port–city and cluster research	Geographical proximity is neither necessary nor sufficient for interaction and innovation	Functional complementarity P3
Sheffi (2012) [40]	Port–city and cluster research	Logistics clusters create value through agglomeration, shared services and employment	Spatial and urban embedding P4
Zhang, Woo and Li (2024) [41]	Port–city and cluster research	Transport networks, industrial structure and regional policy shape port–city synergy	Spatial and urban embedding P4
Slack (1993) [1]	Port governance	Ports depend on the routing decisions of carriers in a global transport system	Institutional orchestration P5
Pallis, Vitsounis and de Langen (2010) [3]	Port governance	Port research spans economics, policy and management, with governance as a central theme	Institutional orchestration P5
Lam and Notteboom (2014) [15]	Port governance	Leading ports use pricing, monitoring and market-access tools to green port activities	Institutional orchestration (legitimacy) P6
Monios et al. (2024) [16]	Port governance	Climate change calls for a broader conception of port governance	Institutional orchestration (legitimacy) P6
Brooks and Pallis (2008) [46]	Port governance	Governance performance depends on the fit among structure, strategy and environment	Institutional orchestration P5

Table A1. *Cont.*

Study [Reference]	Role in Synthesis	Insight Used and Qualification	Mechanism and Proposition Link
van der Horst and de Langen (2008) [47]	Port governance	Hinterland chains face coordination problems because no single actor controls the chain	Institutional orchestration P5
Ng and Pallis (2010) [48]	Port governance	Generic governance reforms are implemented asymmetrically across institutional frameworks	Institutional orchestration P5
Verhoeven (2010) [49]	Port governance	Port authority functions extend beyond landlord and regulator to community manager and facilitator	Institutional orchestration P5
Brooks, Cullinane and Pallis (2017) [50]	Port governance	Port reform outcomes vary across countries and institutional settings	Institutional orchestration P5
Sirajuddin et al. (2026) [52]	Port governance	A governance/digitalization model addresses logistics performance in an operating setting; transfer to an interdependent asset portfolio is untested	Institutional orchestration P5
Adner (2017) [42]	Business ecosystems	Alignment of activities around a value proposition can be examined before realization as well as during operation	Functional complementarity P3
Teece (2007) [43]	Business ecosystems	Dynamic capabilities of sensing, seizing and transforming sustain performance under change	Functional complementarity P3
Jacobides, Cennamo and Gawer (2018) [44]	Business ecosystems	Ecosystems rest on unique and supermodular complementarities	Functional complementarity P3
de Langen, Sornn-Friese and Hallworth (2020) [45]	Business ecosystems	Port development companies can orchestrate transitions in the port business ecosystem	Functional complementarity; institutional orchestration P3, P5
Valionienė and Župerkienė (2024) [51]	Business ecosystems	Resilience of port organizational ecosystems depends on how common uncertainties are managed	Functional complementarity P3
Martin and Sunley (2006) [8]	Megaproject and lock-in research	Regional economies are path dependent; lock-in can be broken through path creation	Temporal alignment P2
Ansar et al. (2014) [53]	Megaproject and lock-in research	Large dams systematically overrun their cost and schedule estimates	Temporal alignment P2
Cantarelli et al. (2010) [54]	Megaproject and lock-in research	Early lock-in of decisions contributes to cost overruns in large transport projects	Temporal alignment P2
Flyvbjerg (2014) [55]	Megaproject and lock-in research	Megaprojects face systematic uncertainty, political commitment and escalation	Temporal alignment; institutional orchestration P2, P6
Ishihara, Ishiguro and Takebayashi (2024) [56]	Competing explanations (Section 7.2)	Generalized-cost simulation through Japan finds route-specific sea–air potential; not observed Gadeokdo demand	Functional complementarity P3 (challenge)
Frémont (2009) [57]	Competing explanations (Section 7.2)	Shipping lines integrate logistics services and shape network choices	Institutional orchestration P5 (challenge)
Notteboom, de Langen and Jacobs (2013) [58]	Competing explanations (Section 7.2)	Institutional plasticity permits adaptation within path-dependent port institutions; rigidity is not universal	Institutional orchestration P2, P5 (challenge)

Table A1. *Cont.*

Study [Reference]	Role in Synthesis	Insight Used and Qualification	Mechanism and Proposition Link
Haralambides (2017) [59]	Competing explanations (Section 7.2)	Port reform and supply-chain governance require scrutiny of public and private incentives and investment outcomes	Institutional orchestration; temporal alignment P2, P4, P5, P6 (challenge)
Song (2003) [60]	Competing explanations (Section 7.2)	Co-opetition offers a competition/cooperation account; it does not alone establish duplicated investment	Functional complementarity P4, P6 (challenge)
Chandra and Thompson (2000) [61]	Competing explanations (Section 7.2)	Highway evidence identifies spatial redistribution; used as a displacement analogy, not a port-region effect	Spatial and urban embedding P4, P6 (challenge)
Sengupta, Chen and Meadows (2018) [62]	Competing explanations (Section 7.2)	Documents coastal reclamation in megacities; motivates land and environmental assessment, not a Busan impact estimate	Institutional orchestration (legitimacy) P4, P6 (challenge)
Gonzalez Aregall, Bergqvist and Monios (2018) [63]	Competing explanations (Section 7.2)	Hinterland traffic is a major environmental dimension of green port strategies	Institutional orchestration (legitimacy) P4, P6 (challenge)
Notteboom, Pallis and Knatz (2025) [64]	Competing explanations (Section 7.2)	Examines stakeholder attitudes to automation; does not measure employment losses in this region	Institutional orchestration (legitimacy) P4, P6 (challenge)
Airriess (2001) [65]	Comparative cases (Section 7.3)	Singapore's container hub was built by a developmental state linking regional production and information technology	Institutional orchestration
Lee, Song and Ducruet (2008) [66]	Comparative cases (Section 7.3)	Asian hub port cities follow a spatial evolution distinct from Western port–city models	Temporal alignment; spatial and urban embedding
Jacobs and Hall (2007) [67]	Comparative cases (Section 7.3)	Dubai's port strategies are conditioned by state-linked institutions and free zones	Institutional orchestration
Hvidt (2009) [68]	Comparative cases (Section 7.3)	Dubai's development model relies on strong central leadership and government-linked companies	Institutional orchestration
Akhavan (2017) [69]	Comparative cases (Section 7.3)	Dubai's port–city interface developed through government-led port, free-zone and logistics projects	Spatial and urban embedding
Akhavan (2017) [70]	Comparative cases (Section 7.3)	Prior comparison of Dubai and Singapore directly informs case selection and limits novelty of the comparison	All four
Jaakkola (2020) [18]	Research design (Section 2)	Conceptual articles can be designed as theory synthesis, theory adaptation, typology or model	—
Torraco (2005) [19]	Research design (Section 2)	Integrative reviews critique and synthesize a literature to generate new frameworks	—
Snyder (2019) [20]	Research design (Section 2)	Integrative reviews suit the critique and synthesis of diverse studies for theory development	—
Rahayu, Busscher and Woltjer (2026) [21]	Critical review/governance rival	Temporal and spatial governance already investigated	P1, P5; limits originality
Zhang et al. (2026) [22]	Systematic review/inferential benchmark	Integration levers, constraints and few identified causal impacts	P1–P6; limits causal claims

Table A1. *Cont.*

Study [Reference]	Role in Synthesis	Insight Used and Qualification	Mechanism and Proposition Link
Eo and Choi (2026) [23]	Stated-preference/market benchmark	Busan–Gadeok sea–air attributes, not realized demand	P3; conditional demand evidence

Entries may inform more than one mechanism. A qualification or rival is analytically relevant without constituting disconfirming evidence from Busan. Methodological works inform research design. The inventory does not establish search completeness or theoretical saturation.

Appendix C. Documentary Extraction Register

The nine records in Table A2 form a bounded, purposively selected official-document corpus. All nine records were accessed on 28 October 2026, the documentary event cutoff, and all covered events precede that date. Inclusion was based on source coverage of operating results, works packages, published policy horizons, airport design, and pre-operational coordination. This is an included-record register, not an exhaustive search of institutional archives. Retrospective entries on current official webpages are not substitutes for original meeting minutes, appraisal reports or signed decisions.

Table A2. Nine-source official-document extraction register and evidentiary limits. All records were accessed on 28 October 2026, the event cutoff; all documented events preceded that date. An official notice confirms its stated procedure or intention, not its effectiveness.

Record and Date	Extraction Locator	Reason Retained	Evidence and Limit
[12] BPA throughput page; 2024–2025 rows; checked 28 October 2026	Total-port and New Port annual tables	Operating maritime baseline	Realized statistics. Published unit is thousand TEU; divide by 1000 for million TEU. Shares use same-year total-port denominator. No evidence of joint services.
[13] BPA notice; 8 September 2025	Hyundai breakwater and phase 1-1 first-section entries	Works-package timing	Reported periods: April 2024–November 2028 and April 2025–May 2030. A notice is not verified site progress or a whole-phase commercial opening.
[14] MOF strategy; posted 22 July 2026; announcement 23 July 2026	Strategies 1–4, especially strategy 2	Policy sequencing and capability intentions	Targets and proposed measures, including 2032/2040 horizons. Does not establish adoption, outcomes or commercial demand.
[9] Busan announcement; 5 March 2026	Subtitle and dated announcement	Airport design procedure and opening target	Reports planned 9 March 2026 design commencement and second-half-2035 opening target. Does not establish progress after the announcement.
[24] BPA 2026 development page; checked 28 October 2026	Item 8, implementation record and future plan	Retrospective institutional challenge	Records consultative activity in August 2019; appraisal non-passing in 2019–2020; reappraisal passing in 2021; implementation period 2025–2030. Does not reveal deliberations or coordination effects.
[25] MOLIT announcement; 5 March 2026	Government release and attached PDF	Cross-check airport procedure and proposed coordination	Reports the 9 March 2026 site briefing and design procedure; proposes a project-promotion consultative arrangement. Intention is not an established, effective gateway-wide mechanism.
[10] MOLIT, 7 September 2026	Official basic-design receipt notice, title and summary; event 7 September 2026	Design documents received for Gadeokdo airport site formation; following design/contract work intended	Reported design submission; not completion, civil-works progress, cargo demand or integration
[11] MOLIT, 18 September 2026	Airport project council inauguration release; first meeting 18 September 2026	MOLIT, Busan and construction corporation convened on cost/project delivery; future quarterly meetings stated	One reported meeting is actual convening, not effectiveness, port–airport remit, authority for land/data or social acceptance

Table A2. *Cont.*

Record and Date	Extraction Locator	Reason Retained	Evidence and Limit
[26] EIASS public environmental-scoping notice; dated 29 April 2024; checked 28 October 2026	Public participation portal, project RE20240212, publication and comment-window fields	Pre-operational environmental procedure and prospective legitimacy measurement	Notice identifies Gadeokdo airport EIA scoping publication and 29 April–13 May 2024 response window. Portal does not measure representative acceptance, comment quality, permit compliance or eventual impact.

BPA = Busan Port Authority; MOF = Ministry of Oceans and Fisheries; MOLIT = Ministry of Land, Infrastructure and Transport; TEU = twenty-foot equivalent unit. Dates refer to source records, not independent site verification.

Appendix D. Audit-Ready Research Protocol and Limited Process Observations

Appendix D.1. Bounded Documentary Process Evidence

The following chronology reports what can be observed in dated official accounts, not a complete process-tracing test. A process-tracing causal claim would additionally require contemporaneous minutes, decisions, alternative options, counterfactuals and actor-level testimony. Source reports have been classified by action, institutional scope and observable limitation before any proposition is evaluated.

Table A3. Source-grounded process observations and missing causal links.

Observed Event	Narrowly Supported Inference	Missing Inference/Rival
From August 2019: BPA public–private consultation [24]	Some port-development consultation preceded operation	No minutes or linkage to airport services; outcomes not attributed
2021: reappraisal sequence recorded by BPA [24]	Official record identifies an appraisal status change over time	Neither decision-maker influence nor causal effects recovered
29 April–13 May 2024: environmental-scoping public-notice period [26]	Formal opportunity for public input documented before airport operation	No public acceptance measure, no proof of all comments or stakeholder responses, and no causal effect on redesign
March 2026: airport basic-design initiative [9,25]	Pre-operational airport procurement/design activity	No completed work or port–airport commercial interface
7 September 2026: design materials received [10]	A later design submission is officially reported	Not construction completion or gateway service readiness
18 September 2026: first airport-project council meeting [11]	A dated inter-agency airport-project coordination action is reported	Not cross-modal legal mandate, effective orchestration or regional gains

Appendix D.2. Proposition-Specific Challenge Audit of the Nine-Record Corpus

Table A4. Proposition-specific evidence challenge audit. "Not tested" means that the bounded documentary source set lacks the outcome and comparison required for that proposition; it does not signify failure of the proposition.

Proposition	Documentary Trace	Rival/Potentially Adverse Reading	Adjudication Required
P1 | unresolved interface timing	Port and Jinhae/airport targets have different project horizons [9,12–14]; no required joint-service timing has been independently documented.	Harmless non-simultaneous openings, or services that do not require both assets.	Not tested: identify named service, required link, comparable service chains and later transactions.
P2 | option preservation	A BPA reappraisal status change is reported [24], but contemporaneous alternative packages and costs are unavailable.	Routine reappraisal or cost escalation need not show net option value; staging creates waiting costs.	Not tested: collect costed alternatives and reconstruct decision-specific risk and adaptation costs.

Table A4. *Cont.*

Proposition	Documentary Trace	Rival/Potentially Adverse Reading	Adjudication Required
P3 | complementarity	National strategy proposes future cross-modal data integration [14]; the airport is pre-operational.	Separate all-sea or all-air routing could dominate; stated preferences are not observed future traffic.	Not tested: independent generalized-cost route comparison followed by recurrent transactions.
P4 | developmental embedding	Supplier and training measures are proposed [14]; BPA reports realized cargo handling [12].	Observed port volume may coexist with imported inputs, relocation, ownership leakage and displacement.	Not tested: supplier records, value added and resident income against a viable counterfactual.
P5 | orchestration	Port consultation from 2019 [24] and the airport-project council in Sep 2026 [11] are documented.	Existing coordination contradicts an institutional-vacuum premise; project-specific airport coordination may not bridge port/airport mandates.	Not tested: trace a binding cross-modal decision, its authority and alternative market-led explanations.
P6 | legitimacy	A dated environmental scoping public-notice window in 2024 is documented [26]; responses and sustained acceptance are not measured.	Procedural public notice is not acceptance or reduced environmental impacts.	Not tested: repeated independent acceptance, grievance and service continuity measures.

Table A5. Reproducible operating-port baseline (BPA [12]). Values are published in thousand TEU; within-port shares and annual changes were recalculated from published annual totals, with intermediate calculations retained. The table is not an estimate of integrated-gateway outcomes.

Year	New Port (000 TEU)	Busan Port (000 TEU)	New Port Share	New Port YoY	New Port TS Share
2023	16,309	23,154	70.44%	Not computed	61.02%
2024	17,880	24,402	73.27%	9.63%	62.51%
2025	18,638	24,882	74.91%	4.24%	63.90%

The status-coded record supports a descriptive precursor sequence, not a smoking-gun test. The rival hypothesis that within-project consultations occurred without a binding cross-modal port–airport decision remains viable. The observed 2023–2025 throughput trend and 2024 environmental notice do not satisfy mediation or moderation identification, and no unpublished minutes, interviews or commercial data were assumed. The available records limit causal inference; they do not establish either an effect or its absence.

Appendix D.3. Proposed Systematic Literature-Search and Process-Study Procedures

For a future systematic review, the search date, database export and exact Boolean query should be preserved independently for each database. Proposed databases are Scopus and Web of Science Core Collection, subject to access and coverage checks. Candidate search blocks are (port* OR seaport* OR gateway*) AND (regionalization OR regionalisation OR hinterland* OR "port-city" OR "multi-port"); (port* OR airport* OR freight*) AND (sequenc* OR "path depend*" OR "real option*" OR "institutional coordinat*"); ("business ecosystem*" OR "logistics cluster*") AND (infrastructur* OR port* OR freight*). Search fields, language, year filters, database index date and export counts would be recorded before screening; these Boolean expressions are proposed for a subsequent database review and were not executed as database searches in this study.

Two independent screeners should record title/abstract and full-text exclusions by a predefined reason hierarchy (not a gateway/logistics setting; no regional or institutional mechanism; no empirical or conceptual relevance; duplicate; inaccessible full text) and reconcile disagreements in an auditable log. The extraction form should record study design, location, period, unit, pre-operational status, actor rights, dependencies, proposed mechanisms, evidence, contradictions and limits. The synthesis should retain negative cases

and distinguish conceptual predictions from observed effects. The 57-work reference-led inventory is not the output of the proposed systematic search.

The proposed empirical study would preregister service-chain or decision-episode units; sample public and private coordination episodes, including non-adoption and failure; recover dated decisions, contracts and costed alternatives; and triangulate interviews with operators, agencies, suppliers, employees and affected residents. Baselines would use the first 12 months of authorized observations, with pre-registration of missing-data rules, competing routes, demand and ownership controls, spatial boundaries and service-specific follow-up horizons. Airport-dependent outcomes are structurally unavailable until relevant facilities operate. No interviews, institutional approvals, populated joint-service baseline or causal estimates are included in the present analysis.

Appendix E. Executed Targeted Scholarly Discovery: Search and Source-Decision Ledger

In October 2026, six predefined theme-specific queries were executed through a publicly indexed academic-web discovery interface. The search produced ranked webpages, not a bulk bibliographic database export. The visible results were screened manually for scholarly provenance, identifiable publication year, explicit port/hinterland/airport relevance and a conceptual, empirical or critical contribution. Record-level inclusion decisions for the three search-identified publications are reported below. Search-engine ranking is unstable and the total number of candidate pages, duplicates and excluded full texts was not available. Accordingly, no PRISMA identification or screening counts, systematic coverage, database equivalence, quality rating or independent dual screening are claimed. The targeted search does not establish systematic coverage of the complete 60-work inventory.

Search limitations: Only visible search results and verified source pages could be inspected; institutional Scopus and Web of Science retrieval, exact export totals, duplicate removal, independent full-text screening, and prospectively registered eligibility criteria were unavailable. The available search records therefore do not support claims of an exhaustive systematic review.

Table A6. Executed search terms and scope. Exact quoted search terms entered in October 2026; no date or language filters were forced by the search interface. This log is reproducible as search wording, not as a fixed exhaustive result set.

ID	Executed Exact Query	Domain/Goal
Q1	“port regionalization” “hinterland” governance systematic review empirical	Port regionalization/governance
Q2	“multi-port gateway regions” “institutional” port cooperation	Multi-port/institutional relations
Q3	“port city” “regional value added” suppliers sustainability review	Regional value/port-city
Q4	“port airport” “sea air” intermodal route comparative cost empirical	Port–airport/services
Q5	“business ecosystem” port infrastructure complements governance	Ecosystems/complements
Q6	“megaproject” “lock-in” “sequencing” transport infrastructure option value	Sequencing/lock-in

Table A7. Scholarly sources identified through targeted discovery and their inclusion decisions. These records do not constitute the results of a complete systematic screening; the 57 reference-led sources are mapped in Appendix B.

Identified Study	Source Verification	Inclusion Judgement/Counterpoint
[21] Rahayu et al. (2026)	University of Groningen/TRID index, DOI 10.1016/j.trip.2026.102128	Include: 49-study governance synthesis; prior attention to temporal and institutional agency directly restricts novelty.
[22] Zhang et al. (2026)	Journal of Marine Science and Engineering publisher page, DOI 10.3390/jmse14151434	Include: 90-study synthesis; provides critical prior work on integration layers and limitations of causal evidence.
[23] Eo and Choi (2026)	KCI journal record, DOI 10.15735/kls.2026.34.4.003	Include: Busan–Gadeokdo stated-preference study; candidate demand attributes, not realized airport cargo or effect size.

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