Spatialized Port Competitiveness (SPC): A New Framework for Demand Forecasting and Strategic Planning

AAPA Port Professional Manager (PPM) Capstone White Paper

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Abstract

This paper presents Spatialized Port Competitiveness (SPC), a methodology to evaluate port competitiveness, estimate the addressable market, and forecast port demand. SPC was designed to overcome limitations of current Brazilian port master planning practice, which relies predominantly on historical data and often overlooks competitive dynamics among ports. The methodology provides a comprehensive analysis by incorporating global logistics costs, port selection criteria, performance indicators, and overlaps in port influence areas. The process begins by defining origin-destination (OD) matrices and identifying competition zones by cargo type. It then analyzes logistics costs to project contestable demand, explicitly accounting for vertically integrated supply chains and rail-borne cargo that are effectively fixed at specific ports. A detailed case study of the Paranaguá and Antonina Port Complex, the first full-scale application of the competition-based approach inside an official Brazilian master plan, illustrates practical application: it shows how SPC identifies potential demand, assesses competitive positioning per cargo family, and supports strategies to capture new cargo. The paper also benchmarks the new projections against the previous official master plan and tests that plan against a decade of observed operation, documenting a systematic underestimation of demand that the competition-aware approach corrects, and it traces the evolution of the methodology through more than 15 applications into an industrialized, auditable analytical framework. By offering a nuanced, competition-aware approach to master planning, SPC aims to enhance the efficiency and competitiveness of ports in Brazil and beyond. It is best understood not as a tool that predicts future cargo flows with precision, but as a disciplined framework for identifying economically plausible opportunities, challenging assumptions, and improving planning decisions under uncertainty.

Keywords: port competitiveness, port competition, global logistics costs, demand forecasting, addressable market, contestable market, hinterland, port influence area

Abbreviations. ADB: Agricultural Dry Bulk; ANTAQ: National Waterway Transportation Agency (Brazil); ANTT: National Land Transportation Agency (Brazil); APPA: Port Authority of Paranaguá and Antonina; CAP: Port Authority Council; CC: Containerized Cargo; CEU: car equivalent unit; GC: General Cargo (breakbulk); GDP: gross domestic product; HS: Harmonized System; LB: Liquid Bulk; MDB: Mineral Dry Bulk; MPor: Ministry of Ports and Airports (Brazil); Mt/kt: million/thousand tonnes; OD: origin-destination; PDZ: Development and Zoning Plan; PNL: National Logistics Plan; PPML: Poisson Pseudo-Maximum Likelihood; RoRo: roll-on/roll-off; SPC: Spatialized Port Competitiveness; TEU: twenty-foot equivalent unit; ZIP: Port Influence Zone (Natural ZIP: least-cost zone); ZC: Zone of Competition. Brazilian source labels (GSA, GSM, CGC, CGNC, GL) are bridged in Annex F.

What SPC Tells a Port Professional

This page is the executive layer of the paper: what the methodology answers, which decisions it informs, what it cannot know, and where to read next. Every figure quoted here is developed, sourced, and bounded in the sections and annexes.

What it answers. Where the port's natural market is, municipality by municipality, under least total logistics cost; which part of that cargo is captive to a rival through rail integration, industrial ownership, or carrier-owned terminals, and which part is free to move; and how much efficiency, in money per tonne, it takes to move it. The method sorts cargo before it projects.

Which decisions it informs. For a port authority: where to invest, with capacity sized on contestable demand rather than on history; how far the port can capture and, in the same ledger, what it stands to lose; and the annual confrontation of observed against projected flows. For a terminal operator: the municipalities ranked by the efficiency gain required to win them, the cargo to protect, and the pricing of service improvements against the road-freight differential rivals must beat. Same outputs, different question.

What the Paranaguá evidence shows. The previous official forecast was surpassed by observed throughput in every substantive year from 2017 to 2025 and reached approximately 13 years ahead of the baseline schedule, with the error concentrated where cargo is contestable. The competition-aware plan revises the 2050 outlook by +88.1%, most of it attributable to the method rather than to the higher starting point, and lowers the projection for vehicles, the one family the analysis finds inelastic. Inside Paranaguá's own natural agribulk hinterland, Santos handles 38.2% of the cargo and Paranaguá 32.5%. The method was scrutinized by the Port Authority Council, submitted to public consultation, and published in the official master plan.

What it does not do. It does not predict flows with precision; cost is central but not the only driver; and competition between ports coexists with competition among global operators. Its value is discipline: plausible opportunities priced in R$/t, assumptions exposed, totals reconciled with official statistics, and judgment kept as the final step.

Reading map. Executive reader: Sections 1, 4, 5, and 9. Practitioner applying the method: Sections 2, 3, and 8, with Annexes A and F. Technical reviewer: model specification in Annex A, case tables in Annex B, benchmark and ex-post computations in Annex C, evolution timeline in Annex D, validation record in Annex E.

Summary

Section 1. Introduction

In Brazil, the port master plan sits inside a formal hierarchy of transport planning instruments, the Integrated Transportation Planning system (PIT), established by Ministry of Infrastructure Ordinance No. 123 of August 21, 2020 (Ministério da Infraestrutura, 2020). At the top, the National Logistics Plan (PNL) covers the continental scale and all transport modes. The PNL provides guidelines for the sectoral plans (port, waterway, airport, rail, and road), from the strategic level down to the tactical and regional levels. In the port sector, the system unfolds into port master plans for each port complex and, at the lowest level, into the Development and Zoning Plan (PDZ) for each landlord port area. All components are updated every four years, closing each planning cycle.

The critical question this paper addresses is that the demand forecasting methodology historically embedded in those instruments allocates projected flows within the logistics system that connects the hinterland to the ports without considering the competitive dynamics among ports and their logistics chains. The projections rely on past demand behavior. They ignore anomalous events, such as tax-driven logistics arrangements that cause cargo to follow highly non-optimal routes, sometimes traveling three times the distance of the technically optimal solution, and they do not identify opportunities or critical solutions for port development. In short, the incumbent method projects the past.

The mechanics of that method deserve a fair description before the critique. Under the methodology developed by the Transport and Logistics Laboratory (LabTrans) of the Federal University of Santa Catarina (UFSC), previous master plans profile the complex's throughput by facility, cargo type, direction, and navigation type for a base year, assemble a five-year historical series for relevant commodities, and then proceed in four steps: construct the origin-destination (OD) matrix for each relevant cargo; analyze market trends from sector publications; fit an econometric model on macro variables (GDP, exchange rates) to project future handling; and allocate flows across the network under a least-logistics-cost precept inherited from the PNL. The workflow is diligent, but it attempts from the outset to estimate the complex's future handling from historical flows alone. Econometric models built solely on past movements tend not to account for the possibility that future conditions differ materially, that operational bottlenecks constrain flows even in the presence of latent demand, or that cargo may be captured from, or lost to, competing complexes.

The planning literature has long warned about exactly this failure mode. Taneja et al. (2010) argue that the central challenge in port planning is the multitude of logistical, technological, and economic uncertainties within which ports operate, and that traditional, static master planning approaches are poorly suited to them. Forecasts spanning 20 to 25 years are likely to be imprecise; they typically extrapolate existing trends and technologies, missing paradigm shifts, structural shocks, and low-probability, high-impact events; and static methods are not designed for dynamic conditions. An adaptive approach, featuring flexibility, continuous learning, and iterative adjustment, is therefore required. Two Brazilian-specific aggravations compound the generic problem. First, the preliminary demand forecast has been developed a priori, without early technical exchanges between the modeling team and the stakeholders of the port complex, which partly explains recurrent mismatches and friction around preliminary results. Second, and decisively for this paper, the prior analysis did not evaluate competitiveness across port complexes or among facilities within the same complex, an omission that no medium- or long-term plan can afford.

The stakes of the omission are not academic. Master plans and PDZs feed the prioritization and allocation of public and private investment: berth expansions, leasing tenders, access works, and dredging programs are all sized against the demand curves those documents publish. When the curves systematically understate demand, as Section 5 of this paper documents for a major complex over a full decade, the system plans for slack while reality delivers congestion; when they overstate it, capital is stranded. And because the forecasting method contains no representation of competition, it cannot answer the questions that actually drive port strategy: which share of the projected cargo is contestable by a rival gateway, which share of a rival's cargo is contestable by the focal port, and what level of service improvement would move it. Understanding competition among port complexes, how the contest for demand occurs in both inbound and outbound operations, and how it feeds demand projections at every planning scale is therefore the analytical need from which this work arises.

This paper offers a different perspective on port complex master planning, based on concepts of competitiveness and obtainable demand, to forecast the addressable market: the Spatialized Port Competitiveness (SPC) methodology (in Portuguese, Competitividade Portuária Espacializada, CPE). The reasoning begins with competitiveness in the logistics supply chain (global logistics costs, port selection criteria, performance and competition indicators, overlap of port influence areas, and the several forms of verticalization in port operations), and then formalizes a ten-stage analytical procedure that separates captive from contestable demand before any projection is made. The approach constitutes a proposal for a new port master plan methodology for the Brazilian government; Infra S.A., the federal planning company, has adopted the approach, and as the author of the methodology I present it here under its original name. A word on what the methodology claims: SPC does not promise to predict cargo flows with precision, because supply-chain decisions are made by shippers, carriers, terminals, railroads, and port authorities, each with objectives and constraints no model fully captures. Its value is discipline: it identifies economically plausible opportunities, makes the assumptions behind a forecast explicit and contestable, and improves planning decisions under uncertainty while remaining clear about what it cannot know.

The paper makes four contributions. First, it consolidates the conceptual and methodological statement of SPC in a single practitioner-facing text. Second, it documents the first full-scale application of the competition-based approach inside an official Brazilian master plan, the Paranaguá and Antonina complex projected to 2050. Third, it supplies the evidence that motivates the change: an ex-post accuracy test showing the previous official forecast surpassed by observed reality in every year of its first decade, together with a like-for-like benchmark of the 2018 and 2025 official projections. Fourth, in keeping with the capstone format, it records how the methodology itself matured through more than 15 applications, from an analytical procedure into an industrialized, auditable framework, and draws the implications of that maturation for replicability.

The paper is organized as follows. Section 2 develops the conceptual foundation: port competitiveness as the driver of contestable demand, the components of global logistics cost, and a taxonomy of vertical integration in the Brazilian port market. Section 3 presents the SPC methodology itself: definitions, databases, the ten stages, and, closing the section, the story the capstone format asks for: how the methodology evolved through application, from a ten-stage analytical procedure into an industrialized, auditable framework. Section 4 presents the Paranaguá and Antonina case study, the first full-scale application inside an official master plan. Section 5 provides the paper's empirical proof: an ex-post accuracy test of the previous official forecast against ten years of observed operation, and a benchmark of the 2018 and 2025 official projections at the 2050 horizon. Section 6 reads the competitive field as a game and derives the strategic response; Section 7 documents stakeholder validation through institutional adoption. Section 8 draws implications for practice and replicability, Section 9 concludes, and Section 10 closes with a first-person reflection on learning.

Section 2. Port Competitiveness and Contestable Demand

This section supplies the concepts the method rests on, in three moves: what makes a port competitive in a layered logistics market (2.1), why total logistics cost is the factor a planner can map even though it is not the only one shippers weigh (2.2), and how vertical integration removes a large share of demand from the contest altogether (2.3). A reader who wants the method itself can proceed to Section 3 and return here for the taxonomy of captive cargo in 2.3, which Stage 5 uses as its checklist.

2.1 Competitiveness in the Supply Chain

The competitiveness of the port sector is a multifaceted concept. It can be improved through structural strategies, which increase the number of competitors, and regulatory strategies, which correct market imperfections and induce ports to operate as if in a competitive market (World Bank, 2007). To operationalize the concept for planning, it helps to place the port inside the layered market of logistics services. Notteboom et al. (2022) describe the progression from first-party logistics (1PL), where the cargo owner arranges its own transport (a Mato Grosso soybean producer trucking to port), through 2PL asset operators (the rail concessionaire RUMO), 3PL integrators (terminal operators such as Santos Brasil, advancing "from the port to e-commerce"), 4PL lead logistics providers that orchestrate entire chains without owning assets, up to technology-driven 5PL providers managing multiple supply chains globally. The relationships among these players are determined by the degree of outsourcing each shipper chooses, and the large players keep acquiring one another to defend their positions. What matters for master planning is the consequence: a competitive port must support all of these relationships with efficient, reliable infrastructure and services, and, as Parola et al. (2017) argue, port authorities and terminal operators must align strategies and coordinate activities if the complex as a whole is to compete.

At the terminal level, the competitiveness drivers are well established (Luo et al., 2022; Munim & Schramm, 2018): infrastructure and equipment quality; operational efficiency across cargo handling, customs clearance, and sanitary and administrative processes; geographic location and connectivity to rail, road, pipeline, and inland waterway networks; integration with supply chains, including digital connectivity; digitization and data use, of which port community systems are the canonical example; exposure to labor disputes and shortages; and overall logistics performance, meaning the cost, time, reliability, and predictability of import and export activities. Intra-port competition among terminal operators generally improves the performance of the whole complex, whereas the effects of inter-port competition vary with geography and cargo type.

Port authorities compete too. Their common strategic goal is competitiveness, alongside contributions to economic growth, employment, trade facilitation, throughput, hinterland and foreland integration, and sustainability (Notteboom et al., 2022). Governance models range from the classic public landlord to operating and private models, with no universally preferred form. Two monitoring duties matter directly for planning: tracking the level of competition inside the complex, for which the Herfindahl-Hirschman Index (HHI) is the standard instrument (already used in Brazil by the antitrust authority CADE and by the port sector in lease auctions), and preparing for structural change in traffic levels, cargo mix, and the geography of flows driven by shocks, nearshoring, the energy transition, and automation.

2.2 Global Logistics Costs

The overall cost of moving goods through a port is among the most decisive competitiveness factors (Luo et al., 2022), but rarely the only one: shipper priorities vary with the market and the circumstances of each industry, and reliability, resilience, service frequency, infrastructure, congestion, transport capacity, and commercial relationships weigh alongside cost, with relative weights that can shift quickly after a major disruption. Cost remains the factor a planner can map municipality by municipality, which is why the methodology starts from it without ending in it. Global logistics costs comprise transportation costs; warehousing and storage; inventory carrying costs; packaging; customs duties and taxes; administrative costs; and loss and damage, which is critical in markets such as RoRo where vehicle damage avoidance is paramount. For port planning purposes these components group into three categories: (i) costs between the port terminal and the cargo hinterland, (ii) port costs, and (iii) costs between the terminal and the seaward interface. Maritime costs lie outside the control of port management, so planning effort should concentrate on the first two: the port authority acts directly on port-controlled costs, and the strategic challenge is to understand hinterland costs well enough to compete for potential demand and to defend existing demand.

Transportation cost behaves as a function of distance and time. Rodrigue (2024) distinguishes, among other structures, the linear effects of distance (costs proportional to distance, expressed in $ per ton-kilometer) and the intermodal transport chain (a combination of linehaul and terminal costs, in $ per ton, where transshipment at terminals increases the friction of distance). Both structures are the raw material of the SPC isocost analysis in Section 3. Beyond direct charges, a penalty term should be estimated, demurrage being the clearest example, using average ship dwell time by complex and cargo type, so that deteriorating performance visibly reduces the obtainable market.

A single Brazilian corridor illustrates how these abstractions play out. Paranaguá and Santos compete intensely for agricultural bulk (soybean, corn, meals). Both are rail served: Paranaguá via the Malha Sul network operated by RUMO, Santos via the internal port railway where RUMO (about 75%), VLI, and MRS operate, with the Rondonópolis to Santos corridor handling essentially all rail flows into Santos. Rail volumes are allocated by the network; the true contest is for trucked volumes, shaped by port capacity (the reception, storage, and handling triad) and by demurrage costs from queuing. The two ports also embody different operating models: Santos is largely vertically integrated terminal by terminal, while Paranaguá's Corex export corridor coordinates more than 12 terminals feeding three berths, each with two ship loaders that can work the same vessel simultaneously, achieving exceptional berth productivity. These are two operating strategies within one rivalry.

2.3 Vertical Integration: A Taxonomy With Brazilian Evidence

The second pillar of the SPC diagnosis is that a large share of port demand is not contestable at all, because vertical integration fixes it to specific ports. Three forms of verticalization dominate the Brazilian market.

Rail-port verticalization. Rail is inherently network-dependent, and Brazil's concession framework organizes contracts by geographic networks. The resulting map is concentrated: RUMO controls virtually all rail transportation in the South and Southeast, including the connections to the Center-West grain belt, and

Vale and VLI control most of the iron ore market. Coverage is thin by international standards: the United States has 29.86 km of railway per 1,000 km2 of territory, more than eight times Brazil's rate, and Mexico, with a network about 10% shorter than Brazil's in kilometers, has nearly four times Brazil's coverage (Associação Nacional dos Transportadores Ferroviários, 2022; full density table in Annex A). Despite a rights-of-way framework, concessionaires typically absorb nearly all available capacity, discouraging competition. Verticalization occurs when the rail operator is corporately aligned with cargo owners or terminal operators: Vale and VLI moving Vale iron ore to the Ponta da Madeira terminal at Itaqui is the emblematic case, and the TERMAG and TGG terminals at Santos, where RUMO is a shareholder, post leading mineral dry bulk (MDB) throughput with fertilizer rail shares approaching 90%. The gauge breaks and missing links between networks complete the effect: rail ties freight to ports, and that tied demand is inelastic.

Verticalization by cargo, production, or industry. Commodity industries selling at exchange-determined prices verticalize logistics to cut costs, exploit specialized operations, and control the chain end to end. Two boxed examples follow.

> **Box 2.1. The orange juice supply chain.** Orange juice is arguably one of the most integrated commodity chains in the world (Neves et al., 2019, 2020). The system is controlled end to end: from company-owned and tenant groves, through industrialization into frozen concentrated (FCOJ) or not-from-concentrate (NFC) juice, to specialized truck fleets, to port terminals with standardized reception and storage, and finally to company-owned specialized tanker vessels rotating between the Port of Santos and consumer markets. Berth occupancy rates of up to 80% reflect the precision of the chain. Approximately 90% of Brazil's orange juice exports pass through Santos, concentrated among the three CitrusBR processors (Citrosuco, Cutrale, and Louis Dreyfus Company) (U.S. Department of Agriculture, 2025). Brazil is the world's leading orange juice exporter, accounting for about 75% of the orange juice marketed in the world: of every ten glasses consumed globally, seven are produced in Brazil (USDA, 2025). The recent seasons prove the chain's rigidity under stress: the 2024/2025 citrus belt harvest fell to 230.87 million 40.8 kg boxes, the smallest since 1988/1989, under drought and a greening

incidence above 44% of belt trees, and rebounded 26.9% to 292.94 million boxes in 2025/2026 (Fundecitrus, 2026; USDA, 2025); throughout the worst supply shock in three decades, the flows never migrated to another port. For a competing port, none of this volume is addressable: it is fixed by design.

Box 2.2. The pulp and paper industry. Pulp follows a similar, slightly looser model: company-owned and leased plantations on hybrid seedlings, a standardized industrial process, contracted transport between mill and port, and strategic vessel chartering. The two critical assets, the mill and the port terminal, are tightly coupled, securing the export channel and controlling logistics cost. Suzano, Eldorado, and Bracell each operate their own port terminal connected to the mill by rail. The planning consequence is identical to the orange juice case: the flow is fixed, and a demand forecast that treats it as contestable overstates the market for everyone else.

Fleet-based vertical integration. The third form arises from ownership or control of ship fleets, with carriers integrating into terminals to protect their core shipping business. In liquid bulk (LB), especially chemicals, Stolthaven and Odfjell expanded from shipping into terminal management because of the specialization the cargo requires (tank types, safety systems, customer portfolios). In containerized cargo (CC), MSC holds Terminal Investment Limited (TIL), Maersk holds APM Terminals, and CMA CGM holds Terminal Link and CMA Terminals; carriers integrate to secure berthing windows and to keep end-to-end cost discipline. Brazil supplied a live case: in 2019, the proposed STS10 container terminal tender at Santos raised the question of concentration when the incumbent joint venture BTP was indirectly held 50/50 by MSC and Maersk through their terminal arms, and competitors challenged participation. The recent takeovers of Santos Brasil by CMA CGM and of Wilson Sons by MSC, together with new positions such as APM Terminals at Suape, have redrawn the capacity map: the three large shipping groups jointly account for more than 60% of Brazil's declared container terminal capacity. An HHI analysis computed across three dimensions (geography: Brazil, North/Northeast, South/Southeast; metric: capacity share and 2021 to 2023 throughput; ownership: terminals individually and grouped by shareholder) classifies most segments as moderately concentrated, with the highest reading, still moderate, on throughput aggregated by shareholder group. The regulatory challenge for ANTAQ and CADE is to monitor service levels and private prices comparatively; the planning lesson, following de Langen (2020), is to account explicitly for minimum efficient scale, market size, and the number of operators a market can support. At Paranaguá, for example, a single competitive container operator, TCP, controlled by China Merchants Port, serves the market.

2.4 From Competitiveness to Contestable Demand

Demand for a logistics solution depends on cost first, but also on the level of service: frequency of transport services, the logistics cycle profile of the cargo, risk of damage or loss, safety requirements, and tax treatment. Projecting potential demand beyond captive, vertically integrated, fixed-effect volumes therefore centers on contestable demand: the origin-destination logistics solution, necessarily including a port at one end, results from the bundle of factors that make one [mode; route; port] combination more competitive than the alternatives. It is not sufficient to allocate OD flows on available capacity alone.

Two refinements sharpen the frame. First, terminals, not ports, are the units of competitive strategy: competition between ports increasingly coexists with competition between market players present in more than one port (DP World, TIL, APM Terminals, and ICTSI in containers; Odfjell and Stolthaven in liquid bulk, across multiple Brazilian complexes). Second, shippers, logistics providers, and carriers do not choose a port; they choose a chain in which the port is a single node. Globalization of production, the global transport network, and the evolving port-hinterland relationship have all intensified inter-port competition, pushing ports to become more market-oriented and more responsive. A planning methodology that ignores these facts will misread both the size and the location of future demand. The SPC methodology, presented next, is built to read them.

Section 3. The SPC Methodology

This section is the operating manual: definitions (3.1), the cargo classification and the six databases the method runs on (3.2 and 3.3), the ten stages (3.4), what changes in planning practice (3.5), and how the method matured through application (3.6). A reader pressed for time can take 3.1 and 3.4 and move to the case in Section 4; the forecasting model specification is in Annex A.

3.1 Definition and Core Concepts

Spatialized Port Competitiveness (SPC) is a methodology for analyzing interactions among ports competing for the same product in the same region, in order to estimate contestable demand and forecast the addressable market. SPC can be applied between different port complexes or among facilities within a complex; a complex is eligible for inclusion when one or more of its infrastructures can handle the cargo under study. Competition occurs among ports along the same coastline that share all or part of the same hinterland, with overlap that varies by cargo type: Paranaguá and Santos contest fertilizer and grain; the Northern Arc complexes contest overlapping influence areas across waterway, rail, and road; São Francisco do Sul and Imbituba contest mineral bulk, at times with the same ship calling at both; and, with the Transnordestina railway, Pecém and Suape are likely to contest MATOPIBA commodities. Demand analyses for competing complexes must therefore be conducted jointly, and the SPC zone defines the set of ports analyzed together.

SPC differs from the port cluster concept, which groups ports in close geographic proximity on the assumption that similar logistics costs let cargo migrate between terminals on operational grounds alone. SPC instead maps, cargo by cargo, which hinterlands actually overlap and at what cost differential. Once the SPC zone is defined, vertically integrated chains are identified and treated separately: the analysis explicitly excludes demand with inelastic behavior, flows fixed to a defined origin-destination pair. The relevant market, in the antitrust sense, is the set of economic agents in the logistics chain (consumers, industries, and 1PL to 5PL providers) that respond to and constrain a firm’s decisions on pricing, quantities, and quality.

Three working definitions recur throughout the paper. The Natural Port Influence Zone (Natural ZIP) of a port, for a given cargo family, is the set of municipalities for which that port is the least-cost option in hinterland logistics; in practical terms, it is the port's natural hinterland under least-cost logic, and the paper uses the two expressions interchangeably. The Zone of Competition is the composition of the overlapping Natural ZIPs of the competing ports. And a crucial reading rule follows: the Natural ZIP volume is not the volume the port actually handles, but the volume that, under least-cost logic, should be handled by it; the gap between the two is the first measure of competitive under- or overperformance.

3.2 The Harmonized System as the Cargo Backbone

All flows are classified on the Harmonized Commodity Description and Coding System (HS) of the World Customs Organization (World Customs Organization, 2022), the international nomenclature under which more than 98% of merchandise trade is classified. The HS is organized in 21 sections and 96 chapters, subdivided into 1,228 headings and 5,612 subheadings: the first two digits (HS-2) identify the broad category, HS-4 the grouping, HS-6 the specific commodity, and Brazil extends the code to eight digits (the NCM). The HS maps onto the PNL macro-product list and, through it, onto cargo types, port operations, and terminals, which is what allows customs statistics, waterway statistics, and rail statistics to be joined into one analytical object.

3.3 Databases DB1 to DB6

The methodology runs on six databases, consolidated in Table 3.1. The labeling below is the paper's canonical dictionary.

Table 3.1.

SPC Database Dictionary (Consolidated)

Code	Content	Source and role
DB1	Foreign trade by product (HS) and municipality	ComexStat/Secex; monthly since 1997; municipality of the exporter's or importer's tax domicile; origin side of the OD matrix
DB2	Foreign trade by product (HS) and port	ComexStat/Secex; monthly since 1997; port side of the OD matrix

Code	Content	Source and role
DB3	Product by municipality by port	Constructed from DB1 and DB2 (Stage 1); the OD trinomial cargo-municipality-port
DB4	Waterway operations: vessel calls, berthing, port attributes	ANTAQ; the only national source for vessel-call information (Paperless Port System filings)
DB5	Harmonized OD matrix (product by municipality by port)	Harmonization of DB3 and DB4: cargo quantities from ComexStat, vessel and port attributes from ANTAQ
DB6	Rail transport by product (HS-4 correlated)	ANTT; identifies rail-handled cargo for the fixing analysis (Stage 6)

One methodological note governs the joint use of the two main sources. Comparative analyses across several studies indicate that, for quantifying cargo handled, the ComexStat data set (Ministério do Desenvolvimento, Indústria, Comércio e Serviços [ComexStat], 2026) generally provides more reliable figures than the ANTAQ data set (Agência Nacional de Transportes Aquaviários [ANTAQ], 2026), and only ComexStat carries the hinterland information (municipality) that makes market share addressable to a port; ANTAQ, however, remains indispensable as the only national source for vessel-call data. The OD matrix therefore takes cargo quantity fields from ComexStat and vessel and port attributes from ANTAQ. The ANTT rail database (Agência Nacional de Transportes Terrestres [ANTT], 2026) has a comparatively simple structure, and its merchandise labels must be correlated to the standardized cargo-type list; despite the limited detail, a large share of products can be mapped to HS-4.

The paper’s cargo family nomenclature, used from here on, is: ADB (Agricultural Dry Bulk), MDB (Mineral Dry Bulk), LB (Liquid Bulk), CC (Containerized Cargo), GC (General Cargo, meaning breakbulk), and RoRo (roll-on/roll-off). The bridge to the Brazilian source labels is given in Annex F. Two structural exclusions apply to the bulk families: iron ore (within MDB) and crude oil (within LB) are so vertically integrated in Brazil, by Vale and VLI on the ore side and Petrobras on the oil side, that they must be analyzed separately from the contestable families.

3.4 The Methodology, Stage by Stage

The ten stages below are the operating procedure of SPC. They are numbered Stage 1 through Stage 10 in the order of the detailed methodological exposition. The analytical engine at the projection stage is a fixed-effects Poisson regression on static panel data, applied to the contestable baseline.

Stage 1. Define the origin-destination (OD) matrix. Consolidate the trinomial cargo, municipality, port into DB3 by joining DB1 and DB2: harmonize HS codes to HS-4, filter events with common keys (year, month, state, partner country, flow direction, HS-4), compute each municipality's and each port's share of every event, and weight event loads by the product of the two shares over the Cartesian product of municipality-port pairs. The result is a complete, weighted OD matrix of foreign trade flows at municipal granularity.

Stage 2. Define the SPC zones. Determine which ports must be analyzed and projected jointly: conceptually, n ports competing for j cargo types within i hinterlands, SPC(n, i, j). The zone proposals start from the strategic logistics corridors of the sectoral plans and coastline groupings, and are validated (adjusted, justified) per cargo family. The planner retains discretion to include additional complexes, particularly for greenfield terminals or new cargo prospecting, provided the inclusion is methodologically justified.

Stage 3. Delineate the area covered by the SPC. Identify the municipalities of interest: filter the harmonized OD base to SPC ports only, generate the list of unique municipalities related to those ports, and map the SPC area of influence. In the Paranaguá ADB export case, this stage identifies 227 municipalities in the complex's Natural ZIP, against 291 for Santos, inside a zone whose terminals exported an annual average of 54.6 Mt of soybeans in 2022 to 2024.

Stage 4. Derive road isocost curves. For every municipality in the SPC area, compute the road transport cost to each SPC port (fuel, tolls, maintenance, capital remuneration, and company and driver remuneration, on a nine-axle truck standard of 74.0 t maximum capacity, shortest-distance routing, current toll rates, and the ANTT minimum-freight rule), and derive the differential freight value relative to the least-cost port. The differential is the port-cost offset required to shift the municipality's preferred port: if inland costs favor the natural port by R$ 200 per shipment, the second-best port must offer more than R$ 200 in port-cost advantages to capture that demand. Converting the differentials to R$ per tonne yields the capture curve: each additional level of port efficiency, understood as any reduction in global logistics cost rather than a tariff discount, brings a larger set of municipalities within reach. The curve exhibits two behaviors: linear stretches that mirror distance proportionality, and step jumps where a small change in the cost differential captures a large block of municipalities and cargo. In the Paranaguá ADB case, each R$ 1.00/t of efficiency gain expands capturable demand by roughly 300 thousand tonnes.

Stage 5. Identify and remove (fix) verticalized supply chains. Exclude from the contestable base the flows that vertical integration fixes to specific ports: map the industries owning or leasing terminals and other logistics assets, map their municipalities of origin and HS-4 cargoes, and flag the corresponding OD rows as fixed. The Section 2 taxonomy is the checklist: orange juice, pulp, iron ore, crude oil, and analogous chains are removed before any capture arithmetic.

Stage 6. Identify and fix rail-bound cargo. Brazil's rail networks have limited interconnection and strong terminal pairing, so railways fix OD relationships to specific ports, and rail's lower unit cost makes those volumes non-contestable in the short to medium term. Cross-reference the OD matrix with the ANTT base (DB6) through an HS-4 correlation table, flag rail-handled flows as fixed at their destination ports, subtract the corresponding volumes, and produce modal-split views per cargo and facility. The magnitude is decisive: of the 78.1 Mt of ADB exported via Santos in 2024, about 65.3 Mt arrived by rail, meaning 83.5% of Santos throughput in the family is captive and its mobility rate is only 16.5%.

Stage 7. Establish the new baseline (contestable demand). Aggregate the remaining (mobile) cargo of every municipality in the zone into a new baseline per cargo type and macro product. The projection in the next stage does not start only from the port's historical base year; it starts from one or more new levels (Baseline 1, Baseline 2) depending on the efficiency gains assumed, which is precisely where SPC departs from the incumbent method.

Stage 8. Develop the demand forecast (contestable demand). Project the disputable baseline with a gravity model estimated by Poisson Pseudo-Maximum Likelihood (PPML), following Santos Silva and Tenreyro (2006). The estimator is chosen for its robustness to heteroskedasticity and for handling zero flows in the origin-destination matrix natively, avoiding the selection bias that traditional log-linearization introduces. The specification regresses cargo volume per family and OD pair on the destination's real GDP (the external demand proxy), the origin GDP, the real effective exchange rate, and the total logistics cost of the route, with bilateral fixed effects per origin-destination pair absorbing time-invariant factors: geographic distance, historical ties, persistent barriers, and structural infrastructure characteristics. The estimated parameters therefore reflect the impact of temporal variation in the economic variables on flows, with structural heterogeneity held fixed. The formal specification (Equation A.1), the variable definitions, and the deflation conventions are given in Annex A, Section A.7; all monetary variables enter in real terms, which keeps the long-run projections to 2050 consistent. The projected curves are then shaped with market intelligence: production constraints, consumption trends, supply shocks, and technological change, supported by sector institutions (IBGE, Embrapa, USDA, Anfavea, Unica, and others) and by growth expectations collected in technical visits. The ZIP baseline projection is, by definition, the addressable market of the complex.

Stage 9. Adjust addressable demand for capacity constraints. Reduce the addressable projection to what the complex can actually handle: Projection 2 filters by operability (remove cargo for which the complex lacks equipment, such as ship loaders or ship-to-shore cranes), and Projection 3 imposes throughput limits from maritime infrastructure, yard, berths, and handling systems. Not all contestable cargo is economically attractive; this is the juncture at which facilities decide which cargoes they realistically intend to target.

Stage 10. Prepare the cargo capture plan. Compare the contestable baseline with the cargo historically handled, evaluate the new cargo mix against current equipment and infrastructure, and define the guidelines, strategies, and investments needed to capture the identified volumes, organized by pressure typology. The capture curve doubles as a commercial instrument: the first municipalities on the curve are the first targets for customer development and pricing plans.

The ten stages convert a statistical exercise into a strategic one. Stages 1 to 4 map the space of competition; Stages 5 and 6 subtract what is not in play; Stages 7 and 8 project what is; Stages 9 and 10 turn the projection into investment and commercial decisions. Section 4 shows every stage from 2 to 8 exercised at full scale in an official master plan.

3.5 What the Method Changes in Planning Practice

Three differences from the incumbent practice deserve emphasis, because they are what a planner inherits by adopting SPC. First, the projection base changes. The incumbent method projects from the port's historical base year; SPC projects from contestable baselines that already incorporate the demand the port should serve under least-cost logic and the demand it could serve at stated efficiency levels. The forecast therefore carries its own strategy sensitivity: each baseline corresponds to a management scenario, not merely to a macroeconomic one. Second, the unit of competition changes. Demand is mapped municipality by municipality, so the plan can state precisely where the port is losing cargo it should hold, to whom, and at what cost differential; "hinterland" stops being a shaded area on a map and becomes an accounted ledger of retention, penetration, and leakage. Third, the treatment of service level changes. Because the capture curve is denominated in R$/t of global logistics cost, any improvement that reduces that cost (shorter dwell time, lower demurrage, better reliability) is commensurable with a freight differential, which lets the plan price non-tariff competitiveness measures that the incumbent method could not even represent.

Two boundaries keep the method honest. The comparison across ports assumes internal port competitiveness is equal across competitors at the isocost stage, isolating inland cost differences; where evidence shows material differences in port-side performance, the demurrage-type penalty indicator described in Section 2.2 adjusts the obtainable market accordingly. And the forecast discipline remains multi-scenario: the point of Stages 9 and 10 is not to publish the largest number, but to confront addressable demand with capacity and with commercial feasibility, and to keep monitoring the confrontation across the four-year planning cycles.

3.6 Evolution of the Methodology

A capstone paper is also a record of professional growth, and the honest record here is that the methodology did not survive practice unchanged: it matured because of it. This section tells that story in three acts and five milestones; the full nine-milestone timeline is in Annex D. Positioning rule: SPC is the methodology, as approved in the capstone proposal; the SPC framework is how the methodology matured through application. The methodology is one; this paper uses the English name throughout. Depth here is publishable-only: concepts, logic, and validation principles, not proprietary code or internal pipelines.

Act 1 (approximately 2022 to 2023): the diagnosis. The starting point was the critique of Sections 1 and 2: Brazilian master plans project the past, and static forecasts ignore inter-port competition. SPC was conceived as the constructive answer: OD matrices at municipal granularity, overlapping port influence zones, and the segmentation of demand into verticalized and contestable components. The conceptual move that mattered most was the smallest sounding one: insisting that the municipality, not the state or the corridor, is the unit at which port choice is decided, because that is the granularity at which freight costs actually differ. Everything that followed, the isocost curves, the capture arithmetic, the bias corrections, is downstream of that choice. The planning decision Act 1 improved is the most basic one there is: sizing the addressable versus the obtainable market before committing capital.

Act 2 (approximately 2023 to 2025): the method. The intuition was formalized into the ten-stage procedure of Section 3 and applied in consulting engagements, including greenfield projects, accumulating more than 15 applications by 2025. Formalization bought two things ad hoc analysis cannot deliver: comparability across ports and cargo families, and repeatability, the precondition for a methodology rather than a study. Greenfield engagements were the hardest test and the most instructive: a port that has never handled cargo has no historical series to extrapolate, so the incumbent method has literally nothing to say about it, while SPC could still delimit its Natural ZIP, price its capture curve against incumbent gateways, and state the efficiency level at which the project becomes viable. Practice, meanwhile, kept returning defects in the method itself. Distance was a poor proxy for cost, so road isocost curves acquired real freight bands per municipality. Customs records assign cargo to the trader's fiscal seat rather than the producing municipality, so hinterland maps were systematically distorted toward corporate headquarters; in commodity markets dominated by trading companies, the distortion is not marginal, it can relocate entire catchments to state capitals where no hectare is planted. Each defect was logged, and each became the specification for the next act.

Act 3 (approximately 2025 to 2026): the industrialization. The response to those defects turned a procedure into a platform. The trader-headquarter bias was attacked with a cross-tabulated reconstruction of flows (HS-8 with HS-4 by municipality), gravitational reallocation in the Reilly tradition, and a composite detector that cross-references agricultural production statistics (PAM) with formal employment records (RAIS) to classify suspect origins at graded confidence, recovering the true productive origin of flows and honest catchment maps. Conservation of mass became a publication gate: reallocated totals must reconcile with official totals with error below 10^-6, so that no reallocation silently creates or destroys tonnage, and every forecast a port authority publishes is auditable. The isocost layer was monetized end to end, replacing distance-based curves with total logistics cost in R$/t built from a routing engine, a toll plaza layer, and regulated tariff tables, so that port choice is modeled on money, the variable shippers actually decide on.

An authorial concept set was operationalized (Zone of Competition, Disputable Demand, Port Captured Volume, Port Market Share), replacing vague hinterland language with measurable constructs that link analysis to commercial strategy. And the whole apparatus reached industrial scale: a national OD cube covering 2022 to 2025, on the order of 23.5 million rows and 3.86 billion tonnes, with versioned outputs and standardized dashboards, turning monitoring and adaptive forecasting into routine rather than one-off studies, which is exactly the adaptive capability Taneja et al. (2010) demanded of port planning. Two further hardening layers belong to this act, summarized here at concept level. A shared-customs audit corrects the attribution distortion that arises when one customs unit clears cargo for several physical ports, reallocating flows non-destructively so that port-level market shares in multi-port complexes are stated correctly while national totals are preserved. And the authorial vocabulary was fixed with measurable definitions precisely so that different analysts, or the same analyst years apart, compute the same quantity when they say "captured volume" or "disputable demand"; a methodology whose central terms drift is not replicable, however good its mathematics.

Table 3.2 condenses the arc into the five milestones that carry the narrative; each row is a weakness found in real application and closed by a methodological response. Periods are indicative of when each capability entered regular use; the full nine-milestone timeline is in Annex D.

Table 3.2.

Evolution of the SPC Methodology, Condensed (Five of Nine Milestones; Full Table in Annex D)

Period	Milestone	Weakness it solved	Planning decision it improves
2022 to 2023	SPC conceived: OD matrices, overlapping influence zones, verticalized vs contestable segmentation	Master plans "projecting the past"; competition ignored	Sizing addressable vs obtainable market before committing capex
2023 to 2024	Ten-stage SPC procedure formalized; applied in consulting cases including greenfields (15+ cases by 2025)	Ad hoc analysis; no replicable protocol	Comparable, repeatable studies across ports and cargo families

Period	Milestone	Weakness it solved	Planning decision it improves
2025	Trader-headquarter bias correction: cross-tab HS-8 + HS-4 by municipality, Reilly gravitational reallocation, composite PAM x RAIS detector	Customs records assign cargo to the trader's fiscal seat, not the producing municipality; hinterlands distorted	True productive origin of flows; honest catchment maps
2026	Total logistics cost monetized end to end: routing engine, toll plaza layer, regulated tariff tables; ZIP recalculated in R$/t	Isocost curves still partly distance-based	Port choice modeled on money, the variable shippers actually decide on
2026	Indústrial scale: national OD cube 2022 to 2025 (about 23.5 million rows, about 3.86 billion tonnes), versioned outputs, standardized dashboards	Analysis speed limited by manual assembly	Monitoring and adaptive forecasting as routine, not one-off studies

The reading intended for the examiner is the sequence itself: each row is a weakness found in real application and closed by a methodological response, which is the capstone learning claim in evidentiary form. The method did not survive practice unchanged; it matured because of it. Three of the milestones deserve a sentence on what they protect against, because they generalize beyond this framework. The bias correction protects against believing one's own maps: any analyst working from customs microdata anywhere in the world inherits the fiscal-seat distortion, and most published hinterland studies have never tested for it. The conservation gate protects against the quiet failure mode of all reallocation methods, tonnage created or destroyed in the arithmetic, by making reconciliation with official totals a condition of publication rather than a good intention. And industrialization protects against the decay that kills most consulting methodologies: when every application is hand-assembled, the method exists only in its author's calendar; when it runs as a versioned pipeline, it survives its author's attention span.

The evolution arc also matters to the reader for a practical reason: it is the replicability argument. A methodology that exists as a document can be admired; a methodology that exists as an audited, versioned, mass-conserving pipeline can be adopted at a marginal cost that keeps falling with each application. Section 8 returns to this point.

Section 4. Case Study: The Paranaguá and Antonina Port Complex

Cargo family labels in this section follow the paper nomenclature (ADB, MDB, CC, GC, LB, RoRo); the bridge to the Brazilian master plan labels is in Annex F, and the full analysis with complete tables is in Annex B.

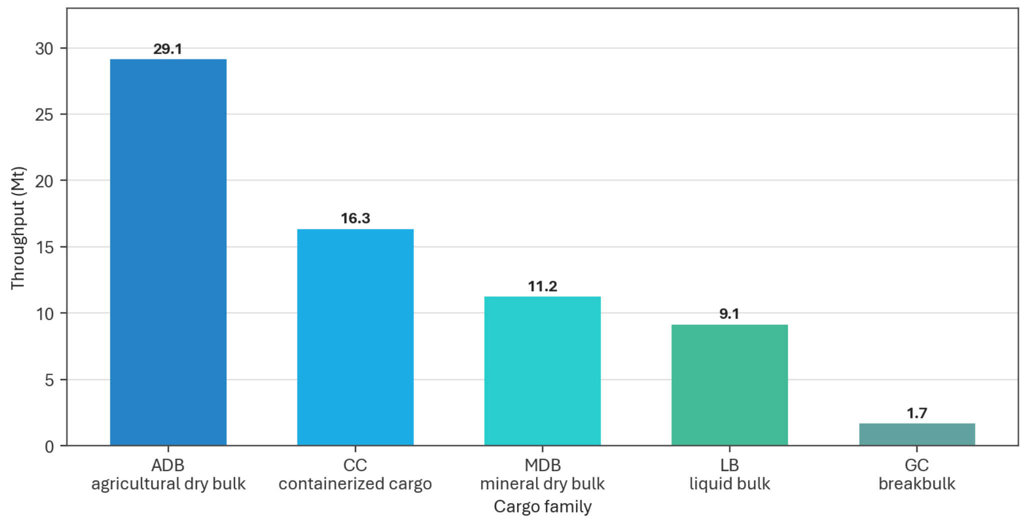
4.1 Complex Profile and the 2024 Movement Record

In 2024 the Paranaguá and Antonina Port Complex (Paraná, Brazil) set a cargo throughput record of 66.7 million tonnes (Mt) (APPA, 2025), confirming its position as the country's second-largest port gateway and a major counterweight to Santos on the southern coast. The complex was selected as the national pilot for the new planning methodology precisely for this profile: it handles every cargo family, in a demonstrably competitive environment (Conselho de Autoridade Portuária de Paranaguá [CAP Paranaguá], 2024). The complex combines the organized ports of Paranaguá and Antonina, with bulk operations distributed across both and container handling concentrated at the Paranaguá Container Terminal (TCP) inside the organized Port of Paranaguá. Agricultural dry bulk (ADB), handled at both ports, remained the anchor of the complex at 28.4 Mt of exports. CC (containerized cargo) at TCP delivered the year's standout growth: 1.46 million TEU as registered by ANTAQ, the national waterway transport agency, an increase of roughly 25% over 2023. The Port Authority's own statistics registered 1,558,450 TEU for the same period; the gap reflects distinct counting criteria, and the analysis adopts ANTAQ as the reference series for comparability.

The remaining families complete the profile: imports of mineral dry bulk (MDB), almost entirely fertilizers, reached 11.6 Mt; liquid bulk (LB) handled approximately 5.9 Mt; general cargo (GC, breakbulk) about 1.1 Mt, led by wood pulp and a fast-recovering bagged sugar trade; imported ADB just over 1.0 Mt; and roll-on/roll-off vehicles (RoRo) approximately 185 kt, or 115.7 thousand car equivalent units (CEU). The record year is a double-edged result: it validates the complex's competitive standing while exposing the need to expand capacity in several segments if the observed growth is to remain sustainable.

Figure 4.1.

Paranaguá and Antonina Port Complex, 2024 Throughput by Cargo Family, in Millions of Tonnes (Mt).



Note. Source: Infra S.A. (2026).

4.2 Competitive Position and the Zone of Competition

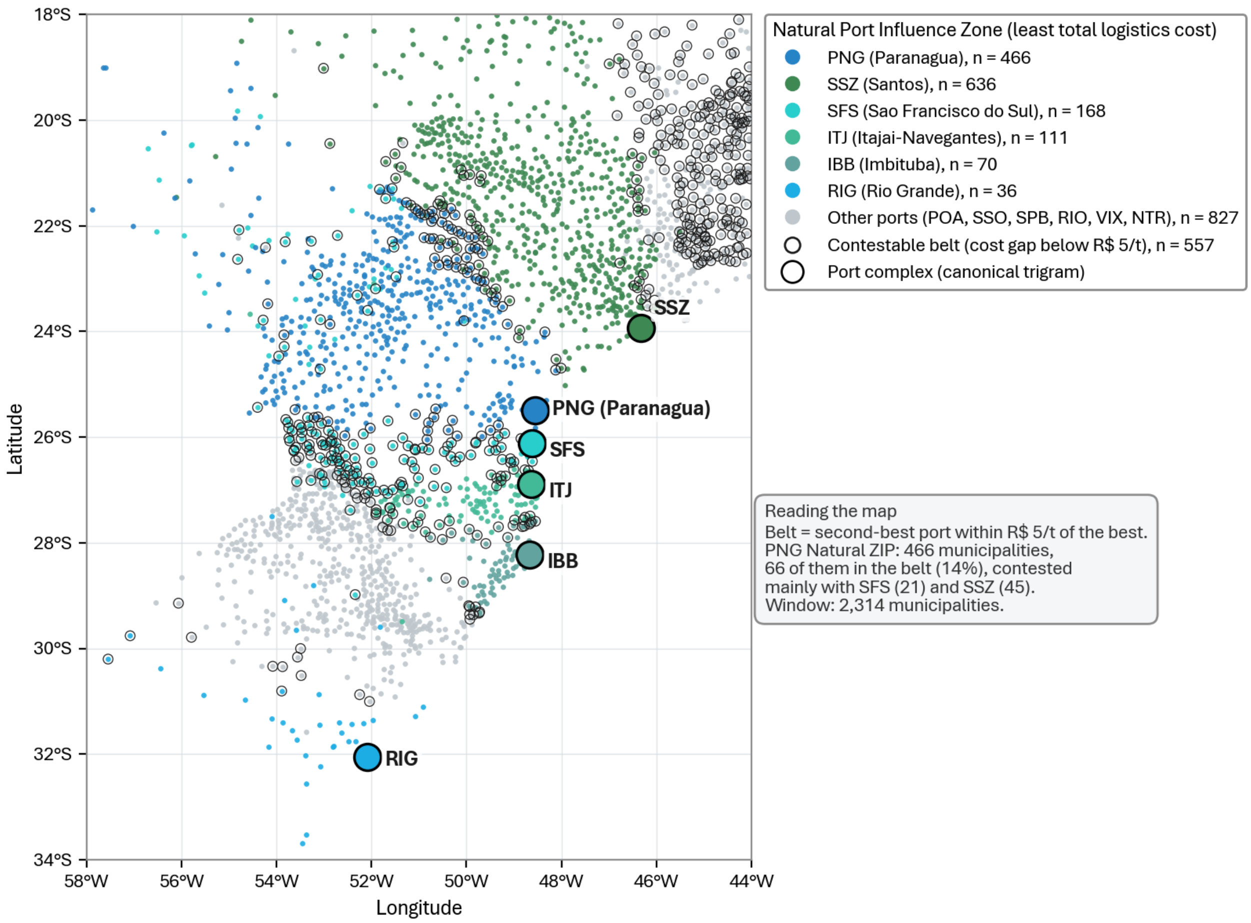
The Master Plan produced under Brazil's 5th Port Planning Cycle (Infra S.A., 2026; projections elaborated 2025 on a 2024 base year) applies a new demand projection methodology whose central premise is that port complexes compete for cargo within a shared hinterland, and that competitiveness is defined by service level rather than price alone: cargo dwell time, vessel waiting at anchorage, damage and loss incidence, workforce qualification, strategic position in the supply chain, and landside access all enter the assessment.

The methodology first delimits, for each cargo family, each port's Natural Port Influence Zone (Natural ZIP): the set of municipalities for which that port is the least-cost option in hinterland logistics. Composing the overlapping Natural ZIPs yields the Zone of Competition. For bulk cargoes, Paranaguá and Antonina compete with complexes from São Sebastião and Santos down to Porto Alegre and Rio Grande;

for general cargo, the zone widens northward to include Rio de Janeiro, Itaguaí-Sepetiba, and Açu. Within this Zone of Competition, territorial competition is measured here through a Pairwise Capture Share index, developed for this paper. For each rival complex R, the index is the share of cargo originating in, or destined to, Paranaguá's cost-based Natural ZIP (467 municipalities) that R actually handles, computed per cargo family on a trader-bias-corrected origin-destination base (ComexStat 2023 to 2025, annual average; gravitational reallocation correction for agribulk exports); Paranaguá's own share of its Natural ZIP is its penetration. The results quantify an asymmetric competitive field. Paranaguá retains 92.9% of fertilizer imports, 96.4% of liquid bulk imports, and 70.1% of containerized exports arising from its natural territory, but only 32.5% of its natural agribulk export market, where Santos alone captures 38.2%, more than Paranaguá itself; Itaqui and Rio Grande follow at 6.2% each and São Francisco do Sul at 5.3%. Across all families and directions, penetration is 51.9% of a 59.82 Mt per year natural market. This ordering, Santos first inside Paranaguá's own grain hinterland, independently corroborates the case figures of the 2025 Master Plan (Santos serving 47% of the natural ADB market against Paranaguá's own 38.7%), computed on a different vintage and ZIP definition. The full Zone of Competition composition is reproduced in Annex B. Figure 4.2 maps the field on which the index is computed: each complex's natural hinterland under least total logistics cost, and the belt of municipalities where a rival lies within R$ 5/t of the least-cost port: 66 of the 467 municipalities in Paranaguá's Natural ZIP sit in that belt, contested mainly with Santos (45) and São Francisco do Sul (21).

Figure 4.2.

Zone of Competition in Center-South Brazil: Natural Hinterland of Each Port Complex Under Least Total Logistics Cost, and the Contestable Belt (Municipalities Whose Second-Best Port Lies Within R$ 5/t of the Least-Cost Port).



Note. How to read this figure: dots are municipal seats colored by least-cost port; ringed dots are contestable; the contest is at the edges of each hinterland, and the edges have a price. Source: author's computation on routing and toll layers and IBGE municipal seat coordinates (Annex A, Section A.4.6).

Table 4.1.

Pairwise Capture Share in Paranaguá's Natural ZIP, Agri Dry Bulk ADB Export, 2023-2025 Annual Average

Complex	Volume (Mt per year)	Capture share (%)
Santos (SSZ)	13.05	38.2
Paranaguá (PNG, penetration)	11.11	32.5

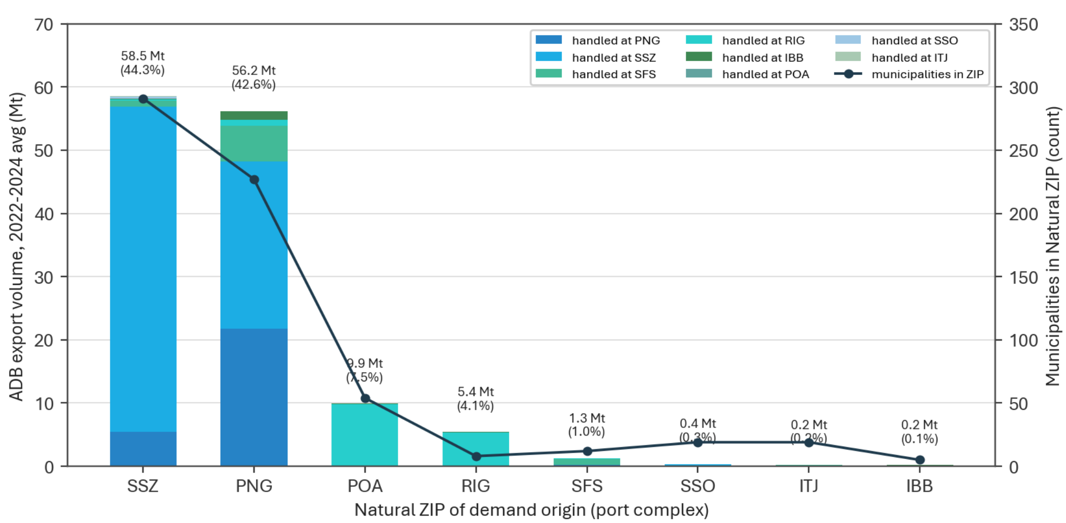
Itaqui (IQI)	2.13	6.2
Rio Grande (RIG)	2.13	6.2
São Francisco do Sul/Itapoa (SFS)	1.83	5.3
Others	3.95	11.6

Note. Source: author's computation, Annex C.6; trader-bias-corrected OD base; total 34.20 Mt per year

A crucial reading rule applies throughout: the Natural ZIP volume is not the volume the port actually handles, but the volume that, under a least-cost logic, should be handled by it; the gap between the two is the first measure of competitive underperformance or overperformance. On top of this spatial mapping, the methodology builds a capture curve for each family: at each level of port efficiency gain, expressed in Brazilian reais per tonne (R$/t) and understood as any reduction in overall logistics cost rather than a tariff discount, the port reaches a larger set of municipalities whose demand constitutes its potential market. A verticalization screen then discounts volumes rigidly tied to competing complexes by rail corridors, proprietary terminals, or integrated industrial plants, isolating the demand that is genuinely contestable. Demand is finally projected to 2050 under a reference scenario, extending the current throughput base, and one or more competitive scenarios that add the capturable increment.

Figure 4.3.

Zone of Competition for Agri Dry Bulk ADB Export: Demand by Natural ZIP and by Handling Complex, Municipality Count and Share of Total, 2022-2024 Annual Average, in Millions of Tonnes (Mt)



Note. Source: Infra S.A. (2026), from ComexStat and ANTAQ data.

4.3 Analysis by Cargo Family

Per-family analysis below keeps the competitive storyline and the headline 2050 projections; full capture curves, OD matrices, and per-product detail are in Annex B.

4.3.1 Agri Dry Bulk - ADB Export

ADB exports reached 28.4 Mt in 2024, an 8.9% decline from the 2023 record of approximately 31.2 Mt, on a long-run trend of about 3% average annual growth over 2010 to 2024. The slate is concentrated: soybeans at approximately 13.5 Mt, sugar at about 7.1 Mt, and meals at approximately 6.0 Mt.

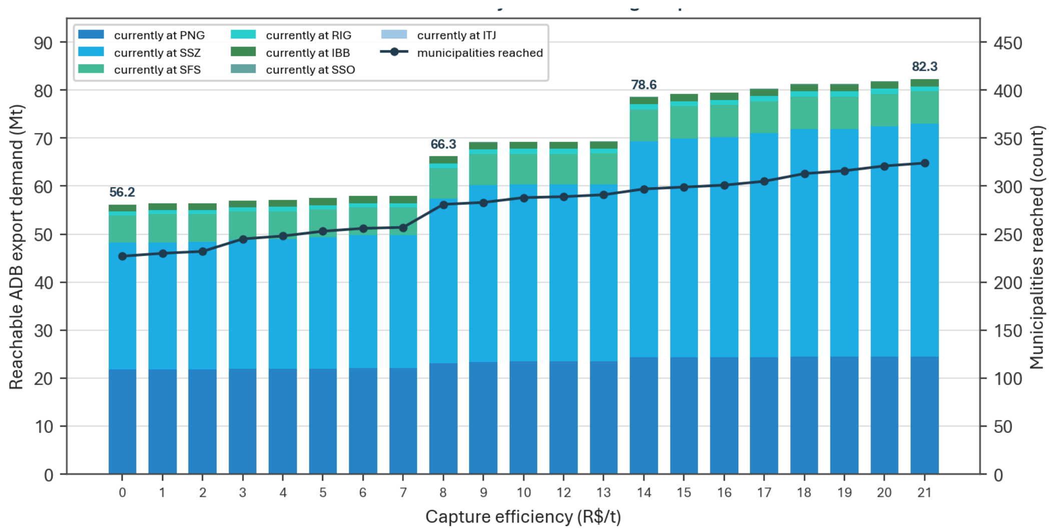
The competitive picture is one of a large natural market only partly retained. The complex's Natural ZIP spans 227 municipalities accounting for 56.2 Mt of export-bound ADB, 42.6% of the Zone of Competition total and second only to Santos's 44.3%. Yet only 38.7% of that natural demand was actually handled at Paranaguá and Antonina: Santos serves 47% of the demand arising inside Paranaguá's own Natural ZIP, while the reverse penetration is just 9.4%, and São Francisco do Sul takes roughly another 10%.

Verticalization explains much of the asymmetry. Santos's hegemony in Center-West grain evacuation rests on rail integration: of its 78.1 Mt of ADB exports in 2024, about 65.3 Mt arrived by rail, meaning 83.5% of its throughput is captive to the corridor. On the Paranaguá side, COAMO operates 100% verticalized ADB flows and PASA approximately 75%, anchoring the local base, while the Moegão intermodal project and the Nova Ferroeste railway (Maracaju to Paranaguá) aim to raise rail retention and contest Center-West volumes now fixed to the Malha Paulista corridor.

The projection reflects this contestability. On the current base alone, ADB export demand reaches 75.6 Mt in 2050, growing about 3.4% per year. Adding the capturable demand unlocked by efficiency gains, 12.0 Mt in 2025 in the base setting, total demand can reach 103.7 Mt at the end of the series, with the capturable component representing about 37% of the reference scenario.

Figure 4.4.

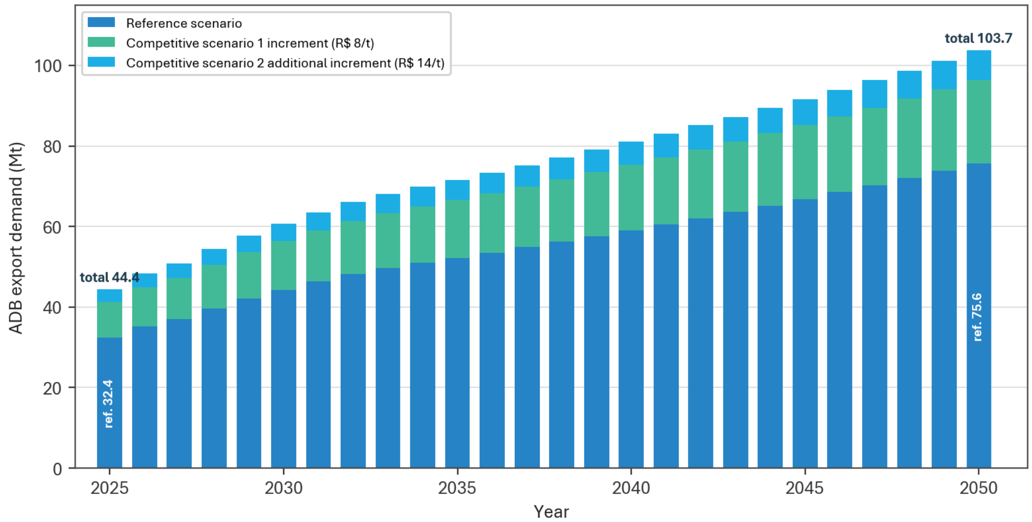
Potential Capture Curve for ADB Export at the Paranaguá and Antonina Complex: Reachable Demand by Capture-Efficiency Level (R$/t)



Note. Split by Current Handling Complex, With Municipalities Reached, 2022 to 2024 Basis, in Millions of Tonnes (Mt). Source: Infra S.A. (2026). How to read this figure: moving right along the horizontal axis means the port becomes more efficient (lower total logistics cost, in R$ per tonne); the bars show how much agribulk demand becomes reachable at each step, colored by the complex that handles it today, and the line counts the municipalities brought within reach. The step jumps mark where a small efficiency gain captures a large block of cargo.

Figure 4.5.

Agri Dry Bulk (ADB) Export Demand Projection at the Paranaguá and Antonina Complex, 2025-2050, Reference Scenario and Two Competitive Scenarios (R$ 8/t and R$ 14/t Capture Efficiency), in Millions of Tonnes (Mt).



Note. Source: Infra S.A. (2026).

4.3.2 Containerized Cargo - CC

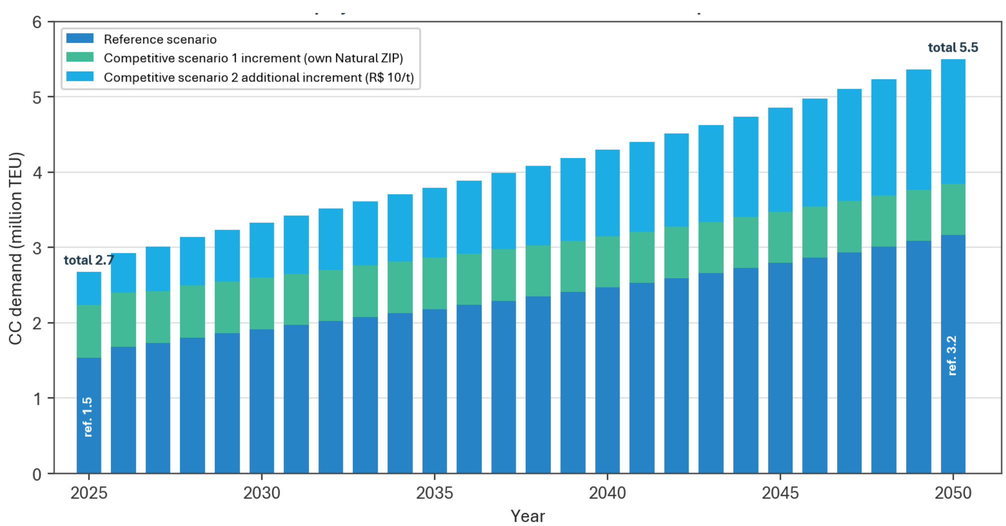
Deep-sea CC throughput was approximately 9.1 Mt in 2024, about 19% above 2023, on an average expansion of 4.9% per year since 2010. Roughly 85% of container movement is deep-sea and about 65% outbound; cabotage, historically a 5% to 6% share, shifted after 2021 toward a new equilibrium in the 10% to 12% band.

The complex is the leading national export pole for containerized meat, with more than 38.5% of the Zone of Competition's 2022 to 2024 average (3.04 Mt per year through TCP), ahead of Santos (24.3%) and Itajaí-Navegantes (18.9%); frozen poultry dominates the mix, and the 2024 export slate confirms the pattern, led by meats at approximately 2,891 kt, wood at 1,333 kt, and paper at 590 kt. In containerized wood products Paranaguá holds 32.6%, second to Itajaí-Navegantes. On the import side, the zone unloaded an average 20.3 Mt per year of CC in 2022 to 2024, led by plastics at about 17% of the flow. Conversely, Santos dominates containerized coffee (73.2%) and cotton (approximately 97.5%), and the pairwise contest is lopsided: Santos absorbed about 29% of the cargo from Paranaguá's Natural ZIP, approximately 2.96 Mt, while Paranaguá captured only 2.7% of Santos's.

The projection points to 3.16 million TEU in 2050 on the current base, about 2.9% per year. Two capture layers add 0.68 million TEU (first competitive layer) and 1.65 million TEU (second layer, at the R$ 10/t efficiency level) in 2050, taking total demand to 5.5 million TEU in the most competitive setting. Container capacity is therefore the single most consequential expansion decision in the portfolio.

Figure 4.6.

Containerized Cargo (CC) Demand Projection at the Paranaguá and Antonina Complex, 2025 to 2050, Reference Scenario and Two Competitive Scenarios (Own Natural ZIP Recovery and R$ 10/t Efficiency Step), in Million TEU.



Note. Source: Infra S.A. (2026)

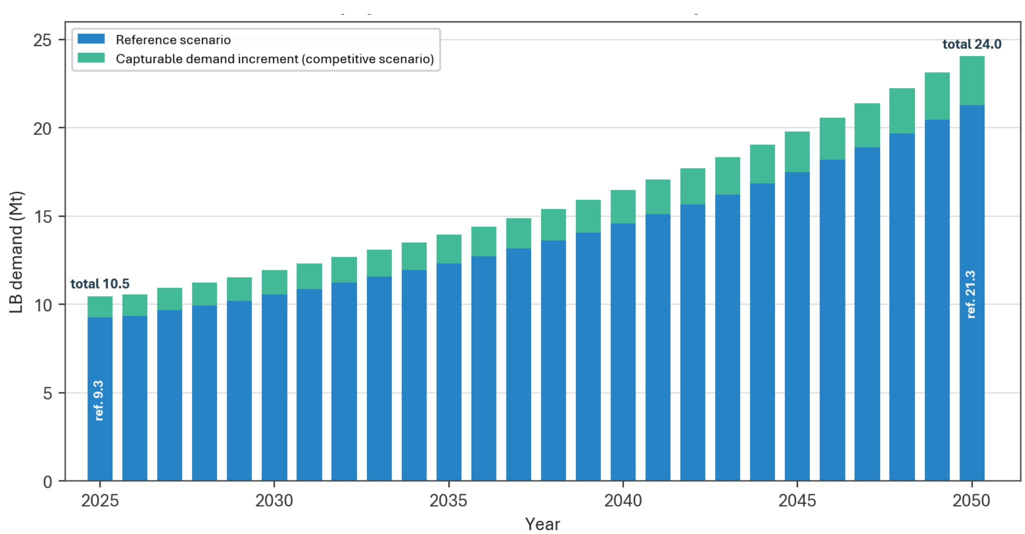
4.3.3 Liquid Bulk - LB

The complex handled approximately 5.9 Mt of deep-sea LB in 2024, 9.4% below 2023, though the series grew 6.4% per year on average over 2010 to 2024. The slate is narrow, led by soybean oil (approximately 663 kt) and diesel oil (about 358 kt); orange juice, a major regional liquid flow, is verticalized at Santos. The notable structural fact is a regime change in cabotage, which jumped from years near zero to 27.40% of LB movement in 2023 and 31.94% in 2024, with a 28% to 32% share projected for 2026 to 2030.

Competitively, LB behaves as a retention story rather than a capture story. Zone of Competition terminals handled an annual average of 24.6 Mt of LB in 2022 to 2024, dominated by diesel oil (12.61 Mt), and Santos's ZIP leads the demand map with 47.0% of the hinterland total against Paranaguá's 25.5%. Yet nearly 81% of the LB handled at Paranaguá and Antonina in the triennium (5.0 Mt) involved municipalities of its own Natural ZIP, and the cross-flows with Santos are roughly balanced (about 813 kt lost, about 800 kt captured). The capture curve rises only gradually across efficiency levels, without abrupt steps. After excluding verticalized volumes (juice, and Transpetro positions at São Francisco do Sul and Santos), the projection reaches 21.3 Mt in 2050 in the reference scenario and 24 Mt with capturable demand of about 2.77 Mt, a capturable share of 13% of reference, the most inelastic of the large families.

Figure 4.7.

Liquid Bulk LB Demand Projection at the Paranaguá and Antonina Complex, 2025 to 2050, Reference and Competitive Scenarios, in Millions of Tonnes (Mt).



Note. Source: Infra S.A. (2026).

4.3.4 Mineral Dry Bulk - MDB

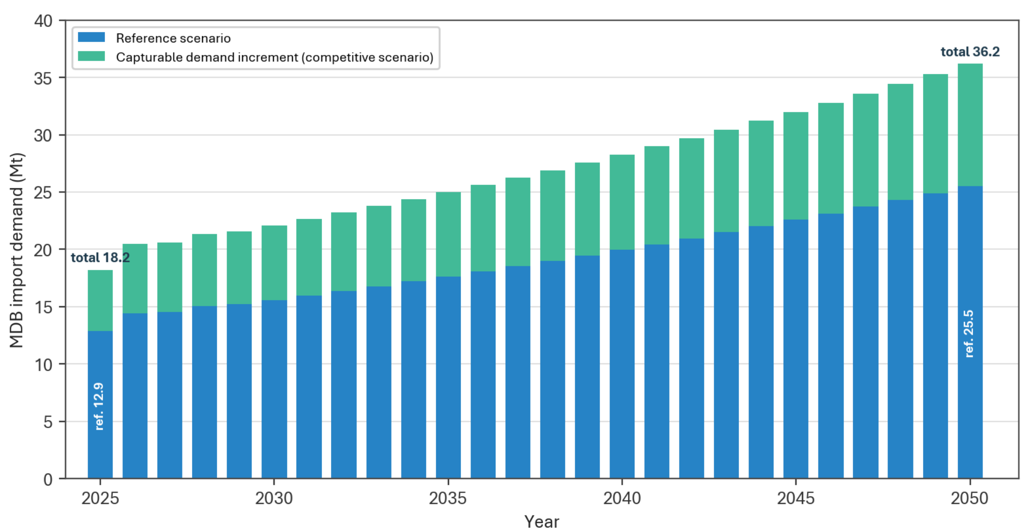
MDB imports reached just over 11.6 Mt in 2024, up 6.3% on 2023, growing 3.5% per year on average since 2010. Fertilizers are the segment: approximately 11.4 Mt in 2024, against a Zone of Competition average of 35.6 Mt per year in 2022 to 2024 of which fertilizers were 82.6%. Here Paranaguá leads its market: its Natural ZIP accounts for 38.1% of the zone's MDB flow (approximately 13.5 Mt), ahead of Santos (31.3%) and Rio Grande (14.7%), the three complexes jointly representing about 83.9% of the zone's throughput. Retention is high, and the complex additionally captured 21.1% of the demand originating in Santos's own ZIP, approximately 2.34 Mt, evidencing direct competition between the two gateways in the fertilizer trade.

Verticalization works in Paranaguá's favor in this family. The Fospar terminal is fully integrated into the Mosaic Fertilizantes and Fertipar chains, much of the discharged volume feeds blending units inside Paraná, and road backhaul efficiency is high, an estimated two fertilizer return loads for every three grain export loads. The reference projection reaches 25.5 Mt in 2050 at 2.78% per year; adding the capturable demand already inside the Natural ZIP but not yet handled (5.4 Mt in 2025), total demand can reach 36.2 Mt, an increment of about 42% over reference.

MDB exports are marginal by comparison (just over 62.5 kt in 2024, mainly slag) but illustrate the capture logic at small scale: the reference projection of 193.7 kt in 2050 rises to 753.7 kt with capture, since the complex today retains only 13.4% of its own Natural ZIP's export demand.

Figure 4.8.

MDB Import Demand Projection at the Paranaguá and Antonina Complex, 2025 to 2050, Reference and Competitive Scenarios, in Millions of Tonnes (Mt).



Note. Source: Infra S.A. (2026).

4.3.5 GC (General Cargo, Breakbulk)

GC throughput was approximately 1.1 Mt in 2024, dominated by wood pulp (nearly 900 kt) and bagged sugar, an operation in clear resurgence at Paranaguá after years of containerization: 372 kt in 2023, 485 kt in 2024, and 644 kt through October 2025 per ANTAQ. The family's regional market is substantial, with Zone of Competition exports averaging 13.4 Mt per year in 2022 to 2024 (pulp alone 83.5%) and imports 3.43 Mt (steel products 72.5%). The competitive gap is the widest of any family: the complex's 256-municipality Natural ZIP trades 5.64 Mt of GC, yet Paranaguá handles only 19.6% of it, with Santos capturing more than 3.83 Mt of that natural demand.

The reason the Master Plan nonetheless projects no capture scenario is verticalization: pulp at Santos is tied to Suzano, Bracell, and Eldorado; steel flows are integrated at São Francisco do Sul; and capital goods imports follow the location of new industrial plants. The projection is therefore reference-only, reaching approximately 5 Mt in 2050 at an average annual growth rate of 4.64%, the steepest organic growth path in the portfolio, carried largely by bagged sugar and pulp.

4.3.6 RoRo (Roll-On/Roll-Off Vehicles)

Paranaguá and Antonina rank among Brazil's main vehicle gateways, handling approximately 185 kt (115.7 thousand CEU) in 2024, essentially flat against 2023. Imported vehicles arrive from Japan, South Korea, China, and Europe for nationwide distribution, while exports, mostly built at plants in Paraná and neighboring states, serve Latin America, Africa, and the Middle East. Demand is bounded by automaker plant decisions rather than by logistics cost: Renault, Volvo, DAF, and CNH plants in Paraná anchor the complex, while the São Paulo industrial belt anchors Santos, whose Natural ZIP concentrates 56.7% of the zone's RoRo movement against Paranaguá's 22.1% (about 170 kt across 116 municipalities). Retention exceeds 90% on both sides and the capture curve adds only about 20 kt at maximum efficiency: a textbook inelastic family.

Given that structure, the projection replaces GDP-based drivers with projected global light vehicle sales reported in the International Energy Outlook 2023 (U.S. Energy Information Administration [EIA], 2023), from 79.5 million units in 2024 to 103.9 million in 2050, yielding 237 thousand CEU in 2050 in the reference scenario, 2.75% per year, with a capturable component of up to 21 thousand CEU, about 9% of reference. Installed capacity of 378 thousand CEU per year is not binding within the horizon.

4.4 Consolidated Outlook to 2050

Aggregating all families, the reference scenario indicates throughput of 150.5 Mt in 2050, a constant compound growth rate of 3.22% per year; excluding containers, the bulk and breakbulk base reaches nearly 128 Mt at 3.29% per year, doubling by 2047. The capturable demand mapped across the families amounts to 20.8 Mt in 2025 and 45.1 Mt in 2050, about 30% of the reference demand (the final plan reports 27% in the narrative and 30.00% and 26.33% in the corresponding table on p. 148). Were the mapped capture consolidated, the complex would grow at an average rate above 4.3% per year.

These rates are ambitious but externally anchored: they exceed the 2.81% implied by the Brazil 2050 Strategy target of doubling per capita GDP, sit above the Ministry of Agriculture's 2.2% agribusiness projection through 2034, and stand above WTO-based estimates of global GDP and population growth through 2050 (2.72% and 0.62% per year respectively; Infra S.A., 2026). They remain close to, though slightly above, the 3.09% average annual export growth estimated in recent trade literature, which expects trade to outpace world GDP on falling transaction costs and transport productivity gains (Bekkers et al., 2024; Fontagné et al., 2017). Table 4.2 consolidates the headline projections; the smaller segments not detailed above behave as reference-only markets (imported ADB reaches 1.4 Mt in 2050 at 1.19% per year; cruise calls are capped at the 16 calls observed in the 2023/2024 season, conditional on the new passenger terminal). Full per-family projections, capture curves, and the complete growth-rate table are in Annex B, which carries its own table numbering.

Table 4.2.

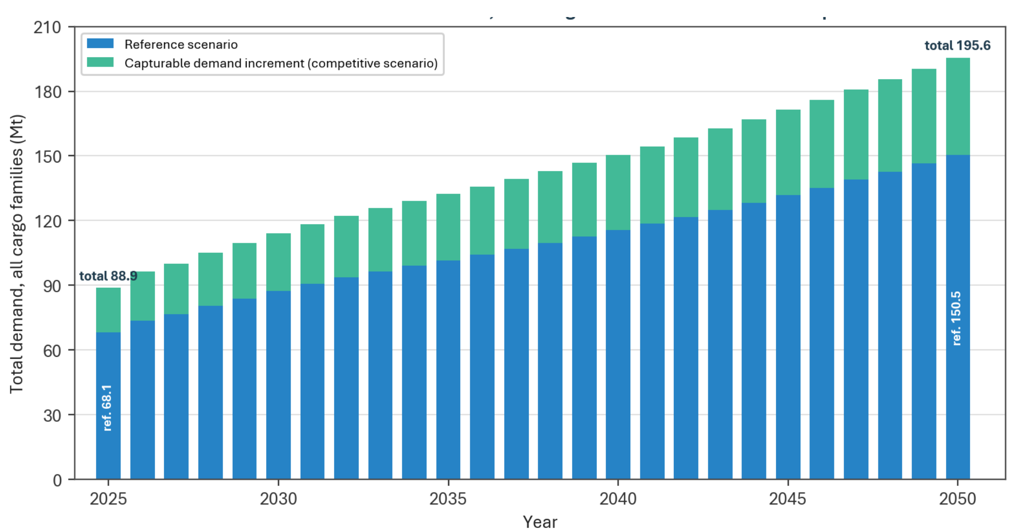
Consolidated 2050 Projection Headline by Cargo Family: 2024 Base, Reference Scenario, and Competitive Capture Scenario

Cargo family	2024 throughput	2050 reference	2050 with capture
Agri Dry Bulk – ADB export	28.4 Mt	75.6 Mt	103.7 Mt
Mineral Dry Bulk – MDB import	11.6 Mt	25.5 Mt	36.2 Mt
Containerized Cargo – CC	1.46 million TEU	3.16 million TEU	5.5 million TEU
Liquid Bulk – LB	5.9 Mt	21.3 Mt	24 Mt
General Cargo Break Bulk – GC	1.1 Mt	~5 Mt	reference only
ADB import	1.0 Mt	1.4 Mt	reference only
MDB export	62.5 kt	193.7 kt	753.7 kt
RoRo	115.7 thousand CEU	237 thousand CEU	up to +21 thousand CEU
Total, all families (Mt)	66.7 Mt	150.5 Mt	+45.1 Mt capturable

Note. Source: Infra S.A., 2026; full detail in Annex B

Figure 4.9.

Total Demand Evolution at the Paranaguá and Antonina Complex, All Cargo Families Including Containers, 2025 to 2050, Reference Versus Competitive Scenario, in Millions of Tonnes (Mt).



Note. Source: Infra S.A. (2026).

4.5 What the Case Demonstrates About the SPC Methodology

The Paranaguá and Antonina case is the first full-scale application of the competition-based projection method inside an official Brazilian master plan, and it exercises every analytical stage of the Spatialized Port Competitiveness (SPC) framework between Stages 2 and 8. Stages 2 to 4 are visible in the spatial mapping: reconciled ANTAQ, ComexStat, and ANTT data feed the Natural ZIP delimitation, the Zone of Competition composition, and the pairwise origin-destination capture matrices that reveal, for instance, that Santos serves 47% of Paranaguá's own natural ADB market. Stages 5 and 6 appear as the verticalization screen, which the case shows to be decisive: it converts a naive capture reading into a contestable one, explains why GC and imported ADB receive no capture scenario at all, and identifies rail integration as the single strongest demand-fixing mechanism. Stage 8 closes the loop with the two-scenario projection, reference versus competitive capture, expressed per family and consolidated.

The case's broader lesson is that the same hinterland data can tell opposite stories by family: ADB export and CC are high-capture markets where efficiency gains measured in single-digit R$/t move tens of millions of tonnes, while LB and RoRo are structurally inelastic. A planning method that cannot distinguish these regimes will systematically misallocate capacity investment; the SPC pipeline exists precisely to make that distinction auditable.

Section 5. Forecast Benchmark and Ex-Post Accuracy

If Section 4 shows what the competition-aware method produces, this section shows why the change was necessary. It asks two questions of the previous official planning instrument, the 2018 Plano Mestre for the Paranaguá and Antonina complex (Brasil, Ministério dos Transportes, Portos e Aviação Civil, Secretaria Nacional de Portos, 2018): how did its forecast perform against a decade of observed reality, and how far did the 2025 competition-aware projection move away from it at the common 2050 horizon? The answers are, respectively, "the baseline and pessimistic scenarios were surpassed in every year, while the optimistic scenario was surpassed in every year except 2019" and "the total was revised by 88.1%, with the change concentrated where competitive capture logic applies."

5.1 The Ex-Post Test: 2018 Forecast Versus Observed Operation, 2016 to 2025

The test compares the 2018 Plano Mestre demand curves under its three scenarios: baseline (baseline), optimistic (optimistic), and pessimistic (pessimistic); English names are used hereafter against observed throughput reconstructed from ANTAQ cargo-level data (long haul plus cabotage, organized ports of Paranaguá and Antonina plus the Cattalini terminal, matching the plan's scope), calibrated at the common 2016 base year, where the major commodities match the plan's figures to the tonne. Two convention gaps are documented rather than adjusted: the ANTAQ container series is gross tonnage and runs 10.7% above the plan's 2016 container figure, and the resulting total base gap is +1.8%. The plan's grid years are 2016, 2020, 2025 and every five years to 2060; intermediate forecast years are linear interpolations.

Table 5.1.

Observed Throughput Versus Plano Mestre 2018 Scenario Forecasts, Paranaguá and Antonina Complex, 2016 to 2025 (Mt)

Year	Observed	baseline	optimistic	pessimistic	Deviation vs baseline
2016	44.77	43.99	43.99	43.99	+1.8% (base-year convention gap)
2017	52.53	46.76	46.99	46.02	+12.4%
2018	54.82	49.53	49.99	48.06	+10.7%
2019	52.93	52.30	52.99	50.10	+1.2%
2020	57.11	55.07	55.99	52.13	+3.7%
2021	63.40	56.26	57.46	53.04	+12.7%
2022	59.72	57.46	58.94	53.94	+3.9%
2023	65.52	58.66	60.41	54.85	+11.7%
2024	65.88	59.86	61.88	55.75	+10.1%
2025	73.23	61.06	63.35	56.66	+19.9%

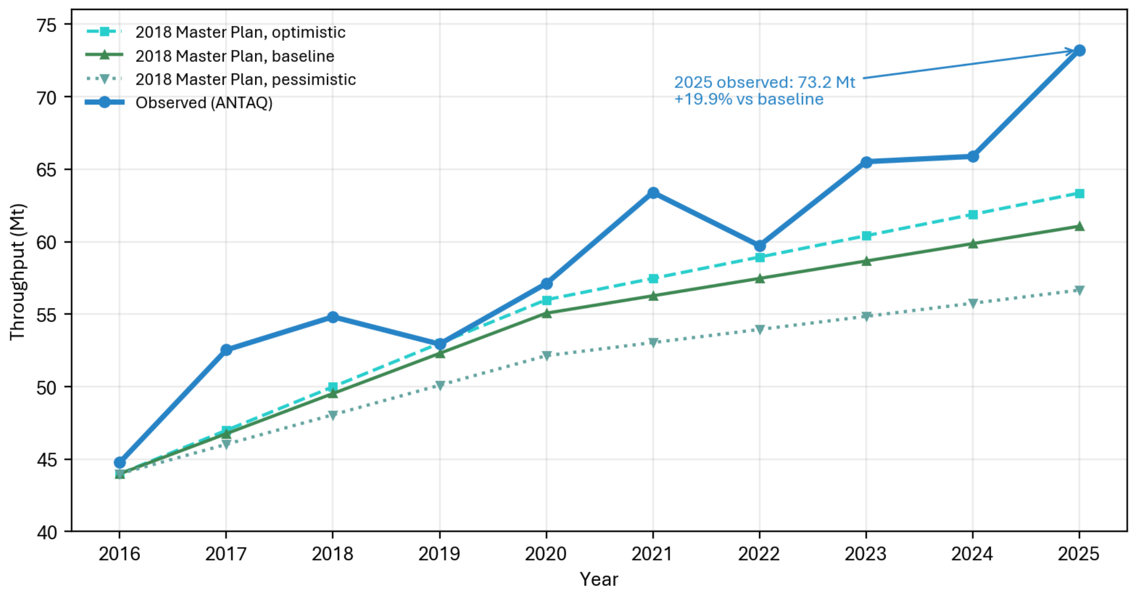
The pattern is unambiguous. Observed throughput beat the baseline curve in every year from 2017 to 2025 (substantively from 2017, at +12.4%), and beat even the optimistic ceiling in every year except a marginal 2019 (-0.1%). At the 2025 grid year, where no interpolation is involved, the complex handled 73.23 Mt against a baseline forecast of 61.06 Mt (+19.9%) and an optimistic forecast of 63.35 Mt (+15.6%). Translated into time, the finding is starker: the baseline curve only schedules the 73.23 Mt level for around 2038, meaning the complex arrived roughly 13 years early, and the pessimistic curve never reaches the 2025 observed level within its entire horizon to 2060 (its 2060 value is 68.46 Mt). As an external anchor, the Port Authority's record figure for 2024 (66.7 Mt, cited in Section 4) sits 1.2% above the ANTAQ reconstruction (65.88 Mt), a normal source-convention difference, reported and not forced.

The error is not uniform across cargo natures, and its distribution is the diagnostic that matters for planning. At 2025, against the baseline, mineral dry bulk (essentially fertilizers) ran +50.2% above forecast, liquid bulk fuels and chemicals +42.9%, containers +24.2% on the ANTAQ gross convention (roughly +12% under the plan's own convention, given the documented base gap), and vegetal dry bulk +11.3%; only the small general cargo (-4.5%) and vegetal liquid bulk (-14.5%) groups undershot. In other words, the underestimation concentrated precisely in the import families where competitive capture and hinterland dynamics were strongest, fertilizers above all, and in the container segment whose capacity decision Section 4 identifies as the most consequential in the portfolio. For a port whose master plan is the statutory reference for leasing and investment decisions, a first-decade ex-post error of this size and sign, demand systematically underestimated, is not a rounding issue: it is the difference between planning for congestion and planning for slack.

This finding extends a well-documented literature. Systematic ex-post studies of transport demand forecasts, built mostly on road and rail passenger projects, established decades ago that forecast error is the norm rather than the exception (Flyvbjerg et al., 2005). The Paranaguá case adds a port cargo observation to that record with one instructive inversion: where the passenger literature documents systematic overestimation driven by optimism bias, the port forecast here erred by systematic underestimation, and the competitive capture mechanism that Sections 4 and 5.2 describe is precisely what the extrapolation-based method could not see.

Figure 5.1.

Observed Throughput Versus the Three 2018 Master Plan Scenario Curves, Paranaguá and Antonina Complex, 2016 to 2025 (Mt).



Note. How to read this figure: the thick line is what actually happened; the three thin lines are what the 2018 plan expected under its pessimistic, baseline, and optimistic scenarios. The observed line sits above the baseline in every year and above the optimistic ceiling from 2020 onward; by 2025 it reaches a level the baseline only scheduled for around 2038.

5.2 The Official Revision: 2018 Versus 2025 Projections at 2050

The second comparison sets the two official products side by side at the common 2050 horizon: the 2018 Plano Mestre baseline scenario and the 5th cycle Master Plan reference scenario (Infra S.A., 2026, as consolidated in Section 4). Capture scenarios are excluded by design; this is baseline against baseline.

Table 5.2.

Demand at 2050, Plano Mestre 2018 Baseline Versus Infra S.A. 2026 Reference, Tonnes-Comparable Families (Mt)

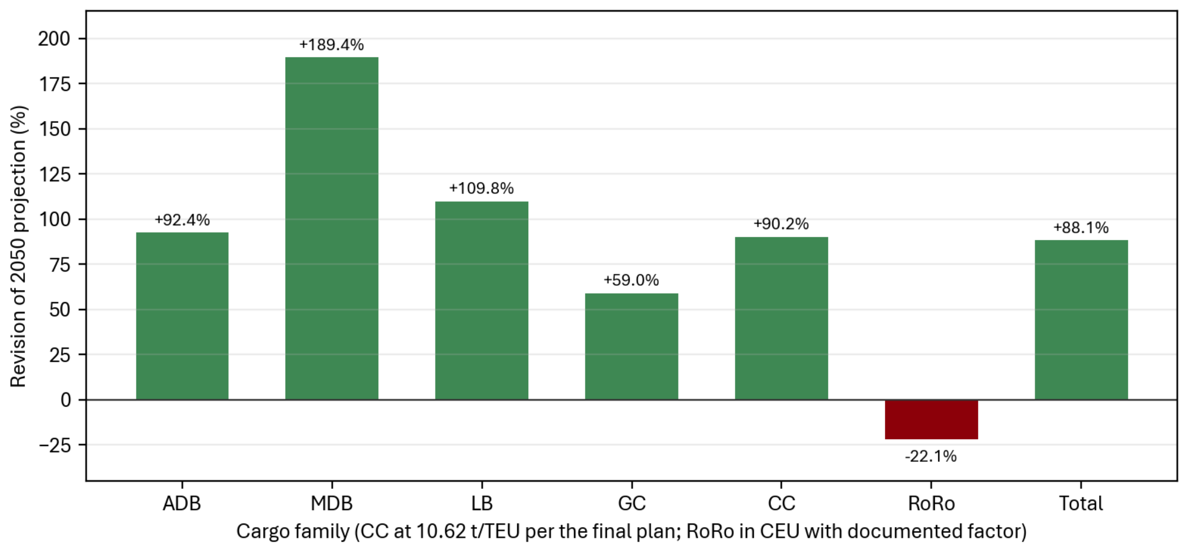
Family	PM 2018, 2050 (Mt)	INFRA 2025, 2050 (Mt)	Gap (Mt)	Gap (%)
Agri Dry Bulk ADB (export + import)	40.02	77.00	+36.98	+92.4
Miberal Dry Bulk MDB (import + export)	8.88	25.69	+16.81	+189.4
Liquid Bulk LB (fuels, chemicals, vegetal oils)	10.15	21.30	+11.15	+109.8
General Cargo GC (pulp, bagged sugar)	2.06	3.28	+1.22	+59.0
Total complex (all families)	80.00	150.50	+70.50	+88.1

All values in the Infra S.A. column are confirmed against the final published plan (Infra S.A., 2026, pp. 91-149). Two families require unit-specific treatment. For CC, the final plan settles the 2024 tonnage at 15.52 Mt for 1,461,000 TEU long-haul (16.3 Mt including cabotage), fixing the conversion factor at 10.62 t per TEU; applied symmetrically, both the tonnes route and the TEU route give a revision of +90.2% at 2050 (PM 2018 at 17.65 Mt, about 1.66 million TEU, against Infra S.A. 2026 at 3.16 million TEU, about 33.6 Mt). For RoRo, on the CEU route with the implied factor of 1.599 t per CEU formally adopted from the 2024 observation (185 kt over 115.7 thousand CEU), the 2018 plan projected 486.6 kt, about 304 thousand CEU, against 237 thousand CEU in 2025: a revision of -22.1%.

The reading, answer first: the new official projection (Infra S.A., 2026) nearly doubles the 2018 official projection at the same horizon (+88.1% on the total), and the revision is not a uniform inflation. It is largest exactly where competitive capture logic applies (MDB +189%, LB +110%, CC +90%, ADB +92%, GC +59%), and it is negative for RoRo (-22.1%). The RoRo counter-case matters for this paper’s credibility: a methodology change that only ever raised numbers would look like advocacy. SPC lowered the vehicle outlook because the competitive analysis, Santos dominance in the RoRo hub structure and the plant-anchored inelasticity documented in Section 4.3.6, justified lowering it. The method follows the competition, not the optimism.

Figure 5.2.

Official 2050 Demand Revision by Cargo Family, 2025 Master Plan Reference Versus 2018 Master Plan Baseline (%).



Note. How to read this figure: each bar is how much the new official 2050 projection differs from the 2018 one for that cargo family; bars above zero are upward revisions. The revision is largest where cargo is contestable (MDB, LB, CC, ADB) and negative for RoRo, the family anchored by automaker plants, where the competitive analysis justified projecting less.

5.3 Decomposing the Revision: Base-Year Effect Versus Methodology Effect

Honesty requires separating two drivers inside the +70.5 Mt total revision. The first is the base-year effect: by 2024, reality (66.7 Mt) had already crossed the 2018 baseline curve's 2030 value and the optimistic 2025 value, so any projection issued in 2025 starts from a much higher floor regardless of method. The second is the methodology effect: competition-aware capture logic versus econometric flow extrapolation, visible in the slope. The decomposition re-bases the 2018 method on 2024 reality: growing the observed 2024 floor by the 2018 baseline curve's own growth over 2024 to 2050 yields the counterfactual "old method, new floor", and the revision splits around it. Two defensible conventions bound the answer. Using the 2018 curve's segment slope for exactly the projected window (1.12% per year, from its interpolated 59.86 Mt in 2024 to 80.0 Mt in 2050), the counterfactual is 89.1 Mt: floor effect +9.1 Mt, methodology effect +61.4 Mt, or 87% of the revision. Using the whole-curve slope 2016 to 2050 (1.78% per year), the counterfactual is 105.4 Mt: floor +25.4 Mt, methodology +45.1 Mt, or 64%. Substituting the ANTAQ 2024 base (65.88 Mt) for the Port Authority figure moves these numbers immaterially. Under either convention the conclusion is verified rather than preliminary: **the methodology effect dominates, accounting for 64% to 87% of the revision**. One caveat belongs in print: this "methodology effect" bundles the method change with any macro-assumption differences between the 2017 and 2025 vintages; what assigns the dominant role to the competitive mechanism rather than macro drift is the ex-post evidence of Section 5.1, where the forecast errors are asymmetric and capture-shaped, largest exactly in the contestable families.

Section 6. Emerging Competition and Strategic Response

6.1 Why a Forecast Needs Game Theory

Every number in Section 4 embeds an assumption about what competitors will do. A capture scenario that adds capturable tonnage to Paranaguá's outlook implicitly assumes that the ports currently serving that demand either cannot or will not respond. That assumption deserves to be examined rather than buried, and game theory supplies the vocabulary: players, moves, commitments, and payoffs. The point is not formal modeling for its own sake. It is the discipline of asking, for each capture initiative in the Stage 10 plan, one question the traditional master plan never asks: what does the rival do next? Demand forecasting under competition is not meteorology, where the weather ignores the forecaster; it is chess, where the projection itself describes a position that both sides can act upon.

6.2 The Board and the Players

The Zone of Competition mapped in Section 4 defines the board. Its core is an asymmetric contest between Santos and Paranaguá: Santos serves 47% of the demand arising inside Paranaguá's own Natural

ZIP, while Paranaguá serves only 9.4% of demand arising inside Santos's, and São Francisco do Sul takes about a further 1% of Paranaguá's natural market. In the container arena the same asymmetry recurs: Santos absorbed about 29% of the cargo originating in Paranaguá's Natural ZIP (approximately 2.96 Mt), against 2.7% in the reverse direction. Santos is therefore not merely the largest neighbor; it is a player holding territory deep inside Paranaguá's natural hinterland, which means most of what SPC classifies as Paranaguá's capturable demand is, from the rival's perspective, incumbent volume worth defending.

The flanks matter for specific families. Itajaí-Navegantes leads containerized wood products, where Paranaguá is second with 32.6%, and competes for reefer cargo; São Francisco do Sul, Imbituba, and Rio Grande absorb southern-origin bulk at the margin. The specialization pattern is itself informative: Paranaguá leads containerized meat (38.5% of the zone against Santos's 24.3%), Santos is hegemonic in containerized coffee (73.2%) and cotton (approximately 97.5%). Where each player already dominates a commodity niche anchored by its own hinterland industry, the contest resembles differentiated competition, stable and low-intensity; the true battleground is the demand in between, geographically the overlap belt where isocost differentials are small, and commercially the families where neither side holds a structural anchor.

6.3 Commitments: How This Game Is Actually Played

Port competition is rarely played in prices alone; it is played in irreversible infrastructure, and irreversibility is precisely what makes a move credible (Schelling, 1960; Dixit, 1980). Three classes of commitment moves are visible on the board.

The first is verticalization, the private sector's commitment device. COAMO's fully integrated cooperative model ties its agricultural export flows to Paranaguá with 100% verticalization; PASA holds approximately 75%. Each verticalized node is demand contractually or physically removed from the game, and Section 4 showed this cuts both ways: rail-anchored flows into Santos over the Malha Paulista corridor are equally fixed. In game terms, verticalization converts contestable payoff cells into locked ones; the SPC verticalization screen (Stages 5 and 6) is, in effect, the procedure that deletes already-committed cells from the board before the game over the remainder is analyzed.

The second is public rail infrastructure, the state's commitment move. Nova Ferroeste, the planned rail link between Maracaju (Mato Grosso do Sul) and Paranaguá, is a direct attempt to contest Center-West flows currently locked to Santos by the Malha Paulista corridor. Its strategic value is not only the freight it would carry but the option it destroys for the rival: once an alternative corridor exists, the incumbent's locked volume becomes contestable again, and contestability alone disciplines the incumbent's pricing and service behavior even before a single tonne shifts.

The third is port capacity, the classic entry-deterrence instrument (Dixit, 1980). The Moegão project raises rail-receiving retention capacity at Paranaguá, simultaneously a defensive move (retaining rail-borne cargo that congestion might otherwise push away) and an offensive one (creating headroom to absorb captured volume). Symmetrically, the container capacity decision that Section 4.3.2 identifies as the most consequential in the portfolio is a commitment problem: the difference between the 3.16 million TEU reference and the 5.5 million TEU competitive scenario in 2050 is only realizable if capacity exists before the demand materializes, yet building it signals intent and invites a response in kind at Santos. Capacity races between neighboring gateways are the port industry's version of the prisoner's dilemma: individually rational expansions can produce collective overcapacity, which is why Stage 9 (capacity constraint) and Stage 10 (capture plan) must be read together rather than as independent steps.

6.4 Where the Game Is Live, and Where It Is Already Decided

The family-level analysis of Section 4 sorts the board into live contests and decided ones, and the distinction drives investment discipline.

The game is live in ADB at the Center-West margin (the Nova Ferroeste contest), in MDB fertilizer imports (where the ex-post analysis of Section 5.1 showed demand running 50.2% above the old forecast, evidence of a hinterland in motion), and in containers, where the meat-anchored strength of Paranaguá and the coffee-and-cotton anchoring of Santos leave a large unanchored middle. These are the families where capture scenarios describe plausible strategic outcomes and where commitment moves change payoffs.

The game is effectively decided in RoRo and in the plant-anchored portions of GC. Vehicle flows are bounded by automaker plant locations: Renault, Volvo, DAF, and CNH anchor Paranaguá's share, the São Paulo industrial belt anchors Santos's 56.7% of the zone, retention exceeds 90% on both sides, and the capture curve adds only about 20 kt at maximum efficiency. No infrastructure move on the port side alters plant geography. The strategic implication is negative but valuable: do not spend capital to contest a decided game. The 2025 projection's downward RoRo revision (-22.1%, Section 5.2) is exactly this discipline expressed in numbers, and it is the single best answer to the suspicion that competition-aware forecasting is systematically inflationary.

6.5 Implications for the Capture Plan

Three strategic principles follow for Stage 10. First, commit where the rival's counter-move is expensive: rail capillarity and specialized intermodal reception (the Moegão class of investment) are hard to neutralize quickly, whereas tariff concessions can be matched overnight. Second, respect decided games: inelastic, plant-anchored, or fully verticalized families receive monitoring, not capture capital. Third, plan for the response, not just the move: each capture initiative should carry an explicit assumption about Santos's likely reaction (accommodate, match, or escalate) and a trigger indicator, which converts the master plan's continuous monitoring requirement from a reporting routine into a repeated game played with open eyes. Scenario planning, in this reading, is not a hedge against macroeconomic uncertainty only; it is the payoff table of a game the port has chosen to play.

Section 7. Stakeholder Validation Through Institutional Adoption

7.1 Validation by Adoption

The original project design contemplated semi-structured interviews with 6 to 8 sector professionals to validate the SPC methodology's criteria and findings. In the course of the work, a stronger form of validation superseded that plan: the methodology was submitted to, scrutinized in, and ultimately adopted by the official planning process of the Paranaguá and Antonina complex, through successive technical validation meetings with the very stakeholders an interview protocol would have sampled. Adoption in a statutory planning instrument subjects a methodology to a higher bar than an interview: the port authority, the national planning company, and the terminal operators who contest its numbers had both the mandate and the incentive to challenge every assumption, because leasing and investment decisions ride on the result. The validation record has three layers of increasing exposure. First, successive technical validation meetings inside the planning process, where the methodology's criteria were challenged and refined by the port authority, the national planning company, and sector participants. Second, institutional adoption: the methodology's projections were incorporated into the 5th cycle Master Plan itself. Third, public scrutiny: the Ministry of Ports and Airports opened the plan to public consultation on February 6, 2026, on the Brasil Participativo platform, with the preliminary plan document publicly available and the deadline extended to March 23, 2026, precisely to accommodate market participation (MPor, 2026); terminal operators, shippers, and sector associations had the formal opportunity to contest the demand projections, and the author's documented responses to the demand-chapter contributions form part of the record. A methodology that progresses from public consultation to publication has passed a consequential form of market scrutiny. This paper therefore reports validation by institutional adoption and public scrutiny, documented in the meeting and consultation record, rather than validation by elicitation.

7.2 The Validation Meeting Record

The validation claim rests on four publicly verifiable documents, reproduced or referenced in Annex E. First, the published plan itself: the demand projection chapter of the final Master Plan (Infra S.A., 2026, chapter 2, pp. 90-210) applies the SPC methodology described in Section 3 of this paper, including the PPML gravity specification, the Natural ZIP delimitation, the verticalization screen, and the reference-versus-capture scenario architecture. Second, the named credit: the author is credited in the plan's technical staff as Senior Engineering Specialist (UNDP Project BRA 13/013), establishing the authorship link between the methodology presented here and the official document that adopted it. Third, the minuted scrutiny of the Port Authority Council, documented in two sessions sixteen months apart. On June 14, 2024, at the council's 87th ordinary session, the framework of the new master plan methodology and the preliminary demand projection were presented to the CAP (Conselho de Autoridade Portuária) of Paranaguá at the pilot stage: the minutes record the full analytical pipeline (origin-destination matrix, competition zone definition and characterization, identification and fixing of verticalized and rail-bound chains, disputable region, isocost lines, municipality acquisition by R$/t efficiency, natural and capturable demand baseline), the explicit justification of Paranaguá and Antonina as the national pilot (a complex handling every cargo type in a competitive environment), and the council's reception, including the port authority president's endorsement of presenting the methodology to the council and the exporters' association's offer of collaboration (CAP Paranaguá, 2024). On October 3, 2025, at an extraordinary session convened for the Master Plan, the author presented the completed methodology and the per-family projections to the same statutory tripartite council, chaired by the Ministry of Ports and Airports and seating government (Federal Revenue, ANVISA), business (ABTRA, AEB, ACIAP), and labor (FNP, FENCCOVIB) representatives, with terminal operators, industry and agriculture federations (FIEP, FAEP, OCEPAR), ANTAQ, and the port authority attending (CAP Paranaguá, 2025). The minutes record named methodological challenges and the author's answers: the industry federation questioned the container utilization assumptions and the pace of the reference projection against animal-protein export growth, answered with the berth occupancy parameters (72% recommended with three berths, 80% attainable) and the distinction between organic demand growth and supply-jump growth; the council also debated terminal ownership neutrality, hinterland service requirements, and landside bottlenecks, and stressed CAP review as a stage prior to the public consultation. The record is therefore one of scrutiny rather than acclamation: the projections were challenged by name, on the assumptions that mattered most to the industries paying for the capacity, and the answers were minuted before the plan advanced. Fourth, the public consultation record: the Ministry of Ports and Airports submitted the plan to public consultation from February 6 to March 23, 2026, on the Brasil Participativo platform (MPor, 2026), during which terminal operators, shippers, and sector associations had formal standing to contest the demand projections before publication. The plan proceeded to publication with the methodology intact.

7.3 What the Record Shows

Four readings follow from that record. First, the bar cleared is the highest available to a planning methodology in Brazil: a statutory instrument, scrutinized in session by the tripartite Port Authority Council, publicly consulted, and published with the methodology and its author identified. An interview protocol samples opinions; a public consultation confers standing on every stakeholder whose money is at stake, and none of the demand projections was overturned. Second, the scrutiny was longitudinal, not ceremonial: the council examined the methodology at the pilot stage (June 2024) and again on the completed projections (October 2025), spanning the framework’s application life cycle. Third, the validation is reproducible by any reader: every document cited in 7.2 is public, which is consistent with the paper’s broader commitment to auditable evidence. Fourth, the limitation should be stated as plainly as the strength: consultation is a no-objection test, not an endorsement survey; it demonstrates that the methodology withstood scrutiny, not that every stakeholder prefers it. That honest boundary is where the continuous monitoring discipline of Stage 10 takes over, because the market votes again, every year, with cargo.

Section 8. Implications for Practice and Replicability

The SPC methodology addresses critical limitations of current Brazilian port planning practice, and it does so as a decision framework rather than a crystal ball: its outputs are plausible, priced, and auditable market opportunities, not point predictions, and the judgment of the people who run ports remains the final step. Traditional master plans rely on historical data and static forecasting models that fail to capture the dynamic, competitive nature of the logistics environment, leading to suboptimal resource allocation and missed opportunities. By defining origin-destination matrices, identifying competition zones by cargo type, and explicitly treating vertically integrated and rail-bound flows, SPC projects the demand ports can realistically contest, and the Paranaguá and Antonina application demonstrates the difference this makes at full scale: capture scenarios worth 45.1 Mt at 2050 in a portfolio whose previous official forecast had underestimated the first decade by double digits (Sections 4 and 5). The same analysis that finds new demand also finds new threats: the methodology highlights competitors that could contest cargo currently moving through the port under study, providing the game-theoretic perspective that Section 6 develops.

The implications differentiate by audience. For **policymakers**, the case for embedding competition analysis in the statutory planning cycle is now empirical, not conceptual: Section 5 shows that the incumbent extrapolation method underestimated a major complex's demand in every year of its first decade, with the error concentrated in the segments where capacity decisions bind. A planning system whose master plans anchor leasing and investment decisions cannot afford forecasts that are systematically early by 13 years. The adoption of the competition-aware approach in the 5th planning cycle is the beginning of that correction, and the monitoring discipline it enables, annual confrontation of observed against projected flows, should become a standing feature of the cycle. For **port authorities**, SPC converts the master plan from a compliance document into a strategy instrument: the Natural ZIP delimitation tells the authority what its market should be, the retention and penetration rates tell it how much it is losing and to whom, and the capture curve prices the service-level improvements (not tariff discounts) required to win specific municipalities. For **terminal operators**, the same outputs read as a commercial plan: Stage 10 ranks target municipalities by required efficiency gain, identifies the step jumps where small improvements unlock large volumes, and grounds pricing decisions in the road-freight differentials competitors would have to overcome. For **consultants and practitioners**, the ten-stage procedure is a replicable protocol with public inputs; and for **academics**, the framework opens a research agenda in forensic market analytics, ex-post forecast evaluation, and the measurement of hinterland contestability.

Replicability deserves its own argument, because it was strengthened by the evolution told in Section 3.6. The methodology's inputs are public and standardized: customs statistics classified on the Harmonized System, which more than 200 countries share; waterway and rail regulatory data; and road cost layers that any routing engine can reproduce. Nothing in the logic is Brazil-specific: any coastline where multiple gateways share a hinterland, and where some flows are fixed by integration while others are contestable, satisfies the framework's assumptions. What industrialization added is the economics of adoption: versioned pipelines, mass-conservation gates (reallocated totals reconciling with official totals at error below 10^-6), bias-correction algorithms for the fiscal-seat distortion that afflicts every customs dataset attributing flows to corporate domiciles, and standardized dashboards reduce the marginal cost of each new application, which is how a methodology moves from one author's practice to a community's practice. The 15+ applications accumulated to date, including greenfield ports with no operating history, are the strongest evidence that the procedure travels.

For an organization considering adoption, the practical path has three steps. The data step is the lowest hurdle: the required inputs (customs statistics by product and locality, waterway operations data, rail statistics, and a road cost layer) exist in some form in most trading economies, and the HS classification travels across borders by construction. The capability step is analytical rather than computational: the demanding skills are the ones Stages 5 and 6 exercise, knowing the local market well enough to identify which flows are fixed by integration, because a wrong verticalization screen corrupts everything downstream. The governance step is the one most often skipped: someone must own the annual confrontation of observed against projected flows and be empowered to trigger revision when the deviation warrants it, otherwise the adaptive promise of the framework reverts to the static practice it was built to replace.

Two cautions bound the claims. First, SPC complements rather than replaces econometric projection: Stage 8 runs a PPML gravity model with bilateral fixed effects (Santos Silva & Tenreyro, 2006), and the innovation lies in what is projected (contestable baselines) rather than in the projection technique itself. Second, the capture scenarios are conditional on management action: the 45.1 Mt at Paranaguá is not a forecast of what will happen, it is a priced statement of what could happen if the identified efficiency gains are delivered. Continuous monitoring and adjustment, the adaptive discipline the literature demands, remains essential, and the industrialized framework exists precisely to make it routine.

Section 9. Conclusion

This paper set out to show that port demand forecasting can be made competition-aware without losing the auditability that statutory planning requires, and to document what happens when it is. The evidence supports four findings. First, the incumbent method fails in a specific and diagnosable way: at Paranaguá and Antonina, the 2018 official forecast was surpassed by observed throughput in every year from 2017 to 2025; the 2016 base-year difference arose from a documented container convention. The volume scheduled for 2038 was reached in 2025, and the 2025 deviation was largest exactly in the families where cargo is contestable (mineral bulk +50.2%, liquid bulk +42.9%, containers +24.2%) and negative where it is anchored (general cargo -4.5%, vegetable liquid bulk -14.5%). Second, sorting cargo before projecting changes the answer materially and in both directions: the competition-aware plan revises the 2050 outlook by +88.1% relative to the 2018 baseline, with 64% to 87% of the revision attributable to the method rather than to the higher starting point, and it lowers the projection for vehicles by 22.1% because the analysis finds that family anchored by plant location. Third, the competitive field is measurable at the granularity at which port choice is made: inside Paranaguá's own natural agribulk hinterland, Santos handles 38.2% of the cargo and Paranaguá 32.5%, a figure that uncorrected customs data would have overstated by about 40 percentage points. Fourth, the method withstood institutional scrutiny: it was examined by the Port Authority Council at pilot stage and on completed projections, challenged by name, answered on the record, submitted to public consultation, and published in the official master plan with the author credited.

Taken together, these findings support the paper's central claim in a bounded form. SPC does not forecast better in the sense of smaller point errors, a claim no ten-year record could yet establish; it forecasts differently, from a base that has already asked which cargo is captive, which is contestable, and at what cost, and it therefore produces numbers that carry their own strategy sensitivity. For a port authority that is the difference between a compliance document and a planning instrument; for a terminal operator it is a target list; for a regulator it is a forecast whose assumptions are exposed and whose totals reconcile with official statistics.

The limitations are the ones a reader should carry into any application. Cost is the layer the method can map, but not the only factor shippers weigh; reliability, frequency, capacity, and relationships enter through the capture-curve steps and through validation rather than through the model. Competition between ports coexists with competition among global operators present in several ports, and a map of gateways does not by itself capture the second. The methodology effect isolated in Section 5.3 bundles the change of method with differences in macro assumptions. The ex-post record covers one complex and one decade, and the 2025 projections will face their own ex-post table. And public consultation is a no-objection test rather than an endorsement survey. None of these limitations undermines the findings; each defines the conditions under which they should be read.

The practical conclusion is the one the Paranaguá case makes concrete: plan for the port you can win, not for the past you had. The inputs that make this possible are public and standardized in most trading economies, the procedure is replicable, and the discipline it imposes, sorting before projecting and confronting projection with observation every year, is available to any port that chooses to adopt it.

Section 10. Reflections on Learning

The most important thing this capstone taught me is that a methodology is not what its author writes; it is what practice leaves of it after repeated contact with reality. SPC began, around 2022, as a diagnosis I could not let go of: I kept seeing master plans that projected the past with great econometric care while the actual contest for cargo, which I watched daily as a practitioner, appeared nowhere in the numbers. Turning that irritation into the ten-stage procedure of Section 3 was the first learning cycle: writing a method down forces choices that opinions never face, about databases, about units, about what counts as captive and what counts as contestable.

The second cycle came from application, more than 15 cases including greenfields, and it was humbling in the specific way only data can be. Every convenient assumption failed in some engagement. Distance was not cost, so the isocost layer had to be monetized end to end, in R$/t, with real tolls and real tariff tables. Customs records lied about geography, attributing cargo to traders' fiscal seats, so the framework had to learn to detect and correct the bias with production and employment evidence, and to prove, at each run, that the correction conserved mass to within 10^-6. Each defect I found in my own method became a milestone in what Section 3.6 calls the industrialization, and I now believe that sequence, weakness found, weakness closed, audit added, is the actual content of professional maturity in analytical work: not being right, but becoming checkable.

The third cycle is the one this paper forced. The ex-post test in Section 5 examines a forecast produced by the planning school I was trained in, and finds it surpassed in every year of its first decade. It would be comfortable to read that as vindication. The honest reading is more useful: it is a warning addressed to me. The 2025 projections I helped shape will face their own ex-post table one day, and the RoRo counter-case, where the competitive analysis led me to project less, not more, is the discipline I most want to carry forward. A method that can only inflate is advertising; a method that can say “this family is inelastic, do not build for it” is planning.

The PPM program’s frame, and the obligation to present this work to a jury of peers, added the final lesson: none of this matters if it cannot be communicated to the people who decide. Writing for policymakers, port authorities, and operators at once taught me to separate the concept (which must be simple: ports compete for municipalities, and money decides) from the machinery (which may be complex, but must be auditable). That separation, I now think, is what makes a methodology adoptable, and it is the standard I will hold my future work to.

What remains open is, appropriately, the future: the projections this method produced will face their own ex-post table one day, exactly as Section 5 did to their predecessor, and the strategic responses that Section 6 anticipates will play out on a board where the competitor also reads the map. I expect both to return defects, and after four years of this method, I have learned to treat that expectation not as a risk to the paper but as its point.

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Annexes

Annex A. Data sources and database dictionary. The Harmonized System backbone and cargo families; the six core databases (DB1 to DB6) of Section 3.3 in detail; the industrialization sources (PAM, RAIS, routing and toll layers, ANP, CONAB, municipal dimension); cross-source keys and reconciliation rules; data quality and provenance notes; and the forecasting model specification of Stage 8 (Equation A.1).

Annex B. Full case analysis, Paranaguá and Antonina Port Complex. The complete case analysis behind Section 4: movement profile, competition profile with the full Zone of Competition composition, the analysis by cargo group (competitive analysis, verticalization, and projections for each family and direction), and the consolidated projections to 2050, with all tables and figures.

Annex C. Forecast benchmark and ex-post accuracy detail. Data lineage and full tables behind Section 5: sources and vintages, the 2018 official projections, the benchmark at 2050 with its comparison conventions and gap tables, the ex-post test against observed operation 2016 to 2025 with verification blocks, the floor versus methodology decomposition, and the Pairwise Capture Share computation (definition, data basis, index tables, validation anchors, and limitations).

Annex D. Evolution timeline, full table. The complete nine-milestone timeline of the methodology, of which Table 3.2 condenses five.

Annex E. Public validation record. The documentary evidence base of Section 7: the published plan and its authorship credit, the two minuted sessions of the Port Authority Council (June 14, 2024, and October 3, 2025) with the named challenge-and-response record, and the public consultation record. Every item is publicly verifiable.

Annex F. Terminology bridge. Paper nomenclature (ADB, MDB, LB, CC, GC, RoRo) against the Brazilian source labels, canonical HS chapters, the authorial concept set in both languages, scenario terms, and an institutional glossary.