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Defining and Managing KPIs for Logistics Optimization: A Critical Analysis of Container Utilization Rate, Cost per Unit Transported, and GHG Emissions

Defining and Managing KPIs for Logistics Optimization: A Critical Analysis of Container Utilization Rate, Cost per Transported Unit, and GHG Emissions

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Summary

This article discusses the design and governance of **key performance indicators (KPIs)** in intermodal logistics operations, focusing on three key metrics: **container utilization rate, cost per unit transported,** and **greenhouse gas (GHG) emissions.** We propose a framework that integrates **rigorous operational definition, data standardization, collection methods ,** and **managerial use** anchored in **trade-offs** between efficiency, resilience, and sustainability. We articulate literature from **operations management, transportation economics,** and **carbon accounting** to show how seemingly technical choices—such as **denominators, measurement windows, cargo mix ,** and **emissions scopes** —alter the **performance narrative** and capital **allocation** (CHRISTOPHER, 2016; CHOPRA; MEINDL, 2016; UNCTAD, 2020; WORLD BANK, 2020; GHG PROTOCOL, 2011; SMART FREIGHT CENTRE, 2019).

Keywords: logistics; KPIs; container; logistics costs; emissions; GHG.

Abstract

This paper examines the design and governance of **key performance indicators (KPIs)** in intermodal logistics, focusing on three backbone metrics: **container utilization rate, cost per transported unit,** and **greenhouse gas (GHG) emissions.** We propose a framework that integrates **rigorous operational definitions, data standardization, measurement methods,** and **managerial use** anchored in the **trade-offs** among efficiency, resilience, and sustainability. Drawing on **operations management, transport economics,** and **carbon accounting,** we show how seemingly technical **choices—denominators, measurement windows, job mix,** and **emissions** scopes—reshape the **performance narrative** and **capital allocation** (CHRISTOPHER, 2016; CHOPRA; MEINDL, 2016; UNCTAD, 2020; WORLD BANK, 2020; GHG PROTOCOL, 2011; SMART FREIGHT CENTRE, 2019).

Keywords: logistics; KPIs; container; logistics costs; emissions; GHG.

1. Fundamentals and scope of logistics KPIs: design principles, standardization and decision-making use

The discussion on logistics KPIs needs to begin with a **principle of utility:** an indicator is only good if **it guides decisions** —capacity allocation, investment prioritization, contract design— and **reduces ambiguity** in coordination between links.
This requires three layers: **a clear operational definition** (what is measured, where, and when), **a measurement method** (sources, formulas, windows, missing data handling), and **usage governance** (thresholds, responsible parties, rights of action). Without this three-pronged approach, metrics become "decorative panels" that multiply noise rather than generate action (CHRISTOPHER, 2016; ISO 22301, 2019). In intermodal chains, the risk of **semantic confusion** is high: "utilization," "unit cost," and "emissions" can mean different things at ports, railways, highways, and operators, leading to **spurious comparisons** without a common dictionary (WORLD E

The second principle is **measurement properties.** Indicators must be **reliable** (same method ÿ same results), **valid** (they measure what they intend to measure), **sensitive** to relevant operational changes, and **robust** to short-term noise. In logistics, **temporal granularity** and **segmentation by service** (route, cargo type, equipment, customer) are crucial to avoid **the law of averages:** an improvement in one service can be masked by a degradation in another, generating erroneous conclusions overall (CHOPRA; MEINDL, 2016). Therefore, it is recommended to publish KPIs by **window/service** and only then compose volume-weighted **indices .**

The third premise relates KPIs to **trade-offs. Container utilization rates** tend to improve with **consolidation** and **the addition of stops,** but this can **worsen lead times** and **variance,** increasing **inventories** and **capital costs; cost per unit transported** decreases with **economies of scale,** but can **weaken resilience** by concentrating gateways and lengthening routes; **GHG emissions** decrease due to **modal shift** and **increased load factor,** but may **conflict** with service windows or **limit optionality** (SMART FREIGHT CENTRE, 2019; UNCTAD, 2020). The dashboard design should make these conflicts **explicit,** with **hierarchical goals** (minimum service, resilience, efficiency, sustainability), avoiding **local optimizations** that destroy global value.

The fourth point is **standardization.** GHG emissions, for example, must follow standards such as **the GHG Protocol – Scope 3 (Category 4/9)** and **EN 16258** for transportation, with consistent **emission factors** by fuel and mode; **the use of containers** requires conventions on **payload** (weight vs. cubic capacity), **exclusions** (empty reefer *pre-trip),* and **backhaul treatment; the cost per unit** must specify whether it is **pure freight** or **cost-to-serve** (including handling, demurrage/detention, storage, and working capital) (GHG PROTOCOL, 2011; EN 16258, 2012; CHOPRA; MEINDL, 2016). Without this basis, **internal and external** comparisons lose their meaning.

The fifth element is **data quality and lineage.** Logistics KPIs arise from **TOS/PCS.** (ports), WMS/TMS(storage/transportation), **telemetry** (AIS, ELDs), **billing** and

energy/fuel systems. To be auditable, there must be **a reconciliation trail** and **versioning:** how were **TEUs, tons, kilometers, fuel ,** and **costs** obtained, aggregated, and cleaned? This due diligence reduces **contractual disputes** (indexing to reliability, *gain-sharing)* and prevents **greenwashing** in emissions (IAPH, 2020; WORLD BANK, 2020). Whenever possible, **APIs** and **data dictionaries** should be part of the contract.

The sixth aspect is **scope of control.** A useful KPI distinguishes **what to control** from what to simply **monitor. Container utilization** can be partially controlled by consolidation, ***match-back* , and triangulation policies ; cost per unit** by **modal mix, contracts, and route redesign; emissions** by **fuel, load factor, speed, and modal shift.** KPIs outside the manager's scope become **sources of frustration;** therefore, the dashboard must display **associated levers** and **thresholds** that trigger **action rights** (CHRISTOPHER, 2016; SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008).

The seventh principle deals with **decision-making rhythm.** KPIs with **high volatility** require **moving windows.** and **smoothed signals** (e.g., weighted averages), while capital decisions require **stable series; issuances** can be closed **monthly** and audited **annually; utilization** and **unit cost** require **weekly/daily cadence** to allow for quick course corrections (SMART FREIGHT CENTRE, 2019; ISO 22301, 2019). The **lag time** between measurement and action is itself a maturity KPI.

Finally, the eighth foundation is **organizational alignment.** KPIs should be incorporated into **S&OP/S&OE** and the **budget cycle,** with **targets and bonuses** linked to **OTIF, cost-to-serve, load factor ,** and **carbon intensity. Training, tabletop exercises ,** and **After Action Reviews** transform indicators into **learning** and **continuous improvement,** consolidating a **resilient operational framework** in which **data** drives **decisions** and **decisions** produce **auditable results** (SHEFFI, 2015; ISO 22301, 2019).

2. Container Utilization Rate: Definition, Measurement, Biases, and Decisions

Container utilization rates measure how much of a container's **useful capacity** (weight or volume) is actually occupied by paying cargo. In simple terms, **utilization (weight)** can be defined as *cargo weight/ (maximum container payload)* and **utilization (volume)** as *cargo volume/ (cubic capacity);* on mixed routes, **conversion factors (stowage factors)** are used to reconcile **weight vs. cubic capacity** (NOTTEBOOM; RODRIGUE, 2021). At the fleet level, weighted average utilization can be reported **by TEU-km** or **by trip,** distinguishing between **headhaul** and **backhaul** to avoid **an averaging effect** that masks structural imbalances (UNCTAD, 2020). When publishing the metric, it is critical to clarify **the basis.**

(weight/volume) and **what exclusions** were applied.

The first challenge is **data quality.** In many environments, **net weight** and **cubic capacity** are not standardized across systems; **EDI** and **shipping documents** arrive with **gaps; mixed loads** require **estimates.** It is recommended to create **layers of data collection:** *level 1* per **manifest/data lake** (estimation), *level 2* per **WMS/TMS** (operational capture), and *level 3* per

Physical audit/sampling on critical routes. **Imputation and outlier rules** should be published to ensure **consistency** and **comparability** (WORLD BANK, 2020; IAPH, 2020). Without this, the use becomes **an opinionated number.**

The second point is the **appropriate denominator.** For **dry 40', payload** is a typical limiting factor; for **bulky products** (tissue, light e-commerce), **cubic capacity** dominates; in **reefer,** part of the capacity is "lost" to equipment and **segregation;** for **dangerous goods, compatibility** reduces occupancy. Therefore, comparing **utilization** across **product classes** without **standardization** creates **unfairness** and **perverse incentives** (CHOPRA; MEINDL, 2016). A best practice is to measure **utilization adjusted** for the SKU's **physical limit** (weight or volume) and publish **benchmarks by family.**

The third aspect is **operational biases.** The pursuit of **maximum utilization** encourages **waiting to consolidate,** increasing **lead time** and **variance;** during peak periods, late consolidation **worsens OTIF** and **triggers demurrage/detention.** On the other hand, **denser** containers can increase **damage** and **safety risks,** with **hidden costs.** The optimal decision balances **marginal utilization** with **time and risk costs,** often via **response curves** estimated in **digital twins** of the corridor (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; CHRISTOPHER, 2016). Therefore, the KPI must be accompanied by **service limits** and **exception rules.**

The fourth theme is **structural underutilization** due to **geographic imbalance.** In flows with **strong headhaul and weak backhaul, average utilization** falls even with **operational excellence;** part of the solution lies in **triangulation,** ***match-back ,*** and **interorganizational container pools** to reduce **empty repositioning** and increase **effective utilization** (UNCTAD, 2020; DREWRY, 2021). Here, the KPI should be read alongside **equipment availability indices** and **repositioning rates,** otherwise **the operator may be blamed** for **market structure.**

The fifth point is **integration with sustainability. Greater utilization** reduces **emissions per ton-km** by **diluting** fuel consumption per unit, but it can **increase absolute emissions** if **consolidation** requires **longer routes** or **waiting times;** in addition, **modal shift**
To reduce carbon, it can temporarily **reduce utilization .** Therefore, it is recommended to publish **carbon intensity (gCOÿe/t-km)** in parallel with utilization and **to explicitly state route/modal offsets** (SMART FREIGHT CENTRE, 2019; IMO, 2020). The correct narrative avoids **efficiency greenwashing.**

The sixth element is **contracts and incentives. SLAs** that **reward** only **utilization** can **penalize service** and **resilience; gain-sharing** mechanisms aligned with **cost-to-serve** and **emissions** balance objectives. In **port congestion, conditional demurrage/detention** policies can **unlock boxes** and allow for **higher utilization.**
without punishing the customer for **systemic causes** (WORLD BANK, 2020; IAPH, 2020). The KPI should inform **contractual reviews** and **exception policies.**

The seventh theme is **cadence and visualization. Usage by window** (hour/day) in **heatmaps** by **service and gateway** helps **identify patterns** and match-back **opportunities ; dashboards** with **dispersion** (not just average) reveal **volatility** and **special causes.** On critical routes, **thresholds** activate **playbooks:** below X% for Y days, **trigger alternative consolidation;** above Z%, **review damage risks** and **stowage policy** (CHRISTOPHER, 2016; WORLD BANK, 2020).

Finally, the eighth aspect is **learning. After-Action Reviews** during **seasonal peaks** and **disruption events** should update **consolidation rules, exception policies ,** and **contracts.** External (sectoral reports) and **internal** (between corridors) **benchmarking** avoids **local myopia.** When well governed, the **utilization rate** ceases to be vanity and becomes **an integrated lever** of **cost-to-serve, OTIF** and **carbon intensity,** with defined **responsibilities and rights of action** (UNCTAD, 2020; NOTTEBOOM; RODRIGUE, 2021; SMART FREIGHT CENTRE, 2019).

3. Cost per unit transported: operational definition, *cost-to-serve* and management decisions

The **cost per unit transported** metric seems trivial at first glance—dividing logistics expenses by a volume denominator—but its **decisive power** depends on the **operational definition** and **scope of** costs adopted. In intermodal chains, there are four dominant denominators: **(i)** cost per **TEU-km** or **ton-km,** suitable for modal benchmarking; **(ii)** cost per **order ,** useful for fragmented B2B portfolios; **(iii)** cost per **SKU or product family,** which internalizes differences in density and *time value;* **(iv)** cost per service **window** (route/service/gateway), which explains trade-offs between reliability and expense (CHOPRA; MEINDL, 2016; WORLD BANK, 2020). In any case, it is essential to state whether the indicator covers **pure freight** or **cost-to-serve (including terminal handling, drayage/chassis, warehousing, demurrage/detention, insurance, working capital ,** and **contingency shipments),** since strategic decisions—such as **multi-gateway, off-dock ,** or **capacity options—** move items outside of freight but within the cost- **to-serve** (UNCTAD, 2020; SHEFFI, 2015).

Calculating **the numerator** requires reconciling **fixed and variable costs** and, ideally, employing an **activity-based costing system.** In networks with a high service *mix ,* **ABC/TDABC** distributes *overheads* (planning, scheduling, customs control, control towers, PCS) by **cost drivers** linked to actual resource use (trips, *stops, touches,* crane time, *truck turntime),* mitigating average distortions (CHOPRA; MEINDL, 2016; KAPLAN; ANDERSON, 2007). The quality of the apportionment determines the usefulness of the KPI: if *overheads* peak and **congestion costs** (detention, *premium surcharges)* remain "outside" the numerator, the indicator **underestimates** the advantage of solutions that reduce variance — for example, **extended windows** and **dry ports** (WORLD BANK, 2020; IAPH, 2020).

On the denominator side , the choice between **TEU-km** and **ton-km** alters comparisons between **light-volume** products (light e-commerce, *tissue)* and **heavy-compact** products (metals, chemicals). Best practices combine **two views:** cost per **ton-km** to reflect physical-energetic effort, and cost per **order/SKU** to capture **operational complexity** (touch points, documentation, inspections) not explained by mass (CHRISTOPHER, 2016; OECD/ITF, 2016). In **refrigerated container services,** including **energy/plug-in** and "unsaleable" capacity losses (equipment, segregations) avoids *bias* against *reefers* when compared to *dry* (UNCTAD, 2020).

Freight and energy volatility recommends incorporating **bands** or **indexes** into the KPI. In fluctuating BAF/GRI and correlated **diesel/bunker** environments , the cost per unit should present **scenarios** (base, high, low) or **sensitivity curves** by mode, showing **indifference points** between **all-water** and **land-bridge,** or between **road** and **intermodal/rail** (EIA, 2021; UNCTAD, 2020). By connecting the KPI to **signal posts** (decrease in *schedule reliability,* docking queues, rail *slot),* S&OE gains **triggers** to **migrate the modal mix** before the *spike* destroys margins (SEA-INTELLIGENCE, 2021; SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008).

The KPI's connection to **reliability** and **time** is structural. **Minutes** on the dock and **hours** in the yard/gate become **margin points** when translated into **safety stocks, contingency shipments ,** and ***lost sales,*** reinforcing the need for **integrated dashboards.** that display **cost per unit along with TTR/TTS, OTIF** and **demurrage/detention (SHEFFI,** 2015; PONOMAROV; HOLCOMB, 2009). Without this integration, **average cost** improvements can hide **a worsening in variance** that **increases** the total **cost of serving** — a typical *mean trap* in networks with bottlenecks (WORLD BANK, 2020; NOTTEBOOM; RODRIGUE, 2021).

In **contracts and incentives,** index part of the **freight** or **handling** to **service indicators** (e.g., *on-time, truck turn time, dwell)* aligns the KPI with the goal of **reducing TTR** and **backlog compression. Gain-sharing ,** which shares **avoided losses** (detention drop, premium freight, air shipments) encourages operators to **open windows, activate off-dock ,** and **divert.** flow when thresholds are crossed, even if this **momentarily raises** the unit cost "on the spreadsheet" (IAPH, 2020; WORLD BANK, 2020). The focus shifts from **cost per TEU** to **cost-to-serve and preserved margin,** language that convinces finance (CHRISTOPHER, 2016).

Heterogeneity **by SKU/customer** requires **a differentiated service policy. Time-sensitive** products accept **higher unit costs** in exchange for **lead time** and **low variance;** *commodities* accept **longer inventory/route. ABC curves for value and criticality,** coupled with **window/service,** avoid "shelf optimums" that reduce a KPI but **increase** *lost sales.* or **emissions** (SMART FREIGHT CENTRE, 2019; CHOPRA; MEINDL, 2016). The dashboard should allow **simulating combos:** *multi-gateway* + *off-dock* + *capacity option* versus "stock only", comparing **cost per unit** and **TTR.**

Finally, **data quality and auditing** support credibility. Integrate **TOS/PCS, WMS/TMS, billing ,** and **energy/fuel** via **APIs** and **metric dictionaries.** published reduces disputes and **greenwashing costs;** *After Action Reviews* and **reconciliations** periodic adjustments adjust imputation rules (outliers, voids, *backhauls)* and ensure **intertemporal comparability** (IAPH, 2020; OECD/ITF, 2016). In summary, the KPI "cost

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per unit" only provides good guidance when it is **explainable, comparable,** decision- **sensitive ,** and **coupled** resilience and **sustainability .**

4. GHG emissions: scopes, calculation methods and management use in the decision portfolio

Measuring **GHG emissions** in logistics requires **recognized standards** and transparent methodological **deliberations .** The **GHG Protocol** consolidates the distinction between **Scope 1** (owned fuels), **Scope 2** (purchased electricity), and **Scope 3** —especially **Categories 4 (upstream transportation)** and **9 (downstream transportation)—,** while **EN 16258** and the **GLEC Framework** offer specific guidelines for **freight transportation** and **fuel life cycle** (GHG PROTOCOL, 2011; EN 16258, 2012; SMART FREIGHT CENTRE, 2019). For operational decisions, the baseline indicator is **carbon intensity (gCOÿe/ton-km or TEU-km),** which can be enriched by **WTT/TTW** *(well-to-tank / tank-to-wheel),* **NOx/SOx ,** and, in air, **radiative forcing** adjustments when politically required (SMART FREIGHT CENTRE, 2019; IMO, 2020). Declaring **inventory boundaries, emission factors ,** and **data quality** (tiering) avoids incomparable numbers.

Data quality can follow a tiered ladder : **Tier 1 (standard factors)** by mode and fuel; **Tier 2 (operational data)** such as actual diesel, bunker, and yard/reefer electricity consumption; **Tier 3 (telemetric measurements)** by trip/service (speed, *idling, cold ironing),* with *matching* to **ETA/ETD** and **yard tasks** (SMART FREIGHT CENTRE, 2019; IAPH, 2020). The higher the **tier,** the greater the **predictive capacity** to analyze **trade-offs** of **load factor, speed** (slow steaming), **route ,** and **modal shift.** The annual audit should clarify **errors and uncertainties** and **recalculate series** when factors are updated, ensuring **comparability** (GHG PROTOCOL, 2011).

The relationship between **container utilization** and **emissions** is **non-linear.** Increasing **load factor** reduces intensity (gCOÿe/ton-km), but can **increase absolute emissions** if it involves **waiting** to consolidate, **longer routes ,** or **re-handling** at *hubs* (NOTTEBOOM; RODRIGUE, 2021; UNCTAD, 2020). Therefore, it is recommended to report **intensity along with absolute emissions** and **service indicators** (OTIF, TTR), making **trade-offs explicit.** On *reefers,* ***set-point*** and **plug-in** (shore power) **decisions** change the hourly emissions profile; in yards, **electrification** and **selective automation** shift **Scope 1 to Scope** 2 emissions, requiring attention to **grid factors** (WORLD BANK, 2020; IMO, 2020).

Modal **shift** is the classic decarbonization lever, but its **net value** depends on **time** and **capacity.** Migrating **from road to rail/intermodal** reduces **intensity** per ton-km; however, if **slots are** scarce or **transfers** multiply *touches* and **dwells,** TLC and **TTR** can **worsen,** producing **contingency** (air) expeditions that cancel out gains (OECD/ITF, 2016; CHOPRA; MEINDL, 2016). Operational scenarios need to **co-simulate** emissions, cost and service level, using **digital twins** that include **energy, efficiency factor load and reliability** to prescribe **efficient portfolios** (IVANOV; DOLGUI, 2020; SHEFFI, 2015).

In **the ocean, IMO 2020** has already reduced **SOx,** and pre-2021 discussions on **CII/EEXI** point to **efficiency per ton-mile; slow steaming** reduces emissions per voyage but **increases inventory in transit** and may **require additional ships** to maintain frequency, with **ambiguous effects** on total emissions (IMO, 2020; UNCTAD, 2020). In **ports, shore power** and **yard electrification** shift the marginal emissions curve, conditioned by the **local electricity matrix; PCS** that expose **queue/anchorage** and coordinate **windows** reduce maritime-land **idling ,** delivering carbon and service **co-benefits** (IAPH, 2020; WORLD BANK, 2020).

WTT+TTW accounting avoids bias in comparisons between **diesel, LNG and electricity.** Fuels with **low TTW emissions** can have **high WTT;** electrification shifts emissions to **Scope 2** and depends on **grid intensity; LNG** reduces **NOx/SOx** and **COÿ TTW** but may have significant **methane leakage** *upstream* (SMART FREIGHT CENTRE, 2019). For decision-making purposes, publishing **WTT and TTW intensity** by mode and **uncertainty margins** protects the KPI from **overly optimistic** interpretations and aligns the portfolio with **realistic targets.**

In **contracts and incentives, carbon indexes** can integrate **SLAs** and **gain-sharing:** discounts or bonuses tied to **gCOÿe/ton-km reductions** maintained without **worsening OTIF/ TTR;** "green" **capacity options** (slots on services/railways with higher intensity), exercisable when **emissions** or **energy** bands require climate resilience (IAPH, 2020; CHRIS-TOPHER, 2016). **Extended windows, off-dock ,** and **multi-gateway** are also **climate instruments** when they reduce **idling** and **rehandling,** even if they slightly increase unit cost—hence the importance of integrated **cost-to-serve + carbon + service panels** (WORLD BANK, 2020; OECD/ITF, 2016).

Governance and transparency prevent *greenwashing.* Publishing **methodologies, factors, tiers ,** and **uncertainty limits;** aligning with the **GHG Protocol/EN 16258/GLEC;** submitting **samples** to **independent verification;** and incorporating **emissions** into **S&OP/S&OE** with **triggers** (e.g., migrating X% to rail when **diesel bandwidth** and **network factor** become the **dominant option)** transform the KPI into **an executive lever** (GHG PROTOCOL, 2011; SMART FREIGHT CENTRE, 2019). Post-peak **AARs** and **quarterly reviews** keep the system **adaptive,** updating **portfolios** as technology, energy, and regulations evolve.

Finally, the **emissions** KPI needs **to align** with **utilization** and **cost per unit** within **efficient boundaries.** In many networks, the **combination of "adequate utilization (without waiting too long)"** + **smart scheduling** + **off-dock to reduce dwell** + **calibrated modal mix"** dominates single-cause solutions, reducing **gCOÿe/ton-km, TTR ,** and **TLC** simultaneously (SHEFFI, 2015; IVANOV; DOLGUI, 2020; WORLD BANK, 2020). The result is a **portfolio of KPIs** that not only measures, but **guides** choices with **responsibilities, thresholds, and rights of action** defined.

5. Integration of the three KPIs in S&OP/S&OE, control towers and contracts: from metrics to the right of action

The integration between **container utilization rate, cost per transported unit** and **GHG emissions** begins with a **governance design** that links metrics to **decision-making rituals** (S&OP/S&OE), **pre-authorized rights of action** and **numerical thresholds** that

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trigger operational *playbooks* . In **S&OP,** the three KPIs serve as **simultaneous constraints and targets:** minimum service levels (OTIF), **cost-to-serve ceilings,** target **utilization** ranges by product family, and **carbon budgets** by corridor; in **S&OE,** these targets become **triggers** with deadlines and responsible parties, reducing **decision-making latency** in the event of shocks (ISO 22301, 2019; CHRISTOPHER, 2016). This architecture only works if there is a common **metric dictionary** and auditable **data lineage ,** avoiding "two truths" in the same room (WORLD BANK, 2020; IAPH, 2020).

In the **S&OP** cycle , it is recommended to treat KPIs in **two layers: base planning** (demand, capacity, modal/gateway redesign) and **scenario planning** with **freight/energy** and **reliability** bands that show utilization **× TTR × gCOÿe/ton-km** *trade-offs* before approving the portfolio and budget. The committee should receive **efficient frontiers** produced by digital twins: for each mix of **bridge inventory, multi-gateway, off-dock, and capacity options,** display the **TLC** and the **area of the expected resilience triangle ,** with **Operational** VaR ranges under freight tails and delays (SHEFFI, 2015; PONOMAROV; HOLCOMB, 2009; CHOPRA; MEINDL, 2016). Thus, the discussion migrates from "averages" to **protected downside.**

In **S&OE,** the key word is **rhythm.** Daily/weekly **dashboards** in the control tower should show **utilization by window/service, cost per unit** (base and *cost-to-serve* with detention/ storage/capital), and **carbon intensity,** always **alongside flow KRIs** (schedule reliability, queue/anchorage, *truck turn time, rail slot),* so that deviations are visible **before** they become losses (SEA-INTELLIGENCE, 2021; IAPH, 2020). Clear **triggers** —e.g., *Utilization (adjusted)* < X% for Y days + *dwell* > Z h—trigger **alternative consolidation, extended windows, off-dock activation ,** or **gateway diversion,** with *owners .*
defined (ISO 22301, 2019; WORLD BANK, 2020).

Inter-organizational control towers are the **engine** of this integration: they consolidate **AIS/TOS/PCS/WMS/TMS/energy,** apply **imputation methods** and reconciliation routines (TOSÿPCSÿbilling) and publish **versions** of the series with **latency SLA** and **audit logs.** At this layer, **APIs** and **standards** (EDIFACT/X12/REST) ensure comparability and enable **contractual indexing** to reliable data (OECD/ITF, 2016; IAPH, 2020). Without this infrastructure, **KPIs become opinions ,** and **SLAs** degenerate into version disputes—a scenario familiar during congestion peaks (WORLD BANK, 2020).

In **contracts,** KPIs should be **instruments,** not *decorations.* **Contingency SLAs** can index part of the price to **reliability and fluidity** (OTIF, *truck turn time, dwell),* establish **conditional exemptions** from **demurrage/detention** when the root cause is systemic, and link **bonuses/penalties** to the **reduction of gCOÿe/ton-km** without sacrificing service (IAPH, 2020; WORLD BANK, 2020). **Capacity options** and **deviation clauses** should have **objective triggers (decrease** in *schedule reliability,* queues, fuel bands) defined from the dashboards, so that **costly actions** are only taken when **the preserved margin** exceeds the premium (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; CHRISTOPHER, 2016).

Shop floor incentives must avoid **perversities.** Exclusively rewarding **utilization** can lead to **delays** and **breakdowns;** rewarding only **unit cost** can

dehydrate resilience and worsen **OTIF;** subsidizing **emissions** alone can **force modal shifts** without capacity. The solution is a **weighted basket:** utilization targets **adjusted** by the SKU limit, **cost-to-serve** per window, and **carbon intensity** with **service limits** and **exception bands** (SMART FREIGHT CENTRE, 2019; CHOPRA; MEINDL, 2016). In peak environments, **prioritizing by time value** legitimizes decisions that **sacrifice utilization** to **save revenue.**

Operational **digital twins** connect planning and execution: receive **signals** (reliability, queues, energy) and test **playbooks** to see **how much** each action reduces **TTR** and **TLC** and **how** it affects **utilization** and **gCOÿe/ton-km.** This *testing technology* avoids "spreadsheet optimums" and anchors **CAPEX/OPEX requests** on **response curves** (IVANOV; DOLGUI, 2020; NOTTEBOOM; RODRIGUE, 2021). By bringing the " *what-if"* into routine, the company transforms **KPIs** into **operational policy,** not *scorecards.*

Selective transparency with the ecosystem closes the loop: publishing **methodologies, data tiers ,** and **uncertainties;** adhering to the **GHG Protocol/EN 16258/GLEC;** sharing **performance dashboards** with partners and, where appropriate, authorities; and submitting **samples** for **independent verification** strengthens legitimacy and **reduces litigation** (GHG PROTOCOL, 2011; SMART FREIGHT CENTRE, 2019; IAPH, 2020). The result is an **Operational Resilience Regime** in which **KPIs ÿ triggers ÿ actions ÿ auditable metrics** (ISO 22301, 2019; SHEFFI, 2015).

Finally, the **cadence** needs to be explicit: **weekly** reviews for *tactical* (S&OE), **monthly** for *tactical-strategic* (S&OP), and **quarterly** for **portfolio and contracts;** post-peak **AARs** update **thresholds** and **exception rules; training** maintains proficiency in reading dashboards and operating *playbooks.* Without **cadence and training,** even the best KPIs **don't translate into behavior** (SHEFFI, 2015; ISO 22301, 2019).

6. Resilience metrics (TTR/TTS, OTIF, VaR) as a governance "envelope" for cost, utilization, and carbon

We call the **resilience envelope** the set of **operational limits** defined by **TTR/TTS** (time to degrade/recover), **OTIF** (delivered service level), and **Operational VaR/Expected Shortfall** (tail loss). **Cost per unit, utilization ,** and **gCOÿe/ton-km** must optimize **within** this envelope—never at the expense —, under penalty of ephemeral gains of **increasing variance** and **destroying margin** in shocks (SHEFFI, 2015; PONOMAROV; HOLCOMB, 2009; CHOPRA; MEINDL, 2016). The envelope makes **explicit** that efficiency and sustainability **are constraints,** not mere aspirations.

TTR /**TTS** should be measured by **node** and by **corridor,** with sufficient granularity to capture **backlogs** and **reinforcement loops.** In ports and intermodal, **berthing time, quay productivity, yard occupancy, truck turn time, and rail slots** are **predictors** of TTR; the control tower needs **to simulate** how **extended windows, off-dock ,** and **diversions** move the network back to the subcritical regime (WORLD BANK, 2020; SEA-

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INTELLIGENCE, 2021). Setting **TTR targets** per scenario creates a "suffering ceiling" that cannot be breached by decisions that only **lower the TEU.**

OTIF is the **customer's compass** and should be **co-monitored** with **utilization:** consolidating to increase load factor without degrading **OTIF** is **optimal ;** consolidating **with** window degradation and **demurrage/detention** is **a false gain.** In **imbalanced** and **peak** environments , **prioritization by time value** and **exception policies** (by critical SKU) preserve **revenue.**
better than blind utilization targets (CHRISTOPHER, 2016; NOTTEBOOM; RODRIGUE, 2021). **Dashboards should** show OTIF **dispersion ,** not just averages, to expose margin-consuming **tails .**

Operational **VaR/Expected Shortfall** translates **service** and **cost** into financial terms: what is the worst plausible **loss** (extra cost, *lost sales, freight premium)* at 95%/99%? In portfolios with capacity and **multi-gateway options ,** VaR **falls** even if the **average cost** rises slightly—a rational tradeoff in **time-sensitive** sectors (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; SHEFFI, 2015). Incorporating VaR into the envelope prevents **static optimizations** from passing the committee without proving **tail protection.**

KRIs form the **anticipatory** edge of the envelope. Persistent drops in **schedule reliability,** bunker /diesel *spikes ,* out-of-band **queuing/anchoring ,** ***truck turntime*** **explosions ,** and limiting ***rail slot*** **utilization** are **precursory signals** that require **automatic action.**
according to *the playbook* (IAPH, 2020; SEA-INTELLIGENCE, 2021; EIA, 2021). Defining **numerical thresholds, sources ,** and **those responsible** prevents the envelope from being **rhetorical** and ensures **reaction time** before **backlogs** grow **superlinearly.**

The envelope also organizes **efficient frontiers** between **utilization × TTR × carbon.**
Graphs displaying **gCOÿe/ton-km** vs. **TTR** under **cost-to-serve** bands reveal **dominant combinations** —e.g., **adequate utilization + smart scheduling + off-dock** —that reduce **carbon** and **time** at a slight incremental cost; single-cause solutions, such as **slow steaming** without recalibrating **inventories** and **frequency,** can **violate** TTR/ OTIF and **widen** the resilience triangle (SMART FREIGHT CENTRE, 2019; OECD/ITF, 2016; IMO, 2020).

The envelope, therefore, is **a portfolio tool,** not just an audit tool.

In the **executive report,** the envelope becomes **the master chart:** boardroom **dashboards** show **OTIF, TTR/TTS, VaR, cost-to-serve, utilization ,** and **carbon intensity ,** along with **methodologies** and **uncertainties; public targets** and **barometers** (IAPH/World Bank) provide **legitimacy** and external **benchmarking** (WORLD BANK, 2020; IAPH, 2020; ISO 22301, 2019). In this language, **CAPEX/OPEX** requests become a matter of **avoided losses** and **TTR reductions,** not aesthetic *slides .*

Finally, the envelope is **alive.** Quarterly **AARs** recalibrate **thresholds,** update **emission factors** and **imputation rules** (tiers, WTT/TTW), and revise utilization **denominators .**
by changing the *mix* and incorporating **new evidence** (e.g., *driver shortages,* climate seasonality). **Training** and **simulations** maintain proficiency; **independent audits**
preserve credibility (GHG PROTOCOL, 2011; SMART FREIGHT CENTRE, 2019; ISO

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22301, 2019). In short, the envelope makes **efficiency, service, and sustainability** permanent **co-pilots** of decisions — not occasional passengers.

7. *Benchmarking* and *gain-sharing* between links: designing incentives without perversities

The starting point for serious *benchmarking* of **container utilization, cost per unit, and emissions** is **methodological standardization:** the same metric dictionary, the same time windows, the same segmentation by **service/route/gateway** and **product family,** with clarity regarding **denominators** (ton-km, TEU-km, order, SKU) and scopes **(pure freight** vs. **cost-to-serve; WTT/TTW** in carbon). Without this, cross-comparisons generate **illusions of efficiency** and **contractual injustices,** especially when there are **structural** *headhaul/ backhaul* imbalances that depress average utilization and distort carbon intensities (CHOPRA; MEINDL, 2016; SMART FREIGHT CENTRE, 2019; UNCTAD, 2020). A robust practice is to publish tiered *benchmarks :* by window/service (base), by corridor (aggregate), and **a corporate index** weighted by time/revenue value.

The second foundation is **data quality and lineage.** *Benchmarks* should indicate data **tiers** (average factors, operational consumption, telemetry), **sources** (TOS/PCS, WMS/TMS, billing, energy), **imputation rules ,** and **independent auditing** by sampling, preventing supposed "improvements" from being the result of **accounting changes** rather than actual productivity (IAPH, 2020; WORLD BANK, 2020; GHG PROTOCOL, 2011). The absence of a reconciliation trail—for example, between published **dwell** and billed **detention** —turns *benchmarking* into a version dispute and neutralizes *gain-sharing* (OECD/ITF, 2016).

The third pillar is **mix adjustment.** The comparison of cost/ton-km and gCOÿe/ton-km needs to **be disaggregated** by **density, reefer vs. dry, hazardousness ,** and **criticality** (time value), otherwise operations that serve inherently more expensive SKUs or those with a lower load factor will be penalized. The solution is to use **adjusted indices** (e.g., *utilization adjusted to the limit,* cost-to-serve by **window/service ,** and **carbon intensity** with WTT/TTW) and publish, alongside the indices, **mix compositions** for contextual reading (CHRISTOPHER, 2016; SMART FREIGHT CENTRE, 2019; UNCTAD, 2020). This adjustment reduces **perverse incentives** to "avoid" difficult cargo.

In the ***gain-sharing*** design , the rule must share **avoided losses** measured in **currency:** drop in **demurrage/detention,** premium freight , **contingency** shipments and **TTR** converted into saved working **capital ,** in addition to the **reduction in gCOÿe/ton-km** weighted by the carbon shadow price, when applicable. The reference is a frozen **baseline** (window/ service) and a **counterfactual** generated by **a digital twin** or adjusted historical series, with *washout* of exogenous effects (fuel, tariffs) to avoid compensating for "tailwind." (SHEFFI, 2015; IVANOV; DOLGUI, 2020; WORLD BANK, 2020). The earnings *pool* finances **extended windows, off-dock ,** and **extra trains,** creating **a virtuous cycle.**

To **avoid perversities,** *gain-sharing* cannot **benefit utilization or unit cost in isolation .** One **-** dimensional targets create **delays** in consolidation (worsening OTIF/TTR), **risk of breakdowns ,** and **hidden carbon** due to *idling;* carbon-only targets can **force modal shifts.**

without capacity, increasing costs and degrading service. The antidote is a **weighted basket: adjusted utilization** + **cost-to-serve** + **gCOÿe/ton-km within** a **resilience envelope (TTR/TTS,** OTIF, VaR) that acts as a **hard constraint** (CHOPRA; MEINDL, 2016; SMART FREIGHT CENTRE, 2019; SHEFFI, 2015). This way, one does not buy "cheap" efficiency that blows the tail of risk.

Another consideration is **timing.** Earnings should be calculated using **seasonally adjusted** rolling **windows .** and explicitly addressed **peaks ,** so that operators **invest** when it matters most (harvests, *peak season).* **Seasonal clauses** that increase the gain *-sharing split* at peak times align incentives with the **marginal elasticity** of measures such as **windows** and **additional trains** (SEA-INTELLIGENCE, 2021; WORLD BANK, 2020). Without this *timing,* gains appear **outside** from the window of pain and the ecosystem regresses to improvisation.

Independent verification is part of the contract: sampling of **dwell, turn time, utilization, fuel ,** and **emissions** by a neutral third party, with **ACIs** and **reprocessing rules** when data gaps exceed tolerances. In carbon, it's worth using **GLEC tiers** and recalculating retrospectively when **factors** change, preserving **intertemporal comparability.** (SMART FREIGHT CENTER, 2019; GHG PROTOCOL, 2011). At cost, **ABC/TDABC** audited ensures that *overheads* and **congestion costs** do not "disappear" (KAPLAN; ANDERSON, 2007; WORLD BANK, 2020).

There are also **regulatory and competitive constraints.** In markets with **alliances** and **vertical integration,** *gain-sharing* and **container pools** must comply with **antitrust** and **non-discrimination,** with **neutral access** and **minimal data transparency ;** otherwise, the remedy becomes a barrier to entry (OECD/ITF, 2016; HARALAMBIDES, 2019). The solution is to standardize **APIs,** publish **methodologies** and **aggregate targets ,** and maintain **multi-stakeholder committees** for technical arbitration, reducing asymmetry and opportunism (IAPH, 2020).

Finally, *benchmarking* and *gain-sharing* only create value when **they feed back into S&OP/S&OE** and **budgets.** Quarterly targets for **TTR reduction and cost-to-serve reduction** and **carbon intensity** should **release funding** from a **resilience fund** for **off-dock, windows, selective automation ,** and **capacity options,** with phase **gates** tied to proven **avoided loss** (SHEFFI, 2015; ISO 22301, 2019). It is in this chain—measuring, comparing, distributing gains, and reinvesting—that the KPI dashboard ceases to be **decorative** and becomes **a driver of governance.**

8. Implementation *Roadmap :* Goals, Cadence, and Independent Verification

The *roadmap* begins with a **materiality assessment:** mapping **critical corridors, A/B SKUs by time value, likely bottlenecks** (port, *drayage,* rail, compliance), **energy profile ,** and **data maturity** by **tier.** The result is a **map of risks and levers.** that links each KPI to **KRIs** (reliability, queue/docking, *turn time,* slots) and available **action rights** — for example, *"Adjusted utilization* < X% + *dwell* > Y h ÿ **activate off-dock/windows;** LPG < Z% for 3 weeks ÿ **exercise capacity/deviation option"** (SEA-

INTELLIGENCE, 2021; ISO 22301, 2019; WORLD BANK, 2020). This **control panel** defines where to start.

Phase 1 (0–90 days): Build the **minimum viable dashboard** and **metric dictionary.** Integrate **TOS/PCS, WMS/TMS, billing ,** and **energy/fuel** via **APIs,** publish **formulas** (utilization, cost-to-serve, gCOÿe/ton-km) and data **lineages ,** and establish **latency SLA** and **imputation rules.** In parallel, run a **pilot** in a **corridor/window** with **a digital twin** to calibrate **response curves** (utilization × TTR × carbon) to **extended windows, off-dock, multi-gateway ,** and **options,** creating **efficient frontiers** for S&OP (IVANOV; DOLGUI, 2020; CHOPRA; MEINDL, 2016).

Phase 2 (90–180 days): Institutionalize the interorganizational control tower , with **S&OE rituals** (daily briefings, weekly *war rooms),* **pre-authorized triggers ,** and **playbooks** actionable. **Contracts** adopt a new logic: **contingency SLAs, reliability indexing, conditional demurrage/ detention exemptions, capacity options with objective thresholds** anchored in the dashboard's KPIs/KRIs (IAPH, 2020; WORLD BANK, 2020; SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008). This phase reduces **decision-making latency** and gives metrics **teeth .**

Phase 3 (6–12 months): Scale **structural buffers** and **technical standardization.** Implement **dry ports/off-dock, chassis cohorts,** seasonal rail **contracts ,** and **packaging/labeling/EDI-API standards** for **plug-and-play substitutability** between gateways, reducing **requalification time** and **diversion costs** (OECD/ITF, 2016; CHRISTOPHER, 2016). In this phase, formalize ***gain-sharing*** with **baseline** and **independent verification,** enabling self-financed **resilience funds** for **avoided losses** (SHEFFI, 2015).

Phase 4 (12–24 months): Prioritize **modular capacity** and **selective automation** where the twin shows **high marginal gain** in **TTR** per unit of capital: **phased berths,** partial **yard automation , additional STS, scalable rail corridors, shore power/yard electrification** with attention to **WTT/ TTW** (WORLD BANK, 2020; IMO, 2020). Structure **availability payments** tied to **SLAs** and **TTR/ OTIF** targets .
and **gCOÿe/ton-km,** reducing demand risk and accelerating *payback* (SHEFFI, 2015).

The *roadmap* requires explicit **goals and cadence . Weekly** for *tactical* (utilization/cost/OTIF KPIs and flow KRIs), **monthly** for S&OP (efficient frontiers and *mix)* modal/gateway) and **quarterly** for **portfolio** and **contracts,** with post-peak AARs to review **thresholds** and **exception rules** (ISO 22301, 2019; CHRISTOPHER, 2016). Public metrics (turnaround, *dwell,* reliability) and sector **barometers** increase **legitimacy** and **execution discipline** (IAPH, 2020; WORLD BANK, 2020).

Independent verification provides credibility and prevents cost and carbon *greenwashing .* For emissions, apply **GLEC/EN 16258/GHG Protocol** with **clear tiers, uncertainty bands ,** and **recalculation** when factors change; for costs, audit **ABC/TDABC** and reconciliations with **detention/storage;** for utilization, audit **weights/cubes** by sampling and ***match-back*** **rules** (SMART FREIGHT CENTRE, 2019; GHG PROTOCOL, 2011; KAPLAN;

ANDERSON, 2007). The audit must be **operationally friendly:** focus on **risk-based sampling** and **API-first.**

Human capital is a prerequisite for success. Training teams in **dashboard reading, digital twin operations, options contracts ,** and **trigger-based S&OP/S&OE;** establishing **internal certifications;** and running monthly table **simulations** consolidates **repeatable capabilities.** (CHRISTOPHER, 2016; SHEFFI, 2015). **Bonuses** linked to **reduced TTR, cost-to-serve** and **carbon intensity** align behavior with strategy, avoiding **local optimizations** that erode service.

Finally, the *roadmap* requires a **financing framework** that translates KPIs into **bankable assets. Resilience funds** capture *gain-sharing* and finance **off-dock, windows ,** and **selective automation; parametric insurance** and **capacity options** with **verifiable triggers** (LPG, queues, *dwell)* protect against **downside; modular capex** with **availability payments** enables larger projects (SHEFFI, 2015; SEA-INTELLIGENCE, 2021). This chain of events converts **measurement** into **action, action** into **results ,** and **results** into **scale.**

— essence of **KPI governance** that optimizes **cost, service and carbon** simultaneously.

Conclusion

The analysis developed throughout this article argues that **logistics KPIs only create value when they cease to be "numbers on a dashboard" and become decision-making mechanisms with attached rights of action.** This requires **unambiguous operational definitions, standardized measurement methods ,** and **governance** that links metrics to **S&OP/S&OE rituals,** *playbooks ,* and contracts. By treating **container utilization rate, cost per unit transported ,** and **GHG emissions** as a **tripod** —efficiency, cost-to-serve, and sustainability—we avoid local optimizations that erode service and margins in times of stress, anchoring choices in the **resilience envelope** (TTR/TTS, OTIF, and VaR) as **hard constraints** (CHRISTOPHER, 2016; CHOPRA; MEINDL, 2016; SHEFFI, 2015).

In the first axis, we show that **container utilization** is a **conditional metric:** it improves with consolidation, *match-back ,* and triangulation, but can **degrade OTIF** and **increase risk** when it leads to excessive waiting and densification. A correct interpretation requires distinguishing **physical constraints** (weight vs. cubic capacity), **headhaul/backhaul, and product classes.** (dry, reefer, hazardous materials), in addition to publishing **utilization adjusted** to the limit and **dispersion** by service window. In markets with **structural imbalance** and port bottlenecks, **interorganizational container pools** and **conditional demurrage/detention policies** are levers to increase effective use without punishing the wrong link (UNCTAD, 2020; NOTTEBOOM; RODRIGUE, 2021; WORLD BANK, 2020).

On the second axis, **cost per unit transported** only provides good guidance when migrating from **pure freight** to **cost-to-serve,** incorporating **terminal handling, drayage/chassis, warehousing, demurrage/detention, contingency shipments ,** and **working capital.** The adoption of **ABC/TDABC** reduces apportionment biases and highlights the cost of variance (delays, queues, rolling), allowing for the comparison of **structural buffers** (multi-gateway, *off-dock)* and **contractual options .**

avoided loss and **reduced TTR.** Without this perspective, decisions that reduce the cost of TEU "on the spreadsheet" **increase** the total cost when measuring what really matters to the business (KAPLAN; ANDERSON, 2007; SHEFFI, 2015; IAPH, 2020).

In the third axis, **GHG emissions** need to move beyond *greenwashing* and into **auditable accounting: the GHG Protocol (Scope 3, Cat. 4/9), EN 16258 ,** and **the GLEC Framework** ensure **clear boundaries,** data **tiers** (averaging factors ÿ actual consumption ÿ telemetry), and **the WTT/TTW distinction. Carbon intensity (gCOÿe/ton-km) should** be reported **alongside** absolute emissions, **utilization ,** and **service level,** as **apparent gains** in intensity can hide **waiting and re-handling** that increase total emissions. Decisions such as **slow steaming, modal shift ,** and **yard/shore power electrification** need to be evaluated **across the portfolio,** with effects on **TTR, OTIF ,** and **TLC** (GHG PROTOCOL, 2011; EN 16258, 2012; SMART FREIGHT CENTRE, 2019; IMO, 2020).

A central finding is that **data and standards** are the invisible infrastructure of this agenda. **Port Community Systems (PCS), Digital Single Windows ,** and **APIs** between **TOS/WMS/TMS/energy** They reduce **information asymmetry,** cut **latency ,** and allow **contracts to be indexed** to reliable metrics. **Data dictionaries, lineage/auditing ,** and **regular publication** of **turnaround, dwell, and reliability data** create legitimacy and **reduce litigation,** especially when **contingency SLAs** and **conditional demurrage/detention exemptions** come into play (IAPH, 2020; WORLD BANK, 2020; OECD/ITF, 2016; ISO 22301, 2019).

We also argue that **interorganizational control towers** and **digital twins** are the link between **metrics** and **action.** By coupling **DES/SD/ABM** with **freight/energy bands** and **precursor signals** (schedule *reliability* decline , bunker/diesel *spikes ,* queuing/docking), companies can **test playbooks** before activating them, estimating **response curves:** how much **extended windows, off-dock ,** and **multi-gateway diversions** reduce **TTR** and **TLC,** and how they affect **utilization** and **gCOÿe/ton-km.** This operational realism avoids "spreadsheet optimums" and anchors **CAPEX/ OPEX** requests **in avoided losses** (IVANOV; DOLGUI, 2020; SEA-INTELLIGENCE, 2021; EIA, 2021).

Literature and practice converge on **mitigation portfolios** that combine **physical buffers** (bridge stocks for *time-sensitive* SKUs), **structural buffers** (multi-gateway, *off-dock,* seasonal rail contracts), and real **options** (capacity reservations, *box pools)* with **objective triggers. Efficient frontiers** show that, in many corridors, the *combo* **"adequate utilization (no waiting), smart scheduling and *off-dock"*** dominates monocausal solutions, reducing **carbon** and **TTR** with a slight incremental cost per unit — **a rational exchange** when measured by **VaR/Expected Shortfall** of service (SHEFFI, 2015; NOTTEBOOM; PALLIS, 2020; CHOPRA; MEINDL, 2016).

At the **contractual level, gain-sharing** should distribute **avoided losses** (reduction in detention, premium freight and contingency shipments; reduction in TTR and gCOÿe/ton-km) over a **baseline** auditable, with **washout** of exogenous effects. **One-dimensional targets** (only utilization, only cost, only carbon) generate **perversities;** the correct design uses a **weighted basket within** the **resilience envelope** and observes **antitrust/non-discrimination** in data pools and exchanges (IAPH, 2020; OECD/ITF, 2016; HARALAMBIDES, 2019; DREWRY, 2021).

We also proposed a four-phase **roadmap : (i)** minimum viable panel and metric dictionary; **(ii)** institutionalization of the tower with **pre-authorized triggers** and **contingency/option SLAs;** **(iii)** scaling of **structural buffers** and **technical standardization** for *plug-and-play* replacement ; **(iv)** investments in **modular capacity and selective automation.** financed by **availability payments. Continuous training, AARs ,** and **independent verification** preserve credibility and keep the organization in **a resilient operating regime** (ISO 22301, 2019; CHRISTOPHER, 2016; SHEFFI, 2015).

From a financial-executive perspective , the shift in perspective is unequivocal: **from average cost per TEU** to **margin preservation, loss avoidance ,** and **tail protection. Operational VaR** makes **physical inventory, structural buffers ,** and **options** comparable , while **carbon budgets** and **TTR/OTIF targets** function as **constraints.** This translation creates **a common language** between operations and the board and accelerates evidence-based approvals (PONOMAROV; HOLCOMB, 2009; SEA-INTELLIGENCE, 2021; WORLD BANK, 2020).

In short, **defining and managing KPIs** for **utilization, cost, and carbon** is **governance engineering:** standardizing, measuring, auditing, **connecting to action rights ,** and **reinvesting earnings.** When **data** becomes infrastructure and **contracts** become **execution engines,** supply chains evolve from a reactive logic to a **predictable and adaptive regime,** in which **efficiency, resilience and sustainability** cease to compete with each other and begin to **co-optimize** economic and operational results, even under **geopolitical and tariff volatility** (CHRISTOPHER, 2016; NOTTEBOOM; RODRIGUE, 2021; SMART FREIGHT CENTRE, 2019).

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