Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year IV, v.1 2024. | submission: 02/04/2024 | accepted: 04/04/2024 | publication: 06/04/2024

Vertical and Horizontal Integration in the Supply Chain: Impacts on Resilience Operational

Vertical and Horizontal Integration in the Supply Chain: Impacts on Operational Resilience

Author: Ivan de Matos

Graduated in Logistics from the Leonardo Da Vinci University Center

Postgraduate in Human Resources Management, from the Leonardo da Vinci University Center

Summary

This article investigates how **vertical integration** strategies (upstream and downstream) and **horizontal integration** (between peers/adjacent sectors) influence the **operational resilience** of supply chains in highly volatile environments. Combining fundamentals of transaction cost economics and the resource-based view with operations management and business continuity literature, we propose an analytical framework that links **governance structure**

(make-or-buy, alliances, and mergers), **network architecture** (centrality, redundancy, modularity), and **response practices** (visibility, flexibility, buffers, and substitutability) to **robustness, agility, and resilience** metrics (MTTR, service level, fill rate, and backlog clearing). It is argued that vertical integration tends to **increase control, coordination, and capacity prioritization,** mitigating the risk of disruption in critical inputs, while horizontal integration can **expand scope, economies of scale, and capacity sharing,** accelerating **reconfiguration** in the face of shocks. However, adverse effects—

Rigidity, risk concentration, lock-in, and loss of optionality —emerge when integration is conducted without criteria for **dynamic viability** and **adaptive governance.** This paper synthesizes evidence and proposes guidelines for organizational design, investment criteria, and resilience measurement.

and of

Keywords:

Vertical integration; horizontal integration; supply chain; operational resilience; governance; transaction costs.

Abstract

This paper examines how **vertical integration** (upstream/downstream) and **horizontal integration** (among peers/adjacent sectors) shape **operational resilience** in supply chains facing high volatility. Combining transaction cost economics and resource-based views with operations

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

and business continuity literatures, we propose an analytical framework linking **governance structures** (make-or-buy, alliances and M&A), **network architecture** (centrality, redundancy, modularity) and **response practices** (visibility, flexibility, buffers and substitutability) to **robustness, agility and recovery** metrics (MTTR, service level, fill rate and backlog clearing). We argue vertical integration typically **increases control, coordination and capacity prioritization,** mitigating supply disruption risks for critical inputs, while horizontal integration can **expand scope, scale and shared capabilities,** speeding **reconfiguration** under shocks. However, downsides — **rigidity, risk concentration, lock-in and loss of optionality** — arise if integration ignores **dynamic viability** and **adaptive governance.** The study synthesizes evidence and offers guidelines for organizational design, investment criteria and resilience measurement.
Keywords: vertical integration; horizontal integration; supply chain; operational resilience; governance; transaction costs.

1. Conceptual foundations, history and value hypothesis of integration

Vertical integration describes the internalization of upstream (suppliers of inputs, technology, primary logistics) and/or downstream (distribution, retail, after-sales services) links, with the aim of reducing **transaction costs,** mitigating **contractual hazards** and capturing **quasi-rents.** coordination (COASE, 1937; WILLIAMSON, 1985). By expanding scope within the **value chain** (PORTER, 1985), firms integrate activities previously mediated by market contracts, seeking **synchronization of flows,** standardization and priority of capacity in contingencies. Historically, waves of integration have accompanied technological and logistical paradigms — from the 20th-century multidivisional company to digital platforms — in which **economies of scope and coordination** were sources of advantage (CHANDLER, 1977; TEECE, 1986).

Horizontal integration, in turn, refers to coordination between companies at the same stage (or adjacent) through **alliances, consortia, joint ventures and M&A,** aiming at **scale, network density and asset sharing** (PORTER, 1985; CHOPRA; MEINDL, 2016). In fragmented networks, horizontal coupling can create **capacity pools,** normalize **technical interfaces ,** and facilitate **cross-switching** when a node fails, improving **functional connectivity** and **rerouting capacity** (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008). At the same time, excessive horizontalization can concentrate market power and reduce provider diversity, making the network **more efficient but less resilient** (SHEFFI, 2005; TANG, 2006).

In economic terms, the decision to integrate is classically treated as a **make-or-buy problem,** dependent on **frequency, asset specificity, uncertainty, and performance measurability** (WILLIAMSON, 1985). Environments with **high specificity** (e.g., dedicated molds, proprietary firmware, critical certifications) and **high hold-up risks** favor vertical integration; contexts with **low specificity** and **liquid markets** favor governance through contracts and **modular partnerships** (COASE, 1937; TEECE, 1986). In resilience, the same logic is reinterpreted as **a trade-off between control and optionality:** internalizing reduces

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

exposure to third parties, but can **rigidify capacity,** while modularizing preserves **degrees of freedom** to recombine suppliers (CHRISTOPHER, 2016).

At the operational level, integration alters **decision architecture:** endogenous lead times, planning synchronization (S&OP/S&OE), **coupled inventory policies ,** and data governance/end-to-end visibility. Verticalization enables **hierarchical planning** with **prioritization of internal orders** in the allocation of critical capacity (e.g., semiconductors, APIs, logistics slots), reducing **supply variance** and the **amplification of the bullwhip effect** (CHOPRA; MEINDL, 2016). Horizontalization, when based on **interoperability,** enables **shared capacity** and **mutual aid** between peers, creating **network buffers** that cushion localized shocks (IVANOV; DOLGUI, 2020).

From a **resilience perspective,** three dimensions are distinguished: **robustness** (resisting without degrading), **agility** (changing rapidly), and **resilience** (returning to the target regime with an acceptable MTTR) (SHEFFI, 2015; PONOMAROV; HOLCOMB, 2009). Vertical integration tends to reinforce **robustness** through control and internal redundancy of critical capabilities; horizontal integration favors **agility** and **recovery** through recombination between partners and **alternative routes.** The optimal solution is contingent on the **risk profile** (rare and severe disruptions versus frequent and mild) and the **technological cycle** (IVANOV; DOLGUI, 2020; TANG, 2006).

Furthermore, integration is not binary: there is a **continuum of hybrid arrangements** —long-term **VMI/CPFR contracts, minority stakes, capacity joint ventures, licensing** with priority clauses, and **technical interoperability agreements** —that allow **orchestration** without full internalization (SIMCHI-LEVI et al., 2008; CHOPRA; MEINDL, 2016). These arrangements enable **configurable resilience,** adjusting link density and fallback rules without losing efficiency.

Critically, integration needs to be assessed in light of the system's **dynamic viability :** its ability to **absorb, adapt, and evolve** in the face of shocks without collapsing into lower-performance regimes (IVANOV; DOLGUI, 2020). This requires measuring **operational elasticities, capacity bottlenecks, critical dependencies ,** and the **cost of reconfiguration** (time, capital, talent). In many cases, **partial vertical integration** of bottleneck inputs combined with **horizontal networks** for peak demand is superior to full integration or outsourcing (SHEFFI, 2005; CHRISTOPHER, 2016).

Finally, the value hypothesis guiding this article is that **mixed designs** — “surgical” vertical integration at points of high specificity and systemic risk, combined with **interoperable horizontalization** — tend to maximize **operational resilience** by balancing **control** and **optionality,** as long as they are supported by consistent **financial and operational metrics** and by **governance** that avoids **rigid lock-ins** (WILLIAMSON, 1985; TEECE, 1986; CHOPRA; MEINDL, 2016).

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

2. Mechanisms of impact on resilience: governance, network architecture and response

The first impact mechanism stems from **governance.** Vertical integration replaces contracts with **hierarchical authority,** reducing **the risk of opportunism** and **monitoring costs.**
(WILLIAMSON, 1985). In terms of resilience, this enables **internal priority, unified standards ,** and **alignment of incentives** to maintain service in times of shock, mitigating **coordination failures** typical of multi-party networks (COASE, 1937). However, the concentration of decisions and assets in a single firm also **concentrates risk:** an internal failure can have greater **systemic reach** when **supplier diversity** is replaced by **single internal dependence** (SHEFFI, 2005).

The second mechanism is **network architecture.** Vertical integration generally **reduces the relational distance** between critical nodes (supplier ÿ factory ÿ distribution), shortening **information paths** and lead times, and making it easier **to synchronize buffers** and **replenishment policies.**
(CHOPRA; MEINDL, 2016). Horizontal integration **increases lateral connectivity,** creates **alternative channels ,** and reduces **bottleneck centrality,** bringing the network closer to a **modular** topology capable of **isolating failures** (IVANOV; DOLGUI, 2020). **Highly centralized** networks are efficient under normal conditions but vulnerable to targeted shocks; adding **modular redundancy** increases robustness at a lower cost than full duplication.

The third mechanism is **response.** With more internalized links, the firm can **mobilize resources** without renegotiation, shortening **decision and execution times;** this is important in rapid shocks, where reaction windows are short (SHEFFI, 2015). Horizontally, **shared capacity** and **mutual aid agreements** provide escape **valves** when a node saturates, especially useful during **peak demand** or when **logistics routes** are interrupted by localized events (CHRISTOPHER, 2016). **Agility** increases when interfaces are standardized (e.g., packaging, EDI/API, cross-qualification), enabling **plug-and-play replacement.**

The fourth mechanism involves **buffers and substitutability.** Verticalization allows for **strategic stocks** in optimal network positions—upstream to protect production, downstream to protect customer service—and **capacity reserves** under single control (CHOPRA; MEINDL, 2016). Horizontalization favors **node substitutability:** multiple qualified suppliers, product co-design for **alternative materials, dual/triple sourcing ,** and **cross-licensing.**

reduce **single points of failure** (SIMCHI-LEVI et al., 2008; TANG, 2006). The optimal design combines **physical buffers** and **structural buffers.**

The fifth mechanism is **visibility.** In vertically integrated organizations, the **integration of** planning and execution data (MRP, APS, WMS/TMS, MES) enables **early detection** of deviations and **dynamic allocation;** in horizontal organizations, multiservice **control towers** and **data-sharing agreements** provide interorganizational situational **awareness** (CHRISTOPHER, 2016). Without visibility, no integration delivers resilience: **information asymmetry** distorts decisions and amplifies whipsaws.

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

The sixth mechanism concerns **reconfiguration costs.** Verticalization reduces **marginal costs of internal replanning,** but can increase **fixed costs** (capex) and **technological rigidity;** horizontalization maintains **distributed capex** and **technological optionality,** but can increase coordination costs and contractual **recomposition time** (WILLIAMSON, 1985; TEECE, 1986). Optimal resilience depends on the necessary **elasticity** in the face of the risk profile: rare and severe shocks justify **controlled idle capacity;** frequent and moderate shocks favor **shared elastic capacity.**

The seventh mechanism is **compliance and continuity.** Vertical integration facilitates **standardized policies** (quality, compliance, safety, continuity), favoring **ISO 9001, ISO 22301 ,** and **ISO 28000 certifications;** horizontal integration requires **service level agreements** and **cross-audits,** mitigating regulatory heterogeneity between partners (ISO 22301, 2019; ISO 28000, 2007). In both, **document governance** and **training** support the ability to execute under stress.

Finally, the eighth mechanism is **financial performance under shock.** Resilience must be expressed in **preserved margin, avoided loss, recovery time ,** and **capital turnover.** Vertical integration affects **the fixed/variable cost mix** and **margins;** horizontal integration alters **economies of scale/scope** and **pricing power.** The decision must be **economic, not ideological,** with **stress-test** simulations and **scenarios** that value **real optionality** (SHEFFI, 2015; CHOPRA; MEINDL, 2016).

3. Transaction cost economics and *make-or-buy* criteria in resilience design

The decision to integrate vertically or couple horizontally traditionally begins with the **make-or-buy dilemma,** whose analysis involves **transaction frequency, asset specificity, uncertainty, and difficulty in measuring performance.** In markets with low specificity and sufficient competition, short and repricable contracts tend to curb opportunism, making external purchasing more efficient. However, in environments with **idiosyncratic assets (dedicated** molds, proprietary APIs, critical certifications) and high uncertainty, the risk of **holdup** increases, and internalization becomes rational (COASE, 1937; WILLIAMSON, 1985). When we bring **operational resilience** to the center of the analysis, the question shifts from "which arrangement minimizes expected cost under normal conditions?" to "which arrangement **minimizes expected loss** under shocks and accelerates **recovery time?"** From this perspective, asset specificity is not just a bargaining problem, but an **amplifier of systemic risk** that can justify **selective verticalization** in bottleneck nodes (WILLIAMSON, 1985; SHEFFI, 2015).

A second foundation is the **resource-based view (RBV)** and the notion of **quasi-rents** arising from superior coordination. If the firm has **dynamic capabilities** to rapidly reconfigure plants, suppliers, and channels, integration can capture synergies that are difficult to replicate through contract, especially when **tacit knowledge** and **operational routines** require joint learning and **hierarchical governance** to flourish (TEECE, 1986). In terms of

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

resilience, the RBV suggests that the **value of optionality** embedded in less integrated arrangements needs to be weighed against the **coordination rents** of integration. Chains subject to **short technological cycles** and risk of obsolescence may prefer **interoperable horizontalization.**
(consortia, cross-licensing), while **high compliance** and **security** chains (health, defense, food) tend to value **vertical control** and the reduction of supply variance (TEECE, 1986; CHOPRA; MEINDL, 2016).

Uncertainty is not homogeneous: **stochastic uncertainty (random** variation in demand/supply) is distinguished from **Knightian uncertainty (not** measurable ex ante) and **structural uncertainty** (regime shifts). Under moderate stochastic uncertainty, **contracts with flexibilities** (windows, bands, volume options) can equalize the benefits of integration at lower costs. Under structural uncertainty—geopolitical disruptions, pandemics, climate shocks—the **command and prioritization capacity typical** of vertical integration reduces exposure to **failed coordination** among multiple firms (WILLIAMSON, 1985; SHEFFI, 2015). In terms of **response, decision latency** matters : the shorter the time between **detection, decision, and execution,** the greater the marginal value of hierarchical authority. Therefore, "surgical" integrations in **time-sensitive links** (e.g., production APIs, critical primary logistics) are often superior to broad and costly integrations (CHRISTOPHER, 2016; CHOPRA; MEINDL, 2016).

Coordination and **monitoring** costs also change with technology. Digitization and **EDI/API-first reduce** information asymmetries and reduce the cost of interorganizational control, shifting the **market-firm** boundary in favor of **modular partnerships.**
with robust **SLA** and continuous **telemetry** (COASE, 1937; CHRISTOPHER, 2016). However, **technology does not eliminate hazards:** "asset-light" models can **externalize risks** that return in times of crisis (e.g., dependence on a single global logistics operator or a single
foundry). The reality test is the **viability of the network:** how quickly the arrangement can **reroute flows, replace materials ,** and **recover service levels** without collapsing into **cascading effects** (IVANOV; DOLGUI, 2020). If the answer depends on slow renegotiations, the promise of efficiency evaporates in a crisis.

In terms of **inventories and buffers,** vertical integration allows for **the joint optimization** of the positioning and size of strategic inventories, reducing **inefficient duplication** and **coverage gaps.** In contrast, horizontal integration with **qualified dual/triple sourcing**
creates **structural buffers,** that is, **node substitutability,** which can be superior to large inventories when there is **perishability, obsolescence ,** or **expensive capital** (CHOPRA; MEINDL, 2016; TANG, 2006). From an economic perspective, the **carrying cost** and **depreciation risk** of internal inventories are compared with the **cost of maintaining redundant relationships** and **distributed idle capacity.** In **long-cycle** sectors (chemicals, aerospace), integrated strategic inventories tend to dominate; in **short-cycle** sectors (consumer electronics), **modular redundancy** through horizontalization is often more resilient (SHEFFI, 2015).

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Risk concentration is a classic side effect of integration. By internalizing, the firm reduces its exposure to opportunism, but **increases its exposure to internal failures** and **risk correlation** between units (same ERP, same policies, same energy supplier), which can create systemic **single points of failure** (SHEFFI, 2005). Horizontally, however, the **risk of contagion** can occur due to **hidden interdependencies** (same second-tier subsuppliers, same logistics infrastructure). Resilience design, therefore, requires **multi-scale auditing,** tracking **tiers 2 and 3** and **common infrastructures.** Only with this visibility is it possible to calibrate the **optimal mix** of integration and modularity, avoiding **false diversifications** that collapse under the same shock (CHRISTOPHER, 2016; IVANOV; DOLGUI, 2020).

Another essential lens is the **calculation of optionality.** Well-specified horizontal arrangements operate like **real options:** the firm pays a **premium** (relationship costs, qualification of multiple suppliers, duplication of audits) to have the **right,** not the obligation, to reallocate flow. In high-volatility regimes, **positive optionality** can exceed **average efficiency.** rigid integration, especially when the **demand curve** is unpredictable or when **regulatory risks** change rapidly (TEECE, 1986; CHOPRA; MEINDL, 2016). The recurring error is to compare **the static average cost** of alternatives, ignoring the **asymmetric** value of the ability to choose **after** uncertainty is resolved—precisely what determines **practical resilience.**

At the organizational level , integration requires **governance** that preserves **tactical decentralization** and avoids **single-center syndrome.** The operations literature recommends integrated **S&OP/S&OE , a control tower** with resilience **KPIs/KRIs** (fill rate, OTIF, MTTR, backlog clearing), and **decision-making rituals** that accelerate the **detect-decide-act cycle (CHRISTOPHER** In vertical structures, the risk is **rigidity;** in horizontal structures, the risk is **ambiguity of command** in a crisis. The antidote is to combine **clear roles** (who decides what, at which trigger) with **standardized interfaces** and explicit **escalation rights** between partners, so that **incident command operates** without friction (ISO 22301, 2019; SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008).

Finally, the **financial analysis** must reflect **avoided losses** and **recovery time,** not just **unit cost.** The comparison between integration and horizontalization should be made through **scenario simulations** and **stress tests** that estimate **protected downside** (operational Value-at-Risk), **capacity elasticity ,** and **reconfiguration costs** (CAPEX, qualification lead time, training). The optimal decision is rarely extreme; what the evidence suggests is the superiority of **hybrid portfolios,** with **selective verticalization** in critical nodes and **a horizontal network qualified** for peaks and contingencies, anchored in **contracts with crisis triggers, shared telemetry ,** and previously tested fallback **plans** (SHEFFI, 2015; IVANOV; DOLGUI, 2020).

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

4. Network architectures: modularity, redundancy and fault isolation

Network architecture determines how material, information, and capital flows move through the chain and, therefore, how the organization absorbs and redistributes shocks without functional collapse. In highly coupled chains, local disturbances tend to propagate rapidly, generating nonlinear effects that amplify the original impact. However, in **modular architectures,** with standardized interfaces and decoupling points (buffer stocks, buffer lead times, alternative routes), the shock can be isolated and rerouted, preserving minimum service levels (IVANOV; DOLGUI, 2020; CHRISTOPHER, 2016). This modularity is not merely physical; it is also logical and organizational, requiring contracts that codify priorities, contingency SLAs, and escalation rights. In terms of resilience, the literature suggests that modularity **increases system viability** — the ability to remain operational in degraded states — at the cost of some loss of efficiency in a steady state, a trade-off that needs to be calculated and governed (IVANOV; DOLGUI, 2020).

Redundancy is often treated **as** synonymous with resilience, but its effectiveness depends on the type of redundancy and the network topology. **Capacity** redundancy (parallel lines, additional shifts) provides immediate cushioning but increases fixed costs; **supplier** and **route** redundancy introduces path **diversity ,** reducing the risk of correlated failures, as long as the alternatives do not share hidden vulnerabilities (the same second-tier subcontractor, the same logistics infrastructure, or the same regulatory jurisdiction).
(SHEFFI, 2005; TANG, 2006). In many industries, "false redundancy"—two providers that in practice depend on the same upstream node—is only discovered during a crisis. Therefore, in addition to mapping **direct nodes,** it is essential to map interdependencies at **multiple levels (tier-2/tier-3)** and assess the risks of **common failure** before declaring the network effectively redundant (CHOPRA; MEINDL, 2016).

Failure isolation requires the deliberate construction of **decoupling points ,** locations where strategic inventories and lead times protect downstream segments against upstream supply variance. This concept, a classic in operations management, is gaining centrality in the resilience agenda: buffers positioned where **demand elasticity** and **disruption costs** are higher deliver superior returns than evenly distributed inventories (CHOPRA; MEINDL, 2016). In parallel, **postponement** strategies (postponing customization and differentiation until closer to the customer) reduce premature variety and keep **options open,** increasing the capacity for reconfiguration when an input becomes scarce or a route is interrupted (CHRISTOPHER, 2016). The result is a network with "brakes" engineered to control the propagation of the bullwhip effect.

The language of **network science** provides tools for diagnosing structural vulnerabilities: **betweenness centrality** identifies critical bottlenecks; **k-core** and **clustering coefficients** inform about cohesion and contagion risks; **percolation** and

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
Revista Ibero-Americana de Ciências Ambientais, v.16, n.1, p.1-10, 2025
ISSN: 2675-9128. São Paulo-SP.

Targeted robustness policies simulate the loss of nodes/edges in targeted attacks (IVANOV; DOLGUI, 2020). **Scale-free networks,** although efficient, are particularly sensitive to hub failures; **more homogeneous** networks tend to lose average efficiency but have greater tolerance to random failures. In global chains with a strong concentration in a few logistics hubs, resilience policies should explicitly reduce **the betweenness** of hypercritical nodes, creating **bypas** structural and previously qualified **rerouting** capabilities (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008).

The **standardization of technical interfaces** (packaging, palletizing, electronic labeling, integration APIs) is a discrete pillar of modularity, as it transforms substitution into **plug-and-play operation.** Without standards, each switch between suppliers/routes entails time-consuming requalifications and ad hoc adjustments that undermine the intended benefit of horizontalization (CHRISTOPHER, 2016). In regulated sectors, **cross-qualification** of materials and processes must be done **before** the crisis, under protocols comparable to those of **design for resilience,** with dossiers ready for submission and deployment (CHOPRA; MEINDL, 2016). Modularity, therefore, is not an abstract design: it is codified in documents, tests, and au

At the **geographic level,** the architecture must avoid **risk collinearities:** concentrating redundant hubs in the same climate or geopolitical corridor invalidates redundancy. Maps of **natural hazards, critical infrastructure ,** and **regulations** need to inform **location** and **allocation** decisions so that diversity is real, not merely nominal (SHEFFI, 2015). The same reasoning applies to **time windows:** redundancies that depend on identical seasonal peaks (harvests, holidays) can fail simultaneously, requiring the creation of temporal buffers (advanced inventories, capacity option contracts) that distribute risk over time (TANG, 2006).

Modular architectures benefit from **control towers** and **visibility layers** that aggregate data from S&OP/S&OE, WMS/TMS, MRP/APS, and transportation telemetry into a **unified** decision-making dashboard. Without **cross-organizational visibility,** modularity fails to deliver on its promise, because rerouting and replacement decisions are made blindly (CHRISTOPHER, 2016). Data standards and **open APIs** with security governance (LGPD and equivalents) allow horizontal partners to share relevant signals (capacity, lead times, inventory levels) without exposing competitive secrets, increasing the effectiveness of fault isolation (ISO 22301, 2019).

Finally, modularity and redundancy must be **economically sustainable.** The cost of maintaining physical and structural buffers should be incorporated into a **resilience portfolio** that considers **operational value-at-risk, time-to-survive (TTS) ,** and **time-to-recover (TTR),** choosing design combinations that **maximize the margin preserved** under shock scenarios (SIMCHI-LEVI et al., 2008; SHEFFI, 2015). In practical terms, the resilience committee should periodically review the architecture with **tabletop exercises** and **simulations** that

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

test the effectiveness of fault isolation by adjusting standards, contracts and location as the external environment evolves (IVANOV; DOLGUI, 2020).

5. Metrics and models for measuring operational resilience

Measuring resilience means moving beyond the comfort of average efficiency metrics and quantifying **avoided losses.** and **speed of recovery** after shocks. The **"resilience triangle"** framework measures the area between the target performance line and the trajectory observed during/post-disturbance: the smaller the area (drop × duration), the greater the resilience (SHEFFI, 2015; PONOMAROV; HOLCOMB, 2009). In addition, indicators such as **MTTR** (mean time to recovery), **OTIF** (on-time, in-full), **fill rate, backlog clearing time ,** and **order loss rate** provide operational granularity for continuous monitoring. Resilience, thus, ceases to be a vague attribute and becomes part of the executive dashboard, with clear goals and responsibilities (CHRISTOPHER, 2016).

Among the predictive **(KRI)** and outcome **(KPI) indicators,** some stand out. **TTS**/**TTR** — **Time-to-Survive** and **Time-to-Recover** — connect network design and decision-making stock/capacity to disruption scenarios: it is known how long a node can hold out with current stock and capacity and how long it needs to return to normal (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008). The **bullwhip coefficient** (order variance/demand variance) reveals unwanted amplification; **lead time variance** and **decision latency time** (detect-decide-act) complete the picture (CHOPRA; MEINDL, 2016). In parallel, **exposure to a common supplier** and **the betweenness centrality** of logistics hubs should be monitored as structural KRIs (IVANOV; DOLGUI, 2020).

Robust measurement requires **experiments** and **quasi-experiments. On**/**off** testing by region (planned campaign blackouts, inventory policy changes) and **geographic A**/**B** testing with equivalent time windows allow estimating **the incrementality** of resilience interventions (e.g., introducing dual sourcing, inventory repositioning) (SHEFFI, 2015). In complex contexts, **discrete-event simulation** and **agent-based models** reproduce queue dynamics, lead-time variation, and distributed decisions, allowing for the evaluation of failure percolation scenarios and buffer calibration (IVANOV; DOLGUI, 2020). The key is to replace narratives with **causal evidence,** albeit approximate.

Digital twins of critical operations expand the scope of simulations: by integrating data on demand, capacity, inventory, transportation, and policy parameters, it is possible to conduct large-scale **stress tests** and identify **dynamic bottlenecks** that cannot be identified in spreadsheets (IVANOV; DOLGUI, 2020). These models allow the quantification of **operational elasticities** —how much increasing capacity in a specific link reduces MTTR in different scenarios—and guide resilience investments toward points of **greatest economic leverage** (CHRISTOPHER, 2016). Furthermore, they facilitate the design of **contingency protocols** with realistic target times.

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Financial measurement should translate resilience into **economic value.** Approximations such as **Operational VaR** (operational value at risk) and **Expected Shortfall** in service metrics estimate the "tail" of losses under shocks; ROSI (return on investment in safety/continuity) can be adapted to investments in buffers, redundancy, and supplier qualification, comparing **CAPEX**/ **OPEX** with **avoided loss** and **risk reduction** (SHEFFI, 2015). The **cost of capital tied up** in strategic inventories and its effect on turnover are also important ; therefore, resilience decisions must be accompanied by working capital and **financing policies** that avoid strangling cash (CHOPRA; MEINDL, 2016).

Measurement quality depends on **data governance.** Without **metrics dictionaries, calculation methodologies ,** and **reconciliation cycles** (financial ÿ operations), resilience indicators become incomparable over time and across units. In horizontal networks, contracts must specify **mandatory fields, granularity ,** and **latency** of shared data, under **LGPD** standards and confidentiality rules (ISO 22301, 2019). Data discipline is part of resilience: without it, **detection time** increases and decisions are based on noisy signals (CHRISTOPHER, 2016).

Supplier risk assessment should combine **financial** (liquidity, leverage), operational (capacity, contractual vs. realized lead time), **quality** (ppm, incidents), and **geopolitical/environmental** (exposure to climate regimes and events) metrics. Multi-criteria risk maps and tier -by **-tier heatmaps** facilitate audit prioritization and development plans.
The common mistake is to evaluate only **direct suppliers,** ignoring **critical** upstream nodes that, because they have low visibility, concentrate systemic risk (IVANOV; DOLGUI, 2020; TANG, 2006). **Cross-qualification** programs and **mutual aid agreements** should emerge as a counterpart to the mapped risks.

Finally, resilience needs to be built into the **budget cycle** through **targets and triggers.** MTTR targets , **fill rate in a crisis ,** and **recovery time** in baseline scenarios should be included in **S&OP** as operational constraints, not desires. **Crisis triggers** (service level thresholds, hub disruptions, macro indicators) should activate **playbooks** with pre-authorized decisions (production scale, activation of alternative suppliers, inventory reallocation), reducing **decision latency** and avoiding improvisation. Measurement, in this sense, is not an end in itself: it is the mechanism that transforms resilience into **repeatable practice** (SHEFFI, 2015; CHOPRA; MEINDL, 2016).

6. **Integration risks and *trade-offs :*** rigidity, ***lock-in,*** **common failures, and governance**

Integration, while attractive due to its gains in coordination and control, involves structural risks that need to be carefully measured. The first is **organizational rigidity:** by internalizing links and standardizing processes, the firm reduces execution variability, but also reduces its **ability to improvise** when the environment changes rapidly. In scenarios of technological disruption or unforeseen demand, the verticalized architecture may **take time to pivot,** as

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Investment reversals, line requalification, and internal route changes imply greater **sunk costs** and **decision-making inertia** than in modular arrangements (Williamson, 1985; Christopher, 2016). This rigidity becomes critical when information asymmetries about the future are high, which recommends caution against **over-integration** in domains of high uncertainty.

The second risk is **technological and contractual lock-in,** typical of sectors with strong **asset specificity.** By opting for a vertical design with proprietary technologies, the firm captures short-term coordination quasi-rents but **loses the option** to adopt emerging standards and **interoperate** with alternative partners. The literature on dynamic capabilities reminds us that time advantage depends on the ability to **reconfigure** resources and routines; rigid integrations reduce the **room for maneuver** for recombination, especially when intellectual property clauses and **dependency chains** make migration costly (Teece, 1986). In terms of resilience, lock-in impairs the response to **substitutability** shocks (scarce inputs, sanctioned suppliers), increasing **recovery time.**

The third risk is **risk concentration** and the inadvertent formation of **single points of failure.**
Verticalization eliminates external dependencies, but if there is no **internal geographic and technological redundancy ,** the result is only **to transfer** the risk within the firm, now **correlated**
in units that share ERP, energy suppliers, jurisdiction, and even organizational culture. Low-probability, high-impact events—fires, floods, cyberattacks—can disrupt multiple internal links simultaneously, compromising the assumed robustness of the design (Sheffi, 2005). Mitigation requires **intra-firm diversification** (different sites, alternative technologies), which reduces part of the economic gain estimated in the initial integration.

The fourth risk concerns **governance and *compliance.*** The larger the integrated scope, the greater the responsibility for **regulatory compliance** (quality, safety, labor, environmental, data protection). In horizontal arrangements, part of this burden is distributed; in vertical arrangements, **the liability for legal risk** is concentrated. Furthermore, failures in **segregation of duties** and conflicts of interest can emerge when links that previously audited each other become **sister units,** requiring **compensatory controls** and independent audits to maintain process integrity (ISO 22301, 2019). In terms of reputational resilience, integrated incidents tend to resonate more strongly in the market, as they are attributed to the "in-house."

The fifth risk is **economic and financial.** Vertical integration increases **CAPEX** and **fixed costs,** altering operating leverage and the **break-even point** 's sensitivity to volume fluctuations. In recessionary cycles, high fixed structures compress margins; in expansionary cycles, they capture value—a **risk profile** that must be compatible with the board's appetite.
Horizontally, in turn, although CAPEX is distributed, **coordination costs** and **contractual premises** grow , which may not materialize in a crisis (Sheffi, 2015; Chopra; Meindl,

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
Revista Ibero-Americana Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

2016). Resilience decisions therefore require **tail modeling** (losses in adverse scenarios) and not just historical averages.

The sixth risk is **cultural and human.** Integration movements transform professional identities and power relations, potentially generating **resistance,** talent loss, and **the silencing of weak** risk signals. In horizontal networks, the risk is **ambiguity of command** during a crisis; in vertical structures, the risk is **excessive centralization,** which slows down field decisions. The operations and resilience literature emphasizes that **tactical decentralization** with **clear escalation rules** improves response, while total centralization imposes **latency** (Christopher, 2016). The organizational solution involves **decision-making rituals** (S&OP/S&OE) and **scenario-based training.**
and **AARs** that fuel continuous improvement.

The seventh risk relates to **antitrust and market power.** Extensive horizontal and vertical integrations can attract **regulatory scrutiny,** especially when they significantly alter **the prices of essential inputs** or **access to channels.** Regulatory uncertainty creates **enforcement risk.**
and can limit agility at critical moments. At the same time, there is opportunity: **regulatory remedies** can require **interoperability,** effectively fostering systemic resilience by imposing open standards that facilitate substitution between nodes (Porter, 1985; Tang, 2006). The strategy must balance **private efficiency** with **ecosystem stability.**

The eighth risk is **technical-operational: accelerated obsolescence** and **degradation of productivity** when the firm integrates links in technologies that are losing traction. The cost of "converting" internal lines can exceed that of negotiating with updated partners. Therefore, in domains with **short technology cycles,** the pragmatic recommendation is **selective vertical integration** only in **bottlenecks.** whose availability is critical and **interoperable** horizontalization in the rest, with **real options** migration (Teece, 1986; Christopher, 2016). In short, optimal resilience is not maximum integration, but the **portfolio** that best **protects the tail, preserves optionality ,** and **maintains financial strength.**

7. Sectoral evidence and comparative case studies

In the **automotive sector,** the last few decades have highlighted the pendulum swing between **horizontal modularization** (tier-one suppliers responsible for complete systems) and movements to **reinternalize** critical components (power electronics, batteries, semiconductors). The pandemic and the chip crisis revealed **the weaknesses of *single-sourcing*** and the dependence on a few *foundries;* automakers responded with direct upstream **contracts** and **capacity reserves.**
and, in some cases, **equity stakes** in strategic suppliers, a hybrid that combines **vertical control** over bottlenecks with **horizontal ecosystems** for the remainder. The metric of success was not average cost, but rather **recovery time** and **a preserved mix** on higher-margin platforms (Sheffi, 2015; Ivanov; Dolgui, 2020).

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

In the **pharmaceutical and medical device industry,** strict regulations and **material qualification** favor **vertical integration** of sensitive steps (active ingredients, aseptic filling, sterilization), while **cold logistics** and distribution tend toward **certified horizontal arrangements.** During health shocks, organizations with prior **cross-qualification** of **CMOs** and **CDMOs** were able to **reroute production** more quickly, at the cost of greater prior regulatory burden. Industry learning indicates that **regulatory postponement**
(multi-site ready dossiers) and interoperable **packaging standards** increase resilience without sacrificing compliance (ISO 22301, 2019; Christopher, 2016).

In **food and beverages,** cold and seasonal chains require **geographic redundancy** and **temporal buffers.** Vertically integrated producers in the origination of agricultural inputs can **prioritize volume** during adverse harvests, but face **concentrated climate risk;** horizontal **co-packing** and **flexible co-packing** networks have reduced disruptions during peak demand, provided that **specifications are** and **labeling** were standardized. The decisive metric was **OTIF in the promotion window** and **avoided loss** due to expiration, reinforcing that resilience depends on **combining** vertical control over **quality** with **horizontal elasticity** in transformation and distribution (Chopra; Meindl, 2016; Tang, 2006).

In ***omnichannel* retail** and **e-commerce,** operational resilience resulted from **modular architectures: dark stores, microfulfillment ,** and **last-mile partnerships** that allowed **order rerouting** between nodes close to the consumer. Vertically integrating the entire last mile proved costly and rigid in environments with highly volatile demand; *marketplaces* and **3PLs/4PLs** skilled workers provided **elastic capacity,** while **near-customer** inventories reduced **TTS** and **TTR.** Success stories shared **control towers** with **real-time visibility** and **SLA** -oriented **backlog clearing** in peak events (Christopher, 2016; Sheffi, 2015).

In the **energy and oil and gas sector,** vertical integration is historically significant and makes sense where **safety, integrity, and capital-intensive** operations dominate. Even so, incidents have shown that **intra-firm redundancy** and **interoperability** between operators are vital: **mutual aid** in emergencies, **strategic stocks** of critical equipment (BOPs, valves), and ***swap* contracts** for maritime logistics have mitigated disruptions. Resilience here derives from **scenario planning, incident command ,** and **joint training,** with **MTTR** and **recovered production** metrics exceeding the baseline (ISO 22301, 2019).

In **semiconductors and electronics, geographic hyperspecialization** increased efficiency but created **systemic vulnerability.** *Fabless* firms began negotiating **dedicated capacity** and upstream **co-investments ,** a movement toward **contractual verticalization** without full internalization. At the same time, **more replaceable designs** (BOMs with **qualified alternative components)** and **reengineering** for multiple assembly nodes shaped a horizontal response. Organizations that mapped **deep tiers** and implemented **digital twins** of the supply chains recovered faster from *black swans* (Ivanov; Dolgui, 2020).

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

In the **public health sector, horizontal partnerships** between hospitals, distributors, and governments enabled **purchasing pools** and **dynamic allocation** of scarce supplies, while **vertical production** of strategic items by official laboratories ensured **a vital minimum** in crises. Network governance—rules of **ethical prioritization, data transparency ,** and **logistical interoperability** —was more decisive than average pre-crisis efficiency. The lesson learned: **resilience is a property of the network,** not just the firm, and depends on **trust** and **protocols** established prior to the emergency (Christopher, 2016; Sheffi, 2015).

Finally, **IT-intensive services** have shown that **cyber resilience** and **physical resilience** are inseparable. Companies that are vertically integrated with their own infrastructure suffered from **single points of failure,** while those that adopted **multi-cloud architecture** with ***failover*** and **observability** preserved **SLA.** The cross-cutting *case* is clear: **open standards, geographic redundancy, tested playbooks ,** and **integrated telemetry** constitute the core of resilience, regardless of how vertical or horizontal the design is (ISO 22301, 2019; Christopher, 2016).

8. Resilience Implementation and Governance *Roadmap*

The starting point is a **risk materiality diagnosis** that combines **financial** (potential losses, operational leverage) and **operational** (TTS/TTR, bottlenecks, lead time variance) vision. This diagnosis should map **critical assets, dependencies between nodes, deep tiers ,** and **common infrastructures** (energy, IT, transportation), producing a **risk portfolio** with owners, appetite limits, and reference scenarios. From there, the organization identifies **where vertical integration adds relevant control** (bottlenecks, regulatory quality, capacity prioritization) and **where interoperable horizontalization preserves optionality** at lower costs (Christopher, 2016; Sheffi, 2015).

The second stage is **portfolio design: selective verticalization** in areas of **high specificity** and **high systemic impact,** and **qualified horizontal arrangements** (dual/triple sourcing, consortia, cross-licensing) in the remainder. This design requires **technical standards** (packaging, labeling, EDI/API, cross-qualification) that materialize **modularity.** The goal is to create **structural buffers** (node substitutability) and **physical buffers.**
(strategically positioned stocks) in the correct proportion to the risk profile (Chopra; Meindl, 2016; Tang, 2006).

The third step is **contractual.** Contracts with **contingency SLAs, crisis triggers ,** and **escalation rights** should be codified, including timely **data access** for interorganizational **control towers .** For critical suppliers, consider **real options.**
(the right to purchase additional capacity), **capacity reservations ,** and ***gain-sharing mechanisms*** that align incentives in the event of conflicts. At the same time, **define**

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

interoperability and **minimum standards** that enable **plug-and-play replacement** (Christopher, 2016).

The fourth step involves **data capacity and visibility.** Implement **resilience dashboards .** that consolidate **KPIs and KRIs** (OTIF, fill rate, MTTR, backlog clearing, network centralities, exposure to a common supplier) and feed **S&OP and S&OE processes. Secure APIs** and **data governance** (dictionary, latency, quality) with horizontal partners reduce **information asymmetry,** accelerating **detection** and **action.** Without reliable data, rerouting and replacement decisions become reactive and costly (ISO 22301, 2019; Christopher, 2016).

The fifth stage is **enabling: scenario-based training, tabletop exercises ,** and **simulations** (discrete events, agents) to validate playbooks and **calibrate buffers.** Adoption of **digital twins** to **stress-test** tails and estimate **operational elasticities** (how much MTTR drops when adding X% capacity at Y elo). These tests should result in **lessons learned.** incorporated into **SOPs** and **living checklists,** with periodic **AARs** (Ivanov; Dolgui, 2020).

The sixth stage addresses **financing and value metrics.** Resilience projects require **business cases** with **ROSI** (return on investment in safety/continuity) and **Operational VaR** to prioritize allocations. Integrating **strategic inventory** and **redundancy** decisions into **working capital planning** avoids cash bottlenecks. With **TTS/TTR targets** and **loss limits** per scenario, the organization transforms resilience into a **project constraint,** not a proactive initiative (Sheffi, 2015).

The seventh step is **governance.** Establish a cross-functional **resilience committee** (operations, finance, procurement, IT, legal, and risk) with **formal meetings:** monthly for *run-the-business* and quarterly for *change-the-business.* This committee reviews **indicators, incidents, mitigation plans,** vertical/horizontal **portfolio calibration ,** and **adherence to standards.** Internal and external audits validate **segregation of duties, compliance ,** and **evidence of implementation** (ISO 22301,

The eighth stage is **a continuous improvement cycle.** Changes in the environment— **geopolitics, climate, regulation, technology** —require dynamic reviews of the integration portfolio. The *roadmap* should include **annual reassessment windows,** with reviews of **risk maps, tiers, alternative capabilities ,** and **financial assumptions.** The goal is to maintain the system's **dynamic viability :** the ability to **absorb, adapt ,** and **evolve** without sacrificing **margin** and **service** (Ivanov; Dolgui, 2020; Christopher, 2016).

Conclusion

The analysis conducted throughout this article allows us to affirm that **vertical integration** and **horizontal integration** are not antagonistic poles, but rather organizational design instruments that, when prudently combined, increase the **operational resilience** of supply chains subject to volatility, disruptions, and regime changes. Vertical integration, when applied surgically , to links of high specificity and systemic risk, shifts contractual uncertainty to the domain of

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

hierarchical authority, shortening decision-making latencies and enabling **capacity prioritization** at critical moments; horizontalization, when based on **interoperability** and **open standards,** creates **structural buffers** through the substitutability of nodes and routes, reduces the centrality of bottlenecks, and accelerates flow recomposition. The synthesis that emerges is a **hybrid portfolio,** adjusted by sector and risk profile, in which the question is not "integrate or modularize?", but **"whe** integrate to control what cannot fail, and **how** to modularize to preserve optionality and absorb shocks without collapse?" In theoretical terms, this position reconciles **transaction cost economics** and **a resource-based view** with network engineering and business continuity literature (Coase, 1937; Williamson, 1985; Teece, 1986; Christopher, 2016; ISO 22301, 2019).

From an **economic point of view,** the optimal decision requires comparing **coordination quasi-rents** expected with the **value of optionality** embedded in less integrated arrangements, recognizing that average metrics in a steady state **underestimate** the tail cost in shocks. Verticalization increases **CAPEX** and operating leverage, which increases the sensitivity of the breakeven point to volume fluctuations; horizontalization reduces own CAPEX and expands **real options,** but adds **coordination costs** and the risk of **alignment failures** under stress. The efficient frontier shifts with technology (declining data integration and monitoring costs), but **contractual hazards** and **hidden dependencies** persist and reemerge in crises, as observed in semiconductors and global logistics. Therefore, the calculation should be made with **stress tests** and **scenario analysis** that internalize **avoided losses, recovery time ,** and **operational elasticities,** rather than relying solely on historical unit costs (Chopra; Meindl, 2016; Sheffi, 2015; Ivanov; Dolgui, 2020).

At the architectural level , resilience is practiced as **modularity with standards** and **intelligent redundancy.** Standardized technical interfaces (packaging, electronic labeling, integration APIs) transform replacement into **plug-and-play operation,** reducing requalification times and the need for renegotiation **during** a crisis. Redundancy must be **heterogeneous** to avoid common failures —multiple qualified suppliers that do not share the same upstream tier or critical infrastructure— and **geographically diverse.**
to avoid accumulating climate or regulatory risk. Decoupling and **postponement points**
They increase maneuvering space, allowing differentiation to be postponed until uncertainty is resolved, while **buffer stocks** and **alternative routes** are dimensioned based on **TTS/TTR** and **service level** impact . Good architecture does not pursue infinite redundancy, but **rather sufficient redundancy** to reduce the area of the "resilience triangle" without derailing the business (Christopher, 2016; Simchi-Levi; Kaminsky; Simchi-Levi, 2008; Tang, 2006).

In **governance and decision-making,** vertical integration offers **clarity of command** and **uniformity of standards,** but runs the risk of **rigidity.** Horizontal integration, in turn, distributes power and knowledge, but can suffer from **ambiguity of authority** in incidents. A robust arrangement explicitly establishes **escalation rules, incident command roles ,** and **crisis triggers** that authorize capacity reallocations, activation of alternative suppliers, and policy changes.

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

inventory without deliberative paralysis. **S&OP/S&OE** must internalize resilience constraints (MTTR **targets, fill rate in a crisis, backlog clearing)** and operate at **rhythms** that compress the **detect-decide-act cycle.** In horizontal networks, **service level agreements** and **cross-audits** replace hierarchical discipline, sustaining execution under pressure (ISO 22301, 2019; Christopher, 2016; Sheffi, 2015).

At the **heart of metrics,** the transition from rhetoric to practice occurs when the organization measures **avoided losses** and **recovery speed,** not just average efficiency. The combined use of **MTTR, OTIF, fill rate, TTS/TTR, whip ratio ,** and **network centralities** provides operational and structural signals for calibrating portfolios and investments. **Quasi-experiments** and **simulations** —regional on/off, geographic A/B, discrete events, and **digital** twins— allow causal estimation of the effects of **dual/triple sourcing,** inventory repositioning, and route changes. **Operational VaR** and **ROSI** translate resilience into economic value, helping the board prioritize projects by expected **avoided loss** per unit of capital—a more honest criterion than "cost per piece" alone (Ponomarov; Holcomb, 2009; Sheffi, 2015; Ivanov; Dolgui, 2020).

In the **human and cultural** vector , resilience is a collective attribute produced by **training, discipline, and learning.** Verticalized organizations need to balance procedural efficiency with **tactical decentralization** to avoid adding latency in field situations; horizontal networks, in turn, must mitigate **gray areas** with previously agreed-upon leadership and **communication protocols . Tabletop exercises, simulations ,** and **After Action Reviews** transform near-misses into **codified knowledge,** feeding back into **SOPs** and living checklists. **Coherent** recognition and incentive programs prevent the erosion of standards under pressure from short-term goals, maintaining **safety, compliance, and continuity** as non-negotiable priorities (ISO 22301, 2019; Christopher, 2016).

Technology and data expand, but do not replace, design choices. **Control towers** Interorganizational networks, end-to-end **observability ,** and **secure APIs** reduce information asymmetry and anticipate deviations; **digital twins** bring planning closer to reality and help identify **leverage points** for investment. However, the literature warns against **technolatry:** sensors and dashboards without **associated procedures, decision-making rights ,** and defined **responsibilities** create a false sense of control. Real gains emerge when data is **standardized, timely ,** and **actionable,** and when decisions triggered by this data are **pre-authorized,** preserving the reaction time needed to protect service and margin (Christopher, 2016; Ivanov; Dolgui, 2020).

In the **regulatory and ethical domain,** integration alters the distribution of **responsibility** and **market power,** requiring attention to **antitrust, quality, labor, the environment ,** and **data protection.** Vertical integration concentrates **regulatory liabilities** and demands **compensatory controls** and independent audits; horizontal integration requires **collective compliance,** which implies minimum standards and **enforcement mechanisms** among partners. In both cases, **legitimacy**

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

The social stability of supply chains—especially in sensitive sectors such as healthcare and food—depends on transparency regarding **crisis prioritization, scarcity allocation ,** and **privacy,** under frameworks such as **ISO 22301** and data protection legislation. Resilience, in this sense, is not just efficiency under shock, but **expanded responsibility** (ISO 22301, 2019; Tang, 2006).

As a **sectoral implication,** the article suggests **contingent revenues:** in **long and regulated cycles** (pharmaceuticals, aerospace, energy), **selective verticalization** of critical stages combined with **qualified horizontalization** in logistics and secondary transformation tends to dominate. In **short cycles and high obsolescence** (electronics, fashion), **standardized modularity, dual sourcing ,** and **design for substitutability** offer greater protection. In **retail and e-commerce, near-customer inventories, microfulfillment ,** and **last-mile partnerships** provide the necessary elasticity. In all sectors, decisions must respect **real geodiversification** (avoiding collinear redundancies), **mapped tiers ,** and **contracts with triggers,** so that the option to change routes or suppliers is not merely a rhetorical clause. The desired result is **a reduction in the resilience triangle** through choices consistent with risk appetite and capital structure (Sheffi, 2015; Christopher, 2016).

In **normative summary,** we propose that organizations formulate an **Operational Resilience Regime** (ROR) composed of five pillars: **(i)** hybrid portfolio of selective vertical and horizontal interoperable integration; (ii) modular architecture with standards and decoupling points sized by **TTS/TTR; (iii)** incident command governance with predefined roles, triggers, and decision rights; **(iv)** economic and operational metrics integrated with **S&OP/S&OE** and the budget cycle, with **ROSI** and **Operational VaR; (v)** data discipline, technology, and culture oriented toward **rapid detection, reliable execution ,** and **continuous learning.** Such a regime makes resilience a **system property,** not an occasional attribute of heroes, and aligns organizational design decisions with the literatures on **TCE, RBV, network engineering ,** and **business continuity** (Williamson, 1985; Teece, 1986; Ivanov; Dolgui, 2020; ISO 22301, 2019).

Finally, in terms of the **research and practice agenda,** three fronts stand out: **(a)** standardized methods for valuing **real** horizontalization options versus quasi-rents from verticalization coordination, using field data; (b) integrating **percolation models** and **digital twins** into S&OP routines , closing the loop between simulation and decision-making; **(c) systemic impact** metrics that transcend the firm and quantify **ecosystem resilience,** including distributive and reputational effects. The contribution of this work is to offer an **integrative, pragmatic, and theoretically informed framework** for boards and executive teams to replace binaries with **contingent designs,** supported by metrics and governance. By translating integration choices into **preserved value, recovery time ,** and **the ability to evolve** after the crisis, resilience ceases to be rhetorical and becomes a **repeatable competitive advantage** (Sheffi, 2015; Christopher, 2016; Ivanov; Dolgui, 2020).

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

References (up to 2021)

CHANDLER, AD *The Visible Hand: The Managerial Revolution in American Business.* Cambridge, MA: Harvard University Press, 1977.

CHOPRA, S.; MEINDL, P. *Supply Chain Management: Strategy, Planning, and Operation.* 6. ed. Boston: Pearson, 2016.

CHRISTOPHER, M. *Logistics & Supply Chain Management.* 5. ed. Harlow: Pearson, 2016.

COASE, RH The Nature of the Firm. *Economica,* vol. 4, no. 16, p. 386–405, 1937.

HOLLNAGEL, E.; WOODS, D.D.; LEVESON, N. *Resilience Engineering: Concepts and Precepts.* Aldershot: Ashgate, 2006.

ISO. *ISO 22301:2019 — Security and resilience — Business continuity management systems — Requirements.* Geneva: International Organization for Standardization, 2019.

ISO. *ISO 28000:2007 — Specification for security management systems for the supply chain.* Geneva: International Organization for Standardization, 2007.

IVANOV, D.; DOLGUI, A. Viability of intertwined supply networks: extending the supply chain resilience angles. *International Journal of Production Research,* vol. 58, n. 10, p. 2904–2915, 2020.

PONOMAROV, SY; HOLCOMB, MC Understanding the concept of supply chain resilience. *The International Journal of Logistics Management,* vol. 20, no. 1, p. 124–143, 2009.

PORTER, ME *Competitive Advantage: Creating and Sustaining Superior Performance.* New York: Free Press, 1985.

RITCHIE, B.; ZSIDISIN, GA (org.). *Supply Chain Risk: A Handbook of Assessment, Management, and Performance.* New York: Springer, 2009.

SHEFFI, Y. *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage.* Cambridge, MA: MIT Press, 2005.

SHEFFI, Y. *The Power of Resilience: How the Best Companies Manage the Unexpected.* Cambridge, MA: MIT Press, 2015.

SIMCHI-LEVI, D.; KAMINSKY, P.; SIMCHI-LEVI, E. *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies.* 3rd ed. Boston: McGraw-Hill/Irwin, 2008.

TANG, CS Perspectives in supply chain risk management. *International Journal of Production Economics,* vol. 103, p. 451–488, 2006.

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

TEECE, DJ Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy,* vol. 15, no. 6, p. 285–305, 1986.

WILLIAMSON, OE *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting.* New York: Free Press, 1985.

ZHANG, D.; SIMCHI-LEVI, D. Quantifying the bullwhip effect in a multiple-echelon supply chain. *Operations Research,* vol. 58, n. 2, p. 454–470, 2010.

This is an open access article distributed under the terms of the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.