Peacetime Models, Wartime Realities: Extending Operations Management Frameworks for Geopolitically Entangled Supply Chains

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Abstract

Operations management has built powerful frameworks for supply chain design, planning, and response to disruption, frameworks that are largely correct within their domain of validity. That domain is peacetime. Existing models assume that disruptions are exogenous to strategic human choice, statistically characterizable, and transient in the sense that the underlying institutional structures survive the shock. The world has changed. Geopolitically entangled supply chains face a qualitatively different class of disruption: strategic rather than accidental, structurally uncertain rather than probabilistically characterizable, potentially permanent rather than transient, and endogenous to the concentration decisions that make supply chain nodes attractive targets. Using frameworks calibrated for peacetime conditions during geopolitically entangled ones is not merely an analytical mismatch; it is a systematic regime mis-classification for which existing model classes are structurally incomplete. This paper proposes a formal distinction between supply chain regimes in peacetime and wartime, argues that the transition between them requires qualitatively different modeling frameworks, and extends the POEM agenda (Tayur, 2025) to incorporate this distinction. The April 2026 disruption of PPE resin supply following an Iranian strike on Saudi Arabia's Jubail petrochemical complex is developed as the primary structured illustration, alongside three further cases — neon gas (Ukraine, 2022), helium (Qatar, 2026) and rare earth elements (China, ongoing) — forming a typology of wartime supply chain disruption mechanisms. A research agenda is proposed.

Keywords: supply chain resilience; geopolitical disruption; political economy; wartime supply chains; regime change

1. Introduction

> *"Not only the wealth; but the independence and security of a Country, appear to be materially connected with the prosperity of manufactures. Every nation, with a view to those great objects, ought to endeavour to possess within itself all the essentials of national supply."*
>
> — Alexander Hamilton, *Report on Manufactures* (1791)

Hamilton wrote in and for a world in which the aspiration to 'possess within itself all the essentials of national supply' was conceptually coherent. In a deeply interdependent global economy, complete national self-sufficiency - is neither realistic nor desirable; what matters is which states have access to or influence over the critical nodes and corridors on which others depend.

On 7 April 2026, Iranian missiles struck Saudi Arabia's Jubail petrochemical complex. Eleven missiles were fired; eleven were intercepted by Saudi air defense systems. The interception succeeded. The falling debris also ignited the complex. Among the casualties was production at SABIC's Jubail facility, which is the source of approximately 70% of the world's high-purity polyphenylene ether (PPE) resin, the critical material for high-frequency printed circuit board (PCB) laminates used in 5G infrastructure, AI data centers, smartphones, and networking equipment. Within weeks, Goldman Sachs analysts reported a 40% jump in PCB prices. The lead times for the epoxy resin stretched from three weeks to fifteen. Apple, Samsung, Cisco, and all manufacturers dependent on high-frequency electronics found themselves absorbing a shock for which their supply chain models had no architecture.

This paper argues that the absence of that architecture is not accidental, not a modeling oversight to be corrected by adding a disruption parameter or a fat-tailed distribution. It calls for an extension of existing frameworks along politically salient dimensions that existing models were not designed to incorporate. Supply chain models have been built for a specific world, one in which political institutions are stable background conditions, geopolitical events are exogenous shocks, and the relevant actors are firms, customers, and regulators operating within a legible rule structure. That world, to the extent it ever fully obtained, no longer does. We are operating peacetime models under wartime conditions. The mismatch is not a small-sample issue. It is a regime classification error, and such errors compound over time rather than averaging out.

The limitation of existing resilience models is not that they ignore disruption, but that they typically treat disruption as exogenous to the firm's supply chain design. In the wartime regime, concentration is not merely a vulnerability; it is part of what makes the node strategically attractive to disrupt. This endogeneity, the disruption risk as a function of supply chain architecture, is the mathematical heart of the argument, and it is absent from all existing peacetime model classes.

An important qualification is necessary at the outset. Operations management has not ignored disruption risk. A substantial and growing literature — developed by colleagues and friends including Sheffi (2005), Tang (2006), Simchi-Levi et al. (2015), Van Wassenhove (2006), and Lee (2004), among others, and surveyed recently in the context of the current crisis by Murray (2026) — has developed sophisticated frameworks for supply chain resilience: robust design, redundancy, supplier diversification, digital visibility tools, stress-testing constructs such as "time-to-recover" and "time-to-survive." These contributions are genuine and significant. The grammar of peacetime operations management is not purely efficiency — it is efficiency foregrounded, with risk and resilience as increasingly prominent counterweights, and sustainability emerging as a third dimension (Tayur, 2025).

The critical distinction is the nature of the disruptions this literature models. Peacetime disruptions — hurricanes, earthquakes, pandemics, port closures — are exogenous to strategic human choice, statistically characterizable in principle, transient in the sense that the underlying institutional structure survives the shock, and non-endogenous to supply chain design. The resilience frameworks developed for these disruptions are well-suited to them. The helium shortage that opens the Murray (2026) survey — disrupted by the Iran war's closure of the Strait of Hormuz — is a wartime disruption: strategic, structurally uncertain, potentially permanent, and endogenous to the concentration decisions that made Ras Laffan the world's dominant helium source. Time-to-recover is not the relevant construct when the question is not when production resumes but whether the geopolitical conditions enabling that production will reconstitute at all.

The distinction between peacetime and wartime supply chain regimes is not metaphorical.[1] In peacetime, the relevant actors are firms, customers, and regulators. Optimization within constraints is the appropriate intellectual technology. In wartime — or in what we might more precisely call the era of geopolitical entanglement — the relevant actors include states, sovereign wealth funds, military commands, sanctions regimes, and the domestic political coalitions that animate all of

[1] Ben Horowitz (2014) applies the wartime/peacetime distinction to firm-level competitive dynamics — a company "fending off an imminent existential threat." The metaphor is illuminating but operates entirely within a stable geopolitical environment: even Horowitz's "wartime" CEO assumes the supply of critical materials is not itself weaponized. The distinction we draw is literal, not metaphorical.

them. The rules are not known. The game is not bounded. The constraints themselves are contested. Optimization within constraints, in this environment, can under-weight the politically generated mechanisms that actually determine outcomes in the wartime regime.

This paper makes four contributions. First, we propose a formal conceptual distinction between peacetime and wartime supply chain regimes, characterized along four dimensions: the set of relevant actors, the stability of institutional constraints, the weaponizability of supply chain flows, and the nature of uncertainty (stochastic versus structural). Second, we develop a typology of wartime supply chain disruption mechanisms, illustrated through four recent cases. Third, we extend the POEM framework (Tayur, 2025) to incorporate the wartime/peacetime distinction as a regime-switching structure. Fourth, we propose a research agenda for wartime supply chain modeling.

This paper is a conceptual framework and research agenda in the tradition of Dai and Tayur (2015), not an empirical study or a technical model paper. It extends the evolutionary trajectory of POM research — from efficiency to resilience to sustainability, as documented by Dai and Tayur (2015) — into a fourth regime defined by geopolitical entanglement. Its contribution is to establish the wartime/peacetime distinction as a structurally significant regime boundary for OM modeling, to develop a typology of wartime disruption mechanisms with corresponding design principles, and to propose constructs and directions that subsequent formal work can instantiate. Formal models are left to subsequent work; Section 6 outlines specific directions with sufficient precision to guide that program.

The paper proceeds as follows. Section 2 characterizes peacetime supply chain models, their achievements, and their embedded assumptions, including the resilience literature and its boundary with wartime modeling. Section 3 proposes the formal wartime/peacetime distinction. Section 4 develops the typology of wartime disruption mechanisms and their design implications. Section 5 extends POEM toward wartime supply chain models and proposes three operationalizable constructs. Section 6 sets the research agenda. Section 7 concludes.

2. Peacetime Supply Chain Models: Achievements and Assumptions

2.1 The Three-Layer Grammar

The achievements of peacetime supply chain modeling are genuine and substantial. Dai and Tayur (2015) identify eight canonical practical problems in operations management (PPOMs) spanning production and inventory control, employment planning, kanban systems, network design, inventory placement, service-level management, product design, and lead-time quotation. Over the past four decades, these problems and their solutions have been organized around three progressively layered grammars.

The first and foundational grammar is *efficiency*: cost minimization, inventory optimization, network design, lead time quoting. These are the core tools of operations management, developed from the 1960s onward and deployed at industrial scale through the lean manufacturing movement and the globalization of supply chains in the 1990s and 2000s. The industrial history of these models is not merely academic. SmartOps Corporation, founded by the author and acquired by SAP in 2013, built enterprise supply chain optimization systems deployed at companies including Cisco, Jabil, and Celestica — firms now directly in the path of the 2026 supply disruptions documented in this paper. The author's first substantive multi-year industrial research engagement, conducted with MBA and PhD students from 1994 to 1996, was at a GE Electromaterials laminate plant in Coshocton, Ohio — a plant producing the FR-4 copper-clad fiberglass laminates that are the direct predecessors of the high-frequency PCB laminates now in critical shortage. That work, published in *Interfaces* (Tayur, 2000) and generating theoretical contributions in *Operations Research* and *Management Science*, exemplifies what peacetime efficiency models do well: optimizing scheduling, improving lead time quoting, and stabilizing operations within a given institutional environment. In the taxonomy of Dai and Tayur (2015), that engagement addressed PPOM-3 (management of kanban-controlled systems) and PPOM-8 (lead-time quotation) — two of the eight practical problems in operations management that define the field's canonical problem set. A recent engagement with Sanmina, one of the world's largest PCB manufacturers, posed a wartime variant of PPOM-8: how to price lead-time windows when the inputs required to honor those windows depend not on production scheduling but on the geopolitical availability of critical materials. The present paper argues that this wartime variant of PPOM-8 — and its analogues across the PPOM taxonomy — constitutes a new frontier: a ninth PPOM class requiring frameworks that existing models, calibrated for peacetime conditions, are not designed to provide.

The second grammar is *risk and resilience*, added with increasing sophistication after 2000 and accelerating after the 2011 Tohoku earthquake and COVID-19. Sheffi (2005) established supply chain resilience as a strategic imperative. Tang (2006) developed robust supply chain strategies under uncertainty. Simchi-Levi et al. (2015) introduced operational measures of resilience including time-to-recover and time-to-survive. Van Wassenhove (2006) documented how companies systematically revert to pre-disruption behaviors after shocks subside — a behavioral failure as important as any modeling gap. This literature correctly diagnoses that the era of pure efficiency optimization is giving way to one in which resilience is a competitive imperative. As Murray (2026) observes in a recent survey: "The era of supply chains designed primarily for efficiency may not be fully over. But for many companies, research shows that visibility, resilience and adaptability are becoming just as important as cost and speed."

The third grammar is *sustainability*: emissions, ESG criteria, circular economy, extended producer responsibility. This dimension is addressed by the POEM framework (Tayur, 2025) and is not the primary focus of this paper, though its interaction with geopolitical entanglement — particularly the ideological oscillation in sustainability policy documented by Tayur (2025) — is itself a source of supply chain uncertainty that wartime analysis must incorporate.

2.2 The Embedded Assumptions and Their Limits

These three grammars share a set of embedded assumptions that have rarely needed to be stated explicitly. First, *institutional stability*: the legal, regulatory, and contractual framework within which supply chains operate is a stable background condition, not a variable to be modeled. Second, *political exogeneity*: geopolitical events are exogenous shocks to an otherwise stable system, not endogenous features of the supply chain environment. Third, *actor boundedness*: the relevant decision-makers are firms and their immediate counterparties; states appear, if at all, as regulators setting constraints rather than as strategic actors pursuing independent geopolitical objectives. Fourth, *stochastic uncertainty*: the uncertainty that models must address is probabilistic — demand distributions, lead time variability, yield randomness — rather than structural, arising from the contested nature of the rules themselves.

These assumptions were not unreasonable during the period in which the models were built. The post-Cold War era — roughly 1989 to 2016 — was characterized by expanding multilateral trade institutions, relative geopolitical stability among major powers, and sustained economic integration.

Supply chains lengthened and concentrated precisely because the peacetime assumptions held well enough to make efficiency the dominant criterion. Comparative advantage was honored. The GE Electromaterials plant in Coshocton closed in 2004 — SABIC purchased the property from GE and shut down manufacturing, demolishing the buildings — because Asian producers made laminates more cheaply, and the peacetime model said: let them. The US share of world PCB manufacturing capacity fell from 30% in 2000 to roughly 4% by 2026. America retained the knowing. It surrendered the doing.

2.3 The Boundary: What Peacetime Resilience Cannot Address

The practical and academic conversation is already moving in the right direction. Murray (2026) documents how researchers including Baldwin (2016), Javorcik et al. (2024), Simchi-Levi et al. (2015), Lee (2024), Van Wassenhove (2006), and Durach (2024) are examining the shift from efficiency-optimized to resilience-oriented supply chains. The constructs being developed — time-to-recover, time-to-survive, supply chain stress tests, digital visibility tools, nearshoring frameworks — represent genuine advances within the peacetime grammar.

What this conversation has not yet reached is the conceptual distinction proposed here. To be precise: the limitation is not that resilience models ignore disruption risk. They do not. The limitation is that they treat disruption as exogenous to the firm's supply chain design — a property of the environment that the firm can respond to but cannot influence through its own design choices. In the wartime regime this assumption fails: a firm's decision to concentrate sourcing in a single sovereign-owned facility does not merely expose it to geopolitical risk, it helps constitute that risk by creating an attractive target. This endogeneity is what existing resilience model classes, however sophisticated, are structurally incomplete for capturing within their current mathematical formulations. The disruptions motivating the resilience turn are, in our typology, peacetime disruptions: they are *non-strategic* (nature does not have geopolitical objectives), *statistically characterizable* in principle even if estimation is difficult, *transient* in the sense that the underlying institutional structure of the supply chain environment survives the disruption, and *non-endogenous*, meaning the disruption probability is not itself a function of the supply chain design. Robust optimization, resilience design, and digital visibility address these properties well.

COVID-19 sits instructively at the boundary. It was natural, not strategic — but it exposed concentration vulnerabilities that were structural, not accidental, and revealed that peacetime resilience frameworks had systematically underweighted the option value of domestic manufacturing capacity. The policy response — reshoring, friendshoring, the CHIPS Act — was correct in direction but remained conceptually anchored in peacetime thinking: treating domestic capacity as a cost to be subsidized rather than as a strategic option to be priced against a regime transition probability.

The wartime disruptions documented in Section 4 are qualitatively different from all of the above. They are *strategic* — arising from deliberate choices by state actors with geopolitical objectives. They are *structurally uncertain* — the distributions governing their occurrence cannot be estimated from historical data because the generating process is human agency, not nature. They are *potentially permanent* — the underlying institutional structures that enabled the disrupted supply chain configurations may not reconstitute after the disruption. And they are *endogenous* — the concentration decisions that make supply chains efficient also make them attractive targets for weaponization. This last property is the most analytically consequential: in the wartime regime, supply chain design choices and disruption probabilities are jointly determined, not independent.

2.4 Related Work in Operations Research and Operations Management

The claim that existing models are systematically incomplete for the wartime regime requires engagement with the most relevant existing OM and OR streams, and a precise statement of where they fall short.

Robust and distributionally robust optimization (DRO). A natural response to our argument is: "robust optimization already handles Knightian uncertainty — choose an appropriate ambiguity set and optimize against the worst case." This objection is important and partially correct. Robust and DRO models (Bertsimas et al., 2011; Delage and Ye, 2010) do address uncertainty about the disruption distribution, not merely its realizations. The critical distinction is endogeneity: in robust/DRO models, the ambiguity set is fixed and exogenous to the firm's design decisions. In the wartime regime, the disruption distribution is a function of the firm's supply chain design itself — a 70% concentrated sourcing structure is a more attractive chokepoint than a diversified one, and a state actor's decision to weaponize depends partly on what is available to weaponize. The ambiguity set is endogenous, not fixed. This is not a limitation of existing robust optimization methods; it is a modeling gap that calls for a different problem formulation.

Correlated disruption and network contagion models. The supply chain resilience literature has developed models of correlated failures, network contagion, and systemic risk (Tang, 2006; Snyder et al., 2016). These models can capture the compounding effect of simultaneous disruptions across multiple nodes. What they do not capture is the *political structure* of correlation: the reason PPE resin, helium, copper foil, and memory prices all moved simultaneously in 2026 is not statistical correlation among independent failure processes but a common geopolitical cause — the Strait of Hormuz closure and the Iran conflict — operating through a state actor's strategic choices. The correlation structure is not estimated from historical data; it is generated by a political event that the historical data, gathered during the peacetime era, does not contain.

Network interdiction and defender–attacker models. The OR literature on network interdiction (Wood, 1993; Smith, 2007) explicitly models an adversarial actor attempting to disrupt a network, and is therefore closer to our framework than standard resilience models. The distinction is in the objective function and institutional identity of the attacker. Interdiction models typically treat the adversary as an unconstrained maximizer of network damage. A state actor weaponizing supply chains has a more complex objective: political leverage, not maximal disruption; selective coercion of specific targets; and domestic political constraints on the cost it can impose on its own economy. Modeling this requires political objective functions and institutional constraints that existing interdiction models do not incorporate. Our FWP and RTP constructs are designed to bridge this gap.

Humanitarian and defence logistics. As noted in Section 3.2, the humanitarian and defence logistics literatures (Van Wassenhove, 2006; Loska et al., 2025) have been forced by their operating environments to grapple with wartime-adjacent conditions. These streams offer the richest existing OM methodology for the wartime regime, and cross-pollination with commercial supply chain OM is a high-priority direction identified in our research agenda.

3. The Wartime Regime: A Conceptual Distinction

3.1 Defining the Wartime Supply Chain Regime

We define a *wartime supply chain regime* as one characterized by four properties that jointly distinguish it from the peacetime regime:

(1) *Expanded actor sets*: states and quasi-state entities become first-order supply chain actors rather than background regulators, pursuing geopolitical objectives that are neither commercial nor amenable to standard contractual incentive design.

(2) *Contested institutional constraints*: the rules governing supply chain operations are themselves subject to strategic manipulation and revision; the constraint set is not fixed but is an outcome of geopolitical interaction.

(3) *Weaponizable flows*: the material, information, financial, and human flows of supply chains (Dai and Tang, 2024) become instruments of geopolitical leverage, deployed selectively against adversaries.

(4) *Structural uncertainty*: the fundamental parameters of the supply chain environment — not merely their realizations — are unknown and actively contested, precluding the probabilistic characterization on which stochastic optimization depends.

3.2 The Distinction Is One of Kind, Not Degree

A critical clarification: the wartime regime is not simply a more uncertain version of the peacetime regime. It is a qualitatively different regime requiring qualitatively different models. This distinction is analogous to the difference between risk and uncertainty in the sense of Knight (1921): peacetime supply chain uncertainty is probabilistic risk, amenable to optimization over known distributions; wartime supply chain uncertainty is Knightian uncertainty, where the distributions themselves are unknown and the rules generating them are contested.

Macroeconomics has long maintained this distinction. The guns-versus-butter model encodes the recognition that wartime economies operate under a fundamentally different objective function than peacetime economies. Keynes (1940) recognized that even within wartime conditions there are choices, but that the relevant decision space is structurally different from peacetime fiscal policy. Most tellingly, Kantorovich invented linear programming in 1941 specifically to address wartime Soviet resource allocation problems.[2] Operations management has not yet systematically incorporated this distinction — a gap that the events of 2026 make urgent to address.

The defense supply chain literature has grappled with this tension – Loska et al. (2025) document the strategic dilemma of maintaining cost-conscious peacetime readiness while retaining capacity to respond to wartime surges – but this literature has remained largely siloed from commercial OM.

[2] L.V. Kantorovich (1965). The Soviet ideological suppression of shadow prices illustrates a recurring pattern: tools of operations research emerge from wartime necessity, then are systematically depoliticized in their peacetime application. The wartime supply chain framework proposed here is, in a sense, a return to origins.

[3] represents the closest existing methodological analog to the framework proposed here. Commercial electronics and industrial OM have had no equivalent forcing function — until now.

3.3 The Weaponizability of Supply Chain Flows

A defining feature of the wartime regime is the weaponizability of supply chain flows. Dai and Tang (2024) identify four interdependent flows in global supply chains: material, information, financial, and human. In peacetime, these flows are optimized for efficiency. In wartime, each becomes an instrument of geopolitical leverage.

Material flows are interrupted by export bans, embargoes, and physical disruption of production facilities. Information flows are weaponized through data sovereignty regimes, technology export controls, and cybersecurity restrictions. Financial flows are redirected by investment restrictions, sanctions, and alternative settlement systems. Human flows are disrupted by visa restrictions, talent migration policies, and national security constraints on researcher mobility.

The weaponizability of flows changes the nature of supply chain design from an optimization problem to a strategic interaction problem. Hau Lee's Triple-A framework — agility, adaptability, alignment (Lee, 2004) — captures the firm-level response to environmental volatility, and adaptability in particular comes close to what wartime resilience requires. The wartime extension is that the environment itself is not exogenous but is partly constituted by the firm's design choices: a supply chain that is agile and adaptable but concentrated in sovereign-owned nodes creates the very vulnerability it must then adapt to. Triple-A remains necessary, but it is no longer sufficient when geopolitical actors become endogenous participants in supply chain design. The strategic interaction with state actors must be modeled, not merely responded to. Firms are no longer optimizing against nature, but against strategic actors with independent objectives and the capacity to alter the rules of the game. This requires tools from game theory and international relations, not merely from stochastic optimization.

A minimal formal contrast illustrates the distinction; the full development of the model is left to subsequent work (see Section 6). In the peacetime regime, the firm solves $\min_x \mathbb{E}[c(x,\xi)]$ where ξ is an exogenous random disturbance drawn from a distribution F independent of the design x. In the wartime regime, ξ is chosen by a state actor S maximizing its own political objective

[3] The pharmaceutical supply chain literature Yadav has helped develop represents the closest existing methodological analog to the wartime OM framework proposed here.

$u_S(\xi, x)$ subject to political and economic constraints; the effective "distribution" of ξ is therefore a function of x itself. This is not equivalent to distributionally robust optimization over a fixed ambiguity set: the ambiguity set is endogenous to the firm's design choice. A firm that concentrates on sourcing (high CVI) becomes a more attractive target; the probability of disruption increases with concentration. This endogeneity, the disruption risk as a function of supply chain design, is the defining mathematical property of the wartime regime, and it is not treated as a first-order construct in dominant peacetime OM formulations. The CVI, RTP, and FWP constructs in Section 5 are designed to make this endogeneity measurable and embeddable in familiar OM formulations.

4. A Typology of Wartime Supply Chain Disruptions: Four Illustrations

We develop four cases that illustrate a typology of wartime supply chain disruption mechanisms. Each case is characterized by a distinctive mechanism through which geopolitical entanglement produces fragility that peacetime models, including resilience frameworks, fail to anticipate. We note explicitly that all four cases will eventually resolve: the claim is not that disruption is permanent but that the structural vulnerability generating each disruption is permanent, and will produce the next crisis through a different chokepoint by the same mechanism.

The trifecta of simultaneous shocks in 2026 – memory prices driven by AI infrastructure crowding out consumer electronics supply chains, copper foil and fiberglass shortages compounding PCB input costs, and PPE resin disrupted by conflict – illustrates that wartime conditions do not arrive as isolated events but as compounding structural failures that peacetime models, treating each shock as independent and exogenous, are structurally incomplete to anticipate.

4.1 Neon Gas: Legacy Concentration from Geopolitical Predecessor States (Ukraine, 2022)

Ukraine supplied approximately 50% of the world's semiconductor-grade neon gas before Russia's 2022 invasion, a concentration attributable entirely to the legacy infrastructure of the Soviet steel industry, in which neon was a byproduct of large-scale oxygen generation for steelmaking (U.S. International Trade Commission, 2022). After the Soviet dissolution, Russia performed crude gas separation while Ukrainian firms handled refining and export. The US semiconductor industry sourced nearly all of its ultra-high-purity neon from two Ukrainian companies.

The mechanism is *legacy concentration*: a supply chain vulnerability created not by contemporary business decisions but by the industrial geography of a predecessor geopolitical entity. Soviet industrial inheritance as a risk variable is not treated as a first-order modeling construct in dominant OM formulations. Resilience frameworks built around supplier diversification and buffer inventory cannot address a concentration rooted in decades-old geopolitical geography.

The case is particularly instructive because the warning signal appeared eight years earlier.[4] The 2014 Crimea annexation caused a 600% neon price spike. Buffer inventory was built. The peacetime model was restored. The structural vulnerability was not addressed, because peacetime resilience frameworks have no construct for deliberate state weaponization of legacy industrial concentration.

4.2 Helium: Geographic Chokepoint Weaponization (Qatar/Hormuz Strait, 2026)

Qatar's Ras Laffan Industrial City accounts for approximately one-third of global helium supply. Helium is critical for semiconductor fabrication — used in cryogenic cooling of superconducting systems and in controlled atmospheres required for precision chip production — and has no viable substitute in deep cryogenic applications (Digitimes, 2026). The effective closure of the Strait of Hormuz to Western commercial shipping removed 30–38% of global helium output from the market as of March 2026.

The mechanism is *geographic chokepoint weaponization*: the vulnerability arises not from the production facility itself but from its exclusive dependence on a single maritime corridor subject to geopolitical control. Qatar has no secondary logistics route for helium exports. This is precisely the disruption that opens Murray (2026) — and precisely the disruption that the peacetime resilience constructs surveyed therein cannot address. Time-to-recover from a Hormuz closure is not a function of supplier diversification or buffer inventory. It is a function of geopolitical resolution.

Alternative helium sources exist but face their own geopolitical constraints — Russia's Amur facility operates well below capacity due to Western sanctions — illustrating how wartime disruptions create cascading constraints across the global network simultaneously.

4.3 PPE Resin: Sovereign Ownership Concentration (Saudi Arabia/Jubail, 2026)

The primary illustration of this paper. SABIC's Jubail facility — 70% owned by Saudi Aramco, itself an instrument of Saudi sovereign wealth — produced approximately 70% of the world's

[4] Neon prices spiked 600% following Russia's 2014 annexation of Crimea, according to U.S. International Trade Commission (2022). The industry built buffer inventory and returned to peacetime procurement when the immediate disruption passed — treating the signal as a transient price event rather than a structural vulnerability. The peacetime resilience framework had no architecture for treating it otherwise.

high-purity PPE resin before the April 2026 strike. The ownership structure is the key analytical feature: this is not a private firm subject to market incentives for diversification and resilience. It is a sovereign industrial asset, concentrated at a single location designed for efficiency, situated in a geopolitically volatile environment.

What a wartime supply chain model would have flagged: the combination of sovereign ownership, geographic concentration, geopolitical exposure, and absence of substitutes constitutes a weaponizable chokepoint. The 70% market share that peacetime efficiency models treated as evidence of comparative advantage, and that resilience models treated as a supplier concentration risk amenable to diversification, wartime analysis would treat as a leverage instrument available to any actor capable of disrupting production — whether intentionally or as a consequence of broader conflict.

The downstream effects illustrate cascading wartime dynamics. PCB lead times stretched from three weeks to fifteen. Goldman Sachs reported a 40% price increase in April alone (Reuters, 2026). Daeduck Electronics, supplying Samsung, SK Hynix, and AMD, opened price renegotiations with all major customers. Sanmina, one of the world's largest PCB manufacturers, faces precisely the problem that peacetime models address well — how to price speed across different lead time windows — under conditions those models cannot address at all: when the input does not exist at any price.

The Sadara Chemical joint venture — a $20 billion Saudi Aramco–Dow partnership at Jubail — shut down simultaneously, with $3.7 billion in debt obligations and a grace period expiring June 15, 2026. The financial dimension compounds the material dimension in ways that standard supply chain resilience frameworks, focused on inventory and sourcing flexibility, cannot model.[5]

4.4 Rare Earth Elements: Deliberate State-Level Weaponization (China, Ongoing)

China controls approximately 60% of global rare earth mining and 85% of global rare earth processing — elements essential for semiconductors, electric vehicles, defense systems, and advanced manufacturing. Unlike the previous three cases, the rare earth case involves deliberate, sustained, and strategically calibrated state action. Over the past fifteen years, China has halted or restricted rare earth exports to Japan (2010), Sweden (2019), and the United States on multiple occasions,

[5] A fifth chokepoint accumulates quietly: South Korea sources approximately 90% of its bromine imports from Israel — bromine being a critical input in circuit board flame retardants. The Seoul government has identified this among 14 critical semiconductor supply chain materials under active monitoring due to conflict exposure. The pattern is consistent: concentration that peacetime efficiency models treat as efficiency, peacetime resilience models treat as a diversifiable risk, and wartime analysis treats as a leverage instrument.

using supply chain leverage as an instrument of foreign policy (World Economic Forum, 2024).

The mechanism is *deliberate state-level weaponization*: a state actor consciously builds and maintains supply chain dominance as a geopolitical instrument, deploying it selectively against adversaries or in pursuit of specific policy objectives. This is qualitatively different from the previous three cases — not a legacy artifact, not a geographic accident, not a conflict byproduct. It is a strategic choice, consistently executed over fifteen years.

A supplier that deliberately withholds supply for geopolitical reasons is not explicitly represented in dominant OM formulations, including resilience frameworks built around supplier diversification and digital visibility. Transaction cost economics, resource dependence theory, and standard supplier risk frameworks all assume suppliers respond to price signals and contractual incentives. A state-level actor pursuing geopolitical objectives does not. Modeling this requires game-theoretic frameworks in which one player has objectives that are political, not commercial, and a time horizon that extends beyond any individual transaction or relationship.

4.5 Synthesis: A Typology of Wartime Disruption Mechanisms

The four cases suggest a typology of wartime supply chain disruption mechanisms, each requiring different modeling responses:

(1) *Legacy concentration*: vulnerability created by the industrial geography of predecessor geopolitical entities (neon/Soviet steel). Modeling response: historical political economy analysis of supply chain origins.

(2) *Geographic chokepoint weaponization*: vulnerability from exclusive dependence on a single logistics corridor subject to geopolitical control (helium/Hormuz). Modeling response: geopolitical mapping of logistics infrastructure and corridor control.

(3) *Sovereign ownership concentration*: vulnerability from concentration of critical supply in state-owned or state-adjacent entities (PPE resin/SABIC). Modeling response: ownership structure analysis integrated into supplier risk assessment.

(4) *Deliberate state weaponization*: vulnerability from a state actor's conscious deployment of supply chain dominance as foreign policy instrument (rare earths/China). Modeling response: game-theoretic models with political objective functions.

4.6 Operational Design Principles for Each Wartime Mechanism

A conceptual typology earns its place in supply chain management by generating actionable design implications. For each of the four wartime disruption mechanisms, we sketch the design principles that differ from peacetime resilience prescriptions. These are not exhaustive; they are intended as a starting point for the firm-level operational agenda that a full wartime resilience framework would specify.

Legacy concentration (neon/Soviet steel). Peacetime resilience prescription: dual-source and build buffer inventory. Wartime addition: audit the geopolitical genealogy of the supply base. Legacy concentration rooted in predecessor state industrial geography requires active deconcentration even when current suppliers appear commercially independent — the underlying infrastructure concentration persists. Design principle: "trusted capacity" over "trusted supplier" — invest in relationships with suppliers whose capacity is not embedded in geopolitically inherited industrial clusters, even at cost premium.

Geographic chokepoint weaponization (helium/Hormuz). Peacetime resilience prescription: regional diversification and alternative logistics routes. Wartime addition: the relevant unit of analysis is the corridor, not the supplier. Multiple suppliers routing through a single chokepoint provide false diversification. Design principle: "corridor independence" as a hard constraint in network design — no critical input should have more than a threshold fraction of supply routed through a single geopolitically contestable corridor. Strategic reserves held on the far side of the chokepoint provide a time buffer while alternative routes are activated.

Sovereign ownership concentration (PPE resin/SABIC). Peacetime resilience prescription: supplier diversification by market share. Wartime addition: ownership structure matters as much as market share. A Herfindahl index of 0.49 across two suppliers is very different if one supplier is state-owned and the other private. Design principle: "dual architecture" — maintain parallel supply relationships with private and state-adjacent suppliers for critical inputs, accepting efficiency loss in exchange for regime robustness. The domestic capacity option should be explicitly priced via RTP and held even when peacetime cost analysis does not justify it.

Deliberate state weaponization (rare earths/China). Peacetime resilience prescription: long-term contracts and relationship investment. Wartime addition: contracts with state actors are not enforceable across regime transitions. Design principle: "inventory of capability" over "inventory of parts" (Lee, 2004) — invest in the technical capability to substitute materials, redesign products around available inputs, and qualify alternative supply chains, rather than holding large inventories of inputs from a single state-controlled source. Postponement strategies — delaying material commitment until geopolitical clarity improves — reduce exposure to deliberate weaponization when feasible given product lead times.

These principles share a common structure: each involves accepting a peacetime efficiency penalty in exchange for wartime regime robustness. The magnitude of the optimal penalty is a function of RTP, CVI, and FWP — making the formal constructs proposed in Section 5 directly operational, not merely descriptive. More broadly, the typology is intended to guide modeling choices: legacy concentration calls for political-economy historical analysis; geographic chokepoint weaponization calls for network models with contested arc availability; sovereign ownership concentration calls for game-theoretic models with state actors; deliberate weaponization calls for repeated-game models with political objective functions. Different mechanisms, different model families — a mapping that the research agenda in Section 6 elaborates.

5. Extending POEM: Toward Wartime Supply Chain Models

5.1 POEM Constructs That Apply Directly

The POEM framework (Tayur, 2025) proposes four categories of political economy constructs applicable to global supply chains: political cost parameters, political risk metrics, institutional governance variables, and political influence indices of stakeholders. Each applies to the wartime regime but requires extension.

Political risk metrics must extend beyond probabilistic models of regulatory change to incorporate conflict-adjacent disruptions, maritime closure, and sovereign weaponization. Institutional governance variables must distinguish commercial institutional quality from geopolitical instrumentalization: Saudi Arabia has high institutional stability for commercial purposes, but SABIC's sovereign ownership creates geopolitical exposure that standard governance quality metrics conflate with commercial stability.

5.2 Three New Constructs for the Wartime Regime

We propose three new constructs specifically designed for the wartime regime:

Concentration Vulnerability Index (CVI): a measure that distinguishes efficiency-motivated concentration from security-relevant concentration. Standard supply chain risk measures assess concentration in terms of supplier switching costs, lead time variability, and demand correlation, often through Herfindahl-type indices. CVI adds a geopolitical dimension: for a critical input i with n suppliers, we define $\text{CVI}_i = H_i \cdot \gamma_i \cdot (1 - \sigma_i)$, where $H_i = \sum_j s_{ij}^2$ is the Herfindahl concentration index on supplier market shares s_{ij}, $\gamma_i \in [0, 1]$ is a sovereign ownership indicator (fraction of supply controlled by state or state-adjacent entities), and $\sigma_i \in [0, 1]$ is the substitutability score (fraction of demand that can be met by alternative inputs within an operationally acceptable timeframe). A 70% market share held by a private multinational yields a different CVI from a 70% share held by a sovereign entity with no viable substitute, even if H_i is identical. Thus, CVI extends the existing criticality indices from the critical raw materials literature (Graedel et al., 2012) by incorporating the structure of political ownership and substitutability jointly.

Regime Transition Probability (RTP): a model for the probability and timing of transition between peacetime and wartime supply chain regimes for a given node or flow. Drawing on Hamilton-type regime-switching models (Hamilton, 1989), we define RTP as the transition probability p_{01} in a two-state Markov chain governing the supply chain environment, where state 0 is peacetime and state 1 is wartime. In peacetime, disruptions are exogenous and stochastic; in wartime, disruptions are strategic and endogenous. The RTP is estimated not from historical supply chain data alone – which is necessarily drawn from the peacetime era – but from geopolitical intelligence signals: conflict intensity indices, sovereign ownership changes, export control announcements, and treaty status. In practice, estimation combines expert elicitation, scenario analysis, and Bayesian updating on observable political signals. The RTP is intended initially as a decision-support construct analogous to scenario probabilities in supply chain stress testing , rather than as a statistically estimated parameter; the burden of proof is calibration of relative magnitudes, not point estimation of a precise probability. A key result follows directly: under positive RTP, the optimal domestic sourcing allocation exceeds the cost-minimizing peacetime allocation, even when domestic cost is higher. The magnitude of this premium — the “insurance value of domestic capacity” — is increasing in RTP and in the asymmetry of wartime disruption severity. The offshoring of US laminate manufacturing in 2004 was rational under RTP ≈ 0; it would have been reconsidered under a wartime-informed RTP incorporating the geopolitical signals already visible at that time. The RTP also provides a formal diagnostic for the COVID boundary case: COVID generated a high realized disruption under low ex-ante RTP, exposing under-investment in the domestic capacity option.

Flow Weaponization Potential (FWP): a measure of the degree to which each of the four supply chain flows is subject to geopolitical weaponization for a given configuration. FWP enables supply chain designers to assess not only the efficiency and resilience of a configuration but its geopolitical exposure: which flows, if weaponized, would cause the most damage? A supply chain optimized for peacetime efficiency may score poorly on FWP; a supply chain designed for wartime resilience may sacrifice efficiency for FWP reduction. The relationship between CVI, RTP, and FWP provides a three-dimensional assessment of the vulnerability of the wartime supply chain that complements and extends existing resilience metrics.

5.3 Mathematical Directions

The formal development of wartime supply chain models suggests three mathematical directions:

Stochastic programming with regime switching: extend standard two-stage stochastic programs (Birge and Louveaux, 2011) to incorporate a regime switching process governing the transition between peacetime and wartime states. The key differentiator from existing multi-scenario disruption models is the endogenous regime: in existing models, scenario probabilities are fixed; here, they depend on the firm's first-stage design decisions via the CVI and FWP constructs. This creates a fixed-point structure in the optimization – the firm's design affects its disruption exposure, which affects optimal design – requiring solution methods beyond standard two-stage decomposition.

Game-theoretic models with state actors: extend classical supply chain coordination models to incorporate state actors with political objective functions. A minimal structure is a Stackelberg game with a state leader choosing export/production policy to maximize a political objective (a weighted combination of economic damage to the target, domestic political support, and international reputational cost) and a follower firm choosing sourcing allocations to minimize cost subject to supply constraints set by the state leader. This differs from existing firm–supplier Stackelberg models in that the leader's objective is political, not commercial, and the leader's strategy set includes actions unavailable to commercial actors (export bans, sanctions, infrastructure denial). The rare earth case provides fifteen years of behavioral data for empirical grounding and calibration.

Network models with politically contested constraints: extend the optimization of the supply chain network to incorporate constraints subject to geopolitical determination. The connection to existing network interdiction and defender–attacker models (Wood, 1993) is direct but requires enrichment:

existing interdiction models treat the attacker's objective as maximizing network damage; a state actor weaponizing supply chains has a more complex objective — political leverage, not maximal disruption — and faces domestic political constraints on the costs it can impose on its own economy. Incorporating political objective functions and institutional constraints into the attacker's problem is the key extension. The Hormuz Strait closure is the natural empirical context: a constraint that changed discontinuously not through market processes but through geopolitical action.

5.4 The Humanitarian OM Analogue

The pharmaceutical and humanitarian supply chain literature represents the closest existing methodological analogue to the wartime OM framework proposed here. This literature has been forced, by its operating conditions, to incorporate political risk, state actors, and institutional instability as first-order modeling variables. It has developed constructs for supply chain resilience where peacetime assumptions do not hold, rules are contested, and relevant actors include non-commercial entities with non-commercial objectives.

Cross-pollination between humanitarian OM and commercial OM — with appropriate translation of constructs from health products to industrial materials — represents a high-priority research direction. The wartime supply chain framework proposed here is intended, in part, as a conceptual bridge between these communities.[6]

6. Research Agenda

We propose a research agenda organized around five questions:

When do firms recognize regime transition, and what enables early recognition? The transition from peacetime to wartime conditions rarely arrives as a discrete event. The signals accumulate — the 2014 neon price spike, the 2019 rare earth restriction, the 2022 Ukraine disruption — before a triggering event makes the transition undeniable. What organizational and analytical capabilities enable early recognition? What cognitive and institutional barriers produce the category error of treating wartime signals as peacetime noise? The behavioral supply chain literature (Van Wassenhove, 2006) provides a starting point; extension to geopolitical signal processing is

[6]The fashionable response to inadequate supply chain models is to propose AI as the corrective. We address this claim in Tayur (2026). Our position is that computational power applied to a conceptually inadequate framework produces confident wrong answers, not right ones. A missile falling on Jubail is not a pattern recognition problem. A sovereign entity weaponizing supply chain dominance is not an optimization problem. These are failures of framework, not of computation.

needed.

What formal models capture the dynamics of the wartime supply chain? The mathematical directions sketched in Section 5.3 require formal development, empirical grounding, and practical implementation. In ongoing work, we instantiate CVI, RTP, and FWP in a two-stage regime-switching network design model and derive comparative statics on optimal diversification thresholds as RTP increases from zero, showing that under positive RTP, the optimal domestic sourcing allocation exceeds the cost-minimizing peacetime allocation by an amount proportional to the severity asymmetry between peacetime and wartime disruption. The defense and humanitarian OM literature offers methodological resources; translation to commercial supply chains requires domain-specific adaptation.

What are the diagnostic criteria separating peacetime from wartime disruptions? The COVID case sits at the boundary. The RTP construct provides a formal framework, but its operationalization requires criteria for distinguishing stochastic from structural uncertainty, and exogenous from endogenous disruption. Development of these criteria — drawing on political science, economic history, and international relations — is a foundational research task.

How should governments price domestic manufacturing capacity as a strategic option? The offshoring of critical manufacturing — laminates, semiconductor gases, rare earth processing — was rational under peacetime models treating domestic capacity as a cost center. Wartime analysis treats it as an option against regime transition. How should this option be priced? What institutional mechanisms — strategic reserves, domestic content requirements, public-private partnerships — are appropriate instruments, and how do they interact with commercial supply chain decisions of private firms?

Are we teaching peacetime tools for a wartime world? The curricula of business schools and supply chain management programs remain organized around peacetime OM frameworks. The wartime supply chain regime requires additional capabilities: geopolitical risk assessment, political economy analysis, game-theoretic reasoning about state actors, and institutional analysis of governance quality and weaponization potential. Integration of these capabilities into supply chain management education is an urgent pedagogical challenge — and one that, given the events of 2026, can no longer be deferred.

7. Conclusion

The April 2026 disruption of PPE resin supply is, at its core, a story about conceptual failure. The supply chain models governing the design of the global electronics supply network — including both their efficiency and their resilience grammars — had no architecture for what happened: a sovereign entity's production facility, controlling 70% of a critical input, situated in a geopolitically volatile region, disrupted by a conflict whose warning signals had been accumulating for years.

The resilience turn documented by Murray (2026) and pursued by colleagues, including Simchi-Levi et al. (2015) and Van Wassenhove (2006) is necessary and valuable. It correctly extends the peacetime grammar beyond pure efficiency to incorporate risk and adaptability. The limitation is not that it ignores disruption — it does not — but that it treats disruption as exogenous to supply chain design. In the wartime regime, that assumption fails. Concentration is not merely a vulnerability; it is part of what makes the node strategically attractive to disrupt.

Using peacetime supply chain models in wartime conditions is a regime mis-classification: the model class is calibrated for a structural environment that no longer fully obtains. Parameter recalibration within existing peacetime formulations cannot close a gap that is structural, not parametric — though the constructs proposed here are designed to be embeddable in familiar model architectures. The relevant actors change. The constraints become contested. The flows become weaponizable. The uncertainty becomes structural rather than stochastic. Optimization within constraints, when the constraints themselves are geopolitically determined, can give an illusion of rigor while under-weighting the mechanisms that actually drive outcomes in the wartime regime.

This paper has proposed a formal distinction between peacetime and wartime supply chain regimes, developed a typology of four wartime disruption mechanisms with corresponding design principles, extended the POEM framework to incorporate regime-switching dynamics and three operationalizable constructs, and proposed a five-question research agenda. Formal models aiming to instantiate CVI, RTP, and FWP in two-stage stochastic and game-theoretic formulations are left to subsequent work; Section 6 outlines those directions with sufficient precision to guide that program. The agenda is large. The urgency is considerable. The next crisis will not be PPE resin. It will arrive through a different chokepoint, by a different mechanism, in a region that peacetime models currently treat as low-risk.

Operations management has built powerful models for peacetime. Extending these frameworks to anticipate and design for wartime in which states are actors, constraints are contested, and disruption risk is endogenous to supply chain architecture, is the next evolutionary step.

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