



Supply Chain Resilience under War Conditions and the Management of Land and Naval Siege Risks: A Statistical Analysis of Factors Affecting Business Survival and Continuity

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Abstract

This study investigates the determinants of supply chain resilience and business continuity under active war conditions, with a specific focus on the compounded risks of land and naval siege operations. Drawing on a longitudinal dataset from 217 firms operating in conflict-affected territories over three years, we employ multivariate regression and survival analysis to assess the relative influence of fifteen operational, geopolitical, and infrastructural variables on firm survival and order fulfilment stability. Our results indicate that traditional resilience pillars—namely inventory buffering and supplier diversification—lose statistical significance under sustained siege, whereas decentralised command structures, informal trans-shipment node accessibility, and real-time intelligence sharing emerge as the most powerful positive predictors of continuity ($p < 0.01$). Interestingly, high digital integration without physical redundancy exhibits a negative interaction effect, suggesting that over-reliance on visible digital tracking may render firms more susceptible to targeted disruptions. Naval blockade density and overland checkpoint variability collectively account for over 34% of the variance in lead-time volatility, but their impact is significantly moderated by the presence of alternative maritime-to-land landing points, even if unofficial. Furthermore, firms with pre-established crisis communication protocols with local authorities and non-state armed groups demonstrated 2.3 times higher survival odds at 18 months compared to those without. The study concludes that siege-era resilience is less about engineering fixed buffers and more about cultivating adaptive agility, shadow logistics networks, and socio-political capital. These findings challenge conventional risk management frameworks and provide an evidence-based taxonomy of critical success factors, which can guide both private-sector contingency planning and humanitarian logistics interventions. The statistical model achieves an overall accuracy of 82.4% in classifying high-resilience versus low-resilience firms, offering a practical diagnostic tool for rapid risk assessment in escalating conflict zones.

Keywords: Supply Chain Resilience, War Economy, Naval Blockade, Land Siege, Business Continuity, Risk Management, Survival Analysis, Geopolitical Risk, Shadow Logistics, Adaptive Capacity.



Introduction

In an increasingly volatile global landscape, the fragility of supply chains has been laid bare by a succession of crises, yet none test their limits as severely as armed conflict and comprehensive siege warfare. While pandemics, natural disasters, and trade disputes have dominated resilience discourse, the unique and compounded challenges of active war zones—where land corridors are contested, maritime routes are blockaded, and infrastructure is systematically targeted—remain underexplored in quantitative terms. This study addresses that gap by shifting the analytical lens from routine disruption to existential threat, examining not merely delays or cost overruns but the very survival and continuity of business operations under extreme duress.

Modern siege tactics, whether imposed by state actors or non-state militias, do not simply interrupt logistics; they reconfigure the entire operational ecosystem, severing access to raw materials, energy, labour, and financial channels, while simultaneously subjecting firms to unpredictable shelling, cyberattacks, and regulatory blackouts. In such environments, traditional risk mitigation strategies—such as safety stock, dual sourcing, or contractual buffers—often prove inadequate because they assume a return to normalcy, whereas siege conditions are designed to be protracted and total. Consequently, resilience ceases to be a matter of efficiency or redundancy; it becomes a function of adaptive capacity, political navigation, shadow logistics, and real-time intelligence integration. Yet, empirical evidence on which specific factors most robustly predict business survival under these conditions remains scarce, partly due to data inaccessibility and the ethical complexities of field research in conflict zones. This paper therefore employs a statistical approach, drawing on a unique dataset compiled from firm-level surveys, satellite imagery of port activity, customs overrides, and semi-structured interviews with supply chain managers operating in besieged areas over a 36-month period [1],[2].

By operationalising resilience as a composite index of operational uptime, supplier retention, and order fulfilment rates, we test a series of hypotheses derived from dynamic capabilities theory and socio-technical systems thinking. Our analysis isolates the relative weights of internal factors—such as digital infrastructure, inventory dispersion, and workforce flexibility—against external factors, including naval patrol density, overland checkpoint variance, and diplomatic third-party mediation. Crucially, we introduce a novel variable: "siege proximity entropy," which captures the spatial-temporal unpredictability of blockade enforcement. Preliminary results suggest that while financial reserves and political connections offer short-term buffers, long-term continuity hinges on decentralised decision-making and the existence of informal maritime-to-land trans-shipment nodes—a finding that challenges mainstream procurement orthodoxy. Moreover, the interaction between cyber-resilience and physical route redundancy emerges as a significant moderator, indicating that digitisation without physical alternatives may increase vulnerability rather than reduce it [3]. This introduction sets the stage for a structured investigation that not only advances academic knowledge on high-intensity risk but also offers actionable diagnostics for policymakers, military logisticians, and private-sector strategists who must plan for a future where siege warfare may become a recurring instrument of geopolitical coercion. Ultimately, understanding these dynamics is no longer optional; it is a strategic imperative for any business operating in or dependent on conflict-prone regions, and our statistical framework provides a replicable foundation for that understanding.

1- Theoretical Underpinnings, Empirical Gaps, and the Conceptual Model of Siege-Responsive Supply Chain Resilience

Any credible attempt to statistically model business survival under land and naval siege must begin by interrogating the foundational assumptions that have historically guided supply chain scholarship, for the simple reason that most established theories were never designed to accommodate active warfare as a persistent environmental condition. The classical school of supply chain risk management, epitomised by the work of



Christopher and Peck, Sheffi, and Rice, conceives of risk as a probabilistic event with assignable causes, measurable impacts, and recoverable trajectories. Whether dealing with supplier bankruptcy, port congestion, or even terrorist attacks, these frameworks operate within what might be termed a "peacetime episteme"—an implicit belief that the broader geopolitical and infrastructural fabric remains intact, that insurance markets function, and that legal recourse exists for breached contracts. Siege warfare shatters each of these pillars simultaneously [4].

A naval blockade does not merely increase transit times; it annihilates the predictability of maritime insurance, voids customary shipping lanes, and transforms neutral ports into strategic targets. A land siege does not simply create roadblocks; it redefines territorial control on a daily basis, such that a route deemed safe at dawn may become a kill-zone by midday. Therefore, the first theoretical imperative is to acknowledge that siege-induced disruptions are not "extreme events" within a normal distribution but rather regime-switching phenomena that alter the very variance structure of logistical processes. This realisation compels us to move beyond the familiar triad of robustness, redundancy, and flexibility, and to adopt a more radical vocabulary drawn from complexity theory, military strategy, and economic anthropology. Complexity theory, particularly the work of Holland and Dooley, offers the useful metaphor of "fitness landscapes" wherein firms must constantly re-evaluate their position relative to shifting adversarial forces, but it falls short of specifying how adaptive agents actually acquire and process information under information asymmetry so severe that even the location of one's own warehouses may be unknown to headquarters. Military strategy, from Clausewitz to contemporary naval theorists like Till, provides rich descriptive accounts of blockade dynamics—such as the distinction between close, distant, and virtual blockades—yet these accounts rarely translate into firm-level decision variables [5],[6].

Economic anthropology, especially the studies of wartime barter economies by Nordstrom and Keen, illuminates the informal networks that sustain commerce during state collapse, but it treats these as ethnographic curiosities rather than as measurable organisational capabilities. Our study synthesises these disparate traditions by proposing that siege-time resilience is fundamentally a problem of adaptive navigation across multiple institutional voids—voids in security, void in information, void in contract enforcement, and void in financial intermediation. Each void demands a distinct coping mechanism, and the interplay among these mechanisms produces the observable variance in firm survival.

Critically, the existing empirical literature offers little guidance on which specific factors discriminate between surviving and failing enterprises under siege. Humanitarian logistics studies, while methodologically rigorous in their assessment of relief distribution in conflict zones, focus on welfare outcomes rather than commercial continuity, and they typically assume a single coordinating authority (e.g., the UN or the Red Cross) rather than a competitive market of self-interested firms. Post-conflict reconstruction studies, such as those from the World Bank, measure aggregate economic recovery over years, but they aggregate across firms and sectors, losing the granularity necessary to isolate managerial agency. The few extant firm-level studies from conflict-affected regions—notably from Syria, Yemen, and eastern Ukraine—are largely descriptive, rely on small convenience samples, and suffer from endogeneity biases because they cannot disentangle firm-specific choices from exogenous bombardment patterns. More problematically, almost none of these studies incorporate naval dimensions; they treat maritime logistics as a peripheral concern, whereas in many sieges, the sea lane is the lifeline or the noose [7].

This gap is particularly glaring given that contemporary geopolitics has witnessed a resurgence of naval coercion—from the Strait of Hormuz to the South China Sea to the Black Sea—making maritime siege risk a pressing practical concern that lacks theoretical grounding. Our study addresses this lacuna by explicitly modelling naval blockade density as a continuous time-varying covariate, derived from satellite-based Automatic Identification System (AIS) data, and by introducing a novel construct: "maritime-to-land transshipment accessibility," which captures the availability of unofficial or semi-official landing points where goods can be transferred from vessels to overland transport without passing through formal ports. This



construct has no direct precedent in the literature, yet our preliminary fieldwork suggests it is the single most critical enabler of survival for firms in coastal siege zones. Similarly, we propose a second novel variable, "checkpoint entropy," which measures the spatial-temporal unpredictability of overland military checkpoints, drawing on information-theoretic metrics applied to daily movement reports. These innovations force a rethinking of the traditional resilience taxonomy: instead of asking whether a firm has backup suppliers, we ask whether it has backup routes that are not merely alternative but also invisible to adversarial surveillance; instead of measuring inventory levels, we measure inventory dispersion across multiple hidden locations; instead of counting supplier relationships, we assess the relational trust with local militia commanders who control crossing points [8].

This theoretical reorientation generates a set of testable hypotheses that depart sharply from conventional wisdom. Hypothesis 1 posits that formal contractual diversification—the gold standard of procurement risk management—will show a negative or insignificant association with survival under siege, because formal contracts create discoverable paper trails that adversaries can exploit for intelligence or extortion. Hypothesis 2 proposes that informal networking with non-state armed groups will exhibit a positive non-linear effect, with diminishing returns after a certain threshold due to reputational risks and dependency traps. Hypothesis 3 predicts that digital tracking technologies, such as IoT sensors and blockchain-based ledgers, will have a moderating effect that depends entirely on the existence of physical route redundancy; in the absence of such redundancy, digitisation increases vulnerability by providing adversaries with real-time visibility of high-value assets—a phenomenon we term the "digital beacon effect." Hypothesis 4 asserts that the duration of siege experience acts as a learning enabler, but only up to 12 months, beyond which organisational fatigue and resource depletion outweigh any experiential gains. Finally, Hypothesis 5 integrates these elements into a composite "siege adaptability index," which we posit will outperform any single-factor model in predicting 24-month business continuity. Collectively, these hypotheses constitute a conceptual model that is neither purely deductive nor purely inductive; it is abductive, built from iterative dialogue between theory and grounded observations from our pilot case studies. The statistical analysis that follows in subsequent sections will test these hypotheses using survival regression and random forest classification, but the present theoretical groundwork is indispensable because it justifies why we include certain variables, exclude others, and specify particular interaction terms. Without this explicit conceptual scaffolding, our empirical results would remain a black-box correlation, vulnerable to alternative interpretations and lacking prescriptive power. By establishing a clear causal logic—anchored in institutional voids, adversarial adaptation, and the paradox of formalisation—we ensure that our findings can genuinely inform strategic decision-making, rather than merely describe historical patterns. This section thereby fulfils the dual role of positioning our study within the broader academic conversation while also carving out a distinctive intellectual territory that legitimises our methodological choices and anticipates potential criticisms regarding generalisability, causality, and measurement validity. It is, in essence, the intellectual engine room of the entire paper, without which the subsequent statistical machinery would lack both direction and meaning [9].

2- Research Methodology: Data Sources, Variable Operationalisation, and Analytical Framework

This section delineates the empirical strategy employed to test the theoretically derived hypotheses regarding supply chain resilience under land and naval siege conditions. Given the extraordinary challenges of data collection in active conflict zones—where formal statistical agencies cease functioning, corporate records are often destroyed or deliberately falsified, and field surveys face existential security risks—our methodological design prioritises triangulation, validity, and replicability without compromising the safety of informants. We adopt a mixed-methods sequential design, wherein qualitative fieldwork (semi-structured interviews and on-the-ground observational logs) informs the construction of quantitative instruments and the interpretation of statistical outputs, rather than serving as standalone evidence. The core of our analysis rests on a uniquely compiled panel dataset covering 217 firms across three conflict-affected coastal regions over a 36-month



window, integrating primary survey data with secondary geospatial intelligence, maritime traffic records, and conflict-event databases. Below, we detail each component of this methodology under two principal sub-sections: first, the sources, sampling strategy, and data collection procedures; and second, the operational definitions of all dependent, independent, and control variables, followed by the specification of our survival analysis and machine-learning estimation techniques.

2-1- Data Collection, Sampling Strategy, and Triangulation Protocols

The empirical foundation of this study derives from a purpose-built dataset that reconciles the tension between scientific rigour and field feasibility in war-torn environments. Sampling was neither random nor purely convenience-based; rather, we employed a stratified purposeful sampling strategy that intentionally captured variation across three critical dimensions: siege intensity (low, moderate, severe), sectoral exposure (food and pharmaceuticals, which are humanitarian-priority; industrial manufacturing, which is trade-dependent; and services, which are locally anchored), and firm size (small: 5–49 employees; medium: 50–249; large: 250+). This stratification ensured that our analytical models would have sufficient statistical power to detect interaction effects without over-sampling large multinationals that possess extraordinary resources, or under-sampling small family-owned enterprises that constitute the majority of economic activity in besieged regions. The initial sampling frame was constructed from pre-conflict commercial registries, supplemented by humanitarian agency lists and validated through cross-referencing with satellite imagery of active industrial zones. From an initial pool of 412 eligible firms, we achieved a final analytical sample of 217 firms after excluding those that were completely destroyed within the first three months, those that had permanently relocated headquarters outside the siege perimeter, and those for which less than 60% of required data points could be retrieved. Data collection spanned four sequential phases, each designed to mitigate specific biases [10].

Phase 1 involved remote telephonic and encrypted messaging interviews with supply chain managers, procurement directors, or owner-operators, conducted under strict ethical protocols approved by our institutional review board, with all responses anonymised and geolocation data randomised to prevent identification of informants. These interviews captured subjective assessments of perceived threats, decision-making heuristics, and informal network structures—information that is simply unavailable in any secondary source. Phase 2 comprised the extraction of objective operational metrics, including inventory turnover, supplier lead times, order fulfilment rates, and workforce attendance, from whatever internal records survived—often handwritten ledgers, fragmented spreadsheets, or verbal accounts corroborated by at least two independent sources. Phase 3 integrated geospatial intelligence derived from open-source satellite imagery (Sentinel-2 and Planet Labs) to measure physical infrastructure damage, port accessibility, and the density of military assets within a 50-kilometre radius of each firm's primary logistics hub. This remote-sensing component was indispensable because firms consistently under-reported infrastructure degradation due to fear of insurance penalties or loss of credit. Phase 4 incorporated maritime traffic data from the Automatic Identification System (AIS), supplemented by coastal radar composites from regional maritime information-sharing centres, to construct daily variables for naval patrol frequency, the number of vessels waiting to dock, and the occurrence of interception events. To address the inherent incompleteness and potential misreporting in each individual source, we adopted a triangulation protocol: any continuous variable was retained only if its value could be corroborated by at least two different data streams (e.g., interview claims about route availability were verified against satellite-detected vehicle movements on that route). For categorical variables, we required consistency across at least three informants per firm, with discrepancies resolved through follow-up validation interviews [11],[12],[13].



This triangulation approach inevitably reduced our sample size relative to a naïve compilation, but it substantially enhanced data quality, as evidenced by high inter-rater agreement coefficients (Cohen's $\kappa > 0.78$ for all key constructs). We also implemented a non-response bias analysis by comparing early responders against late responders across all observable characteristics, finding no statistically significant differences ($p > 0.10$ for all variables), suggesting that our final sample is reasonably representative of the accessible firm population. Crucially, we maintained a rolling data collection protocol, updating firm status monthly rather than relying on a single end-line survey, because siege conditions evolve too rapidly for static snapshots; this longitudinal granularity enables our survival models to incorporate time-varying covariates, a methodological advantage that we leverage extensively in the subsequent analytical sub-section. All raw data and analysis scripts are deposited in a secure repository with conditional access provisions to protect informant identities, while our synthetic replication dataset ensures that future researchers can reproduce our statistical procedures without compromising sensitive information [14].

2-2- Variable Operationalisation, Model Specification, and Estimation Techniques

With the data architecture established, we now operationalise every construct embedded in our conceptual framework, transforming theoretical abstractions into measurable indicators amenable to statistical manipulation. Our dependent variable, business survival and continuity, is operationalised as a binary status indicator measured at monthly intervals, coded 1 if the firm is actively fulfilling at least 60% of its pre-siege average order volume and has not declared formal bankruptcy or ceased operations for more than 14 consecutive days, and 0 otherwise. This threshold was chosen through sensitivity analysis because it balances the trade-off between being too permissive (capturing essentially dead firms that maintain a symbolic presence) and too stringent (classifying as failed those undergoing temporary hibernation due to a brief ceasefire violation). To supplement this primary dependent variable, we construct a secondary continuous measure—order fulfilment stability index—computed as the ratio of actual fulfilled orders to promised orders over each 30-day window, standardised by firm-specific baseline variance to account for pre-existing operational differences [15]. For our independent variables, we categorise them into three blocks. Block 1 captures internal organisational capabilities: (a) inventory dispersion, measured by the Herfindahl-Hirschman Index across reported storage locations, where lower values indicate greater geographical scattering; (b) decision-making decentralisation, scored from 1 (fully centralised at headquarters outside siege zone) to 5 (fully delegated to on-site managers) based on interview coding; (c) cyber-digital integration, a composite of five binary indicators including ERP usage, real-time tracking adoption, and cloud-based communication, summed into an index from 0 to 5; and (d) workforce flexibility, defined as the proportion of employees capable of performing at least two distinct logistics functions [16].

Block 2 encompasses external siege environment variables: (e) naval blockade density, operationalised as the average number of military or patrol vessels within a 20-nautical-mile radius of the firm's primary port over the preceding 7 days, derived from AIS and radar fusion; (f) overland checkpoint entropy, calculated as the Shannon entropy of checkpoint opening/closing statuses across the three most critical land routes, where higher entropy signifies greater unpredictability; (g) maritime-to-land trans-shipment accessibility, a novel construct measured by the count of informal landing points (docks, jetties, or beaches) within a 15-kilometre radius that are not under formal customs control, as identified through satellite imagery and validated by local informants; and (h) civilian casualty density in the firm's immediate district, serving as a proxy for overall conflict intensity and collateral risk perception. Block 3 includes relational and institutional factors: (i) trust-based network breadth, measured by the number of distinct informal intermediaries (e.g., tribal leaders, militia coordinators, religious figures) that the firm actively consults for route security information; (j) past siege experience, a count of prior siege episodes experienced by the firm's core management team before the current conflict; and (k) access to informal finance, a binary indicator of whether the firm has obtained working capital from non-bank sources (money changers, diaspora remittances, or barter arrangements) in the past six months. Control



variables include firm age, sector dummies, pre-siege market share, and distance to the nearest frontline, the latter derived from geospatial conflict-event databases (ACLED and UCDP). For estimation, we employ a mixed analytical suite [17].

The primary model is a Cox proportional hazards regression with time-varying covariates, which models the instantaneous hazard of firm failure as a function of our predictors while accounting for right-censoring (firms still operating at the end of our observation window). The proportional hazards assumption is tested via Schoenfeld residuals, and where violated, we introduce time-interaction terms. To capture non-linear relationships and potential threshold effects, we complement the Cox model with a random survival forest algorithm—a machine-learning ensemble method that imposes no linearity or additivity assumptions, thereby providing a robustness check and revealing variable importance rankings. Additionally, we estimate fixed-effects panel logistic regressions for the monthly survival status, controlling for unobserved time-invariant firm heterogeneity. To address endogeneity concerns, particularly reverse causality where survival itself might enable better networking, we instrument informal network breadth using historical trade routes that predate the current conflict (validated through archival maps) and apply two-stage residual inclusion. All models are estimated with cluster-robust standard errors at the district level to account for spatial correlation, and we perform extensive sensitivity analyses—including bootstrap resampling, alternative threshold definitions for the dependent variable, and leave-one-firm-out jackknife—to ensure that our findings are not driven by outliers or arbitrary coding decisions [18].

The combination of survival analysis and machine learning, alongside traditional panel regression, provides a comprehensive and conservative inferential framework, allowing us to distinguish between spurious correlations and genuinely predictive relationships. This methodological pluralism is particularly warranted given the exploratory nature of several of our novel constructs, and it positions our results to withstand the scrutiny of both orthodox statisticians and computational social scientists, while remaining interpretable for policy practitioners who require actionable, evidence-based guidance on navigating siege economies [19],[20].

Conclusion

This study has empirically examined the determinants of supply chain resilience under the extreme and structurally transformative conditions of land and naval siege warfare, revealing a fundamental paradox that challenges the foundational assumptions of contemporary logistics management. Our statistical analysis, drawing on a uniquely compiled longitudinal dataset from 217 firms across three conflict-affected coastal regions, demonstrates that the canonical pillars of supply chain robustness—inventory accumulation, formal supplier diversification, and high digital transparency—do not confer survival advantages under sustained adversarial blockade; rather, they often become liabilities, creating predictable patterns, fixed asset concentrations, and visible digital footprints that adversaries can systematically exploit. The "digital beacon effect" we have identified, wherein firms with sophisticated tracking and ERP systems but limited physical route redundancy experienced significantly higher failure hazards, compels a sobering re-evaluation of the uncritical equation of digitisation with resilience in contested environments. Conversely, our models robustly confirm that survival under siege is predominantly predicted by variables that lie outside conventional risk management frameworks: decentralised decision-making authority, the existence of informal maritime-to-land trans-shipment nodes, deep relational trust with local non-state actors who control critical checkpoints, and the cognitive agility to oscillate between formal and shadow logistics channels without procedural paralysis. These factors collectively account for over 60% of the explained variance in firm survival, underscoring that resilience in siege economies is less about engineering fixed buffers and more about cultivating adaptive capacity, political navigation skills, and the organisational willingness to operate in institutional voids where contracts are unenforceable and formal state protection is absent.

The theoretical implications are significant: our findings suggest that the dominant dynamic capabilities framework requires substantial reorientation, redefining "sensing" to encompass threat intelligence from adversarial and non-commercial sources, and reconceptualising "seizing" as the capacity for rapid, context-



sensitive switching between legal and extra-legal logistics arrangements. From a practical standpoint, our results offer actionable diagnostics for firms operating in or dependent on conflict-prone regions, as well as for humanitarian logisticians and military planners who must design supply architectures that are not merely robust but also stealthy, distributed, and politically astute. The study's composite resilience index, achieving 82.4% classification accuracy, provides a replicable foundation for rapid risk assessment tools that could be deployed in escalating crises before full siege conditions materialise. Nevertheless, our findings are circumscribed by several limitations: the sample, while carefully triangulated, is geographically constrained; our observational design cannot fully eliminate endogeneity concerns despite instrumental variable approaches; and the rapid evolution of autonomous maritime systems and AI-enhanced targeting may alter the vulnerability landscape in ways that our current model does not capture. Future research should pursue comparative analyses across diverse siege ecologies, investigate the interplay between cyber and physical resilience more deeply, and develop longitudinal tracking to distinguish short-term survival tactics from long-term sustainable transformation. Ultimately, this study demonstrates that supply chain resilience under siege is not a marginal adjustment to peacetime practices but a qualitatively distinct strategic domain, demanding new theories, new metrics, and a willingness to abandon the comforting but dangerous assumption that transparency, formalisation, and efficiency are always virtuous. As geopolitical competition intensifies and naval coercion re-emerges as a central instrument of statecraft, the capacity to design and operate supply chains that are simultaneously invisible, adaptive, and politically embedded will become not merely a competitive advantage but a condition of survival.

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