What factors predict increased vulnerability in DoD supply chains?

Tagline

The US defense industrial base (DIB) is contracting. Because of the lengthy process for qualifying DoD suppliers, an unforeseen supplier loss causes outsized impacts on production. Consequently, the DoD seeks to anticipate and mitigate supplier failures. While failures are not completely predictable, specific factors can indicate potential risks that increase vulnerability in DoD supply chains.

Keywords

Department of Defense, DoD, supply chain risk management, defense industrial base, predictive analysis, resilience, supply chain management, risk factors, supply chain vulnerabilities, fragility, criticality, defense production act, stockpiles, sole source, foreign dependence, cyber security.

Executive Summary

The defense industrial base (DIB), an ecosystem of suppliers providing goods and services to the US Department of Defense (DoD), is fragile and contracting. Because of the lengthy and complex process for qualifying DoD suppliers, an unforeseen loss of viability causes outsized cost and schedule impacts on weapon system production. This research defines "supplier failure" as an event or condition that precludes a supplier from delivering what is needed at the desired time. Types of supplier failure include insolvency, exiting the market for a given product, ceasing to sell to the DoD (in favor of the commercial sector), ceding ownership to prohibited entities (adversarial nations, etc.), discontinuing the desired product or technology (obsolescence), debarment from Government contracting, and others. Between 2011 and 2020 the number of DoD prime contractors fell from 71,655 to 46,180. Pandemic-induced supply chain disruptions highlighted US vendors' dependence on foreign sources and resulted in the US government spending $750M to shore up critical DIB companies.

The U.S. Executive and Legislative branches are increasingly focusing government-wide efforts on understanding the health of the U.S. DIB and developing initiatives to strengthen it. While corporate supply chain management has been a research topic for decades, since 2000 there has been significant research in supply chain resiliency driven in part by increasing globalization and periodic systemic shocks. Similar to corporations' interest in supply chain resiliency measurement, the DoD has increased its focus on identifying industrial base risks that result in suppliers becoming unable or unwilling to provide critical components. While supplier failure is not completely predictable, research suggests there could be observable factors that indicate potential supplier risk and increased vulnerability in DoD supply chains.

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Introduction

The US considers its defense industrial base a strategic asset and has long sought to protect and strengthen it. One might trace formal efforts to the passage in 1950 of the Defense Production Act, which gives the government broad, but tightly controlled, authorities to intervene in the private sector to support national defense. As globalization expanded and supply chains became more interdependent, the DoD's ability procure from domestic sources lessened. In 2011 the DoD began efforts to assess DIB risk posture "sector by sector, tier by tier" using its "fragility and criticality" (F&C) matrix. F&C used surveys to assess industrial sectors, not individual companies, on four factors measuring supplier strength and six factors measuring products' criticality. The 2016 trade war with China and 2020 pandemic-induced supply chain seizures laid bare not just DoD's dependency on foreign suppliers, but its lack of visibility into supply chains and their resiliency.

Subsequently, the DoD initiated multiple efforts to improve its visibility of supply chain elements and anticipate vulnerabilities that might disrupt the delivery of critical products and materials. The author currently works on a DoD project to collect publicly available data to assess potential company risk. A brief literature search early in the project revealed no proven approaches for calculating supplier risk. The author drew on knowledge of finance theory to consider the development of factor-based predictive models. Specifically, in their seminal 1992 paper, Fama and French proposed that three financial factors, observable from publicly available data, were statistically significant in predicting stocks' future price performance. The resulting "3-factor model" laid the foundation for the "factor-based" or "smart beta" investing approach that underpins hundreds of current mutual funds and ETFs today. This author speculated that a similar approach might be used to predict the riskiness of companies within a supply chain.

Protocol

To identify articles relevant to the research question "what factors predict increased vulnerability in DoD supply chains?" the author searched for scholarly articles in the ABI/Inform Global database using keyword searches focused on supply chain risk management and also on predictive analytics. The author conducted a more limited search on JSTOR. Figure 1 illustrates the author's protocol.

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Appendix A quantitatively tabulates the search parameters, results, and final article selections.

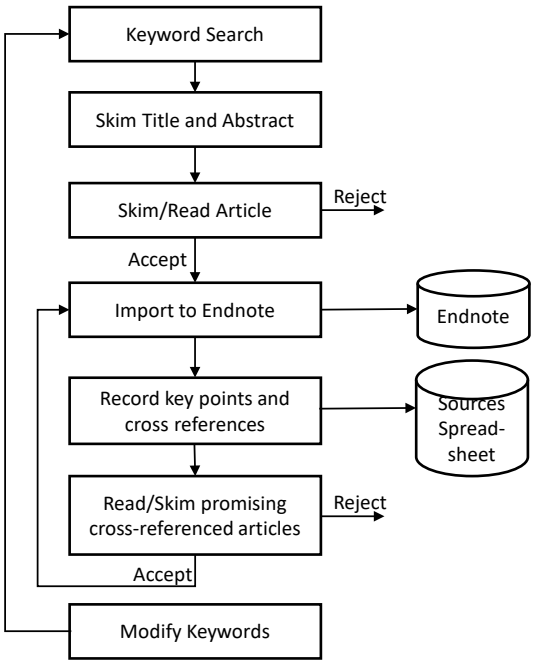

Figure 1: Keyword Search Protocol

As noted above, the author previously searched for studies on identification of DoD supply chain risk factors for his professional work and found limited scholarly publications. Most articles were government reports (GAO, Congressional, DoD) or report summaries published by commercial news outlets. The author found the most relevant research and publications in the Defense Technical Information Center (DTIC). However, the relevant articles were few, and most were not peer-reviewed.

Literature Summary

The health of the Defense Industrial Base (DIB), defined as the "worldwide industrial complex that enables research and development as well as design, production, delivery, and maintenance of military weapons systems/software systems, subsystems, and components or parts, as well as purchased services to meet U.S. Military requirements" (Undersecretary of Defense for Acquisition and Sustainment, 2020), is the subject of increasing concern and scrutiny in an era of globalization and great power competition (Hensel, 2016).

The U.S. Executive and Legislative branches are increasingly focusing government-wide efforts on understanding the health of the U.S. DIB and developing initiatives to strengthen it (House Armed Services Committee, 2022; Interagency Task Force in Fulfillment of Executive Order 13806, 2018; U.S. Department of Defense, 2022). While corporations' supply chain management has been a research topic for decades, since 2000 there has been significant research in supply chain resiliency driven in part by increasing globalization and periodic systemic shocks that include terrorist attacks, financial crises, weather events, and pandemics (Ho et al., 2015). Much of the research into supply chain resiliency focuses on the ability of corporate supply chains to withstand impacts and quickly recover to pre-shock levels or adapt to

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new permanent circumstances. The research addresses the definition, assessment, and measurement of supply chain resilience (Haimes, 2009; Han et al., 2020).

Similar to corporations' interest in supply chain resiliency measurement, the U.S. Department of Defense (DoD) has increased its focus on identifying industrial base risks that result in suppliers becoming unable or unwilling to provide specialized, critical components (Task Force on National Security and U.S. Manufacturing Competitiveness, 2021). Because the DoD leverages the production capacity of contractors and subcontractors whose supply chains are not under its direct purview, it grapples with supplier visibility as well as risk identification (Heritage Foundation, 2021).

Early research in supply chain resiliency developed conceptual supply chain models and identified factors likely to impact resiliency (Sheffi & Rice, 2005). This research established a foundation for understanding resiliency but did not satisfactorily address its measurement. Later attempts at resiliency measurement, including the Supply Chain Resilience Assessment and Management (SCRAM) tool, were qualitative or relied on surveys or focus groups to develop quantifiable inputs (Pettit et al., 2013). In 2011 the DoD began efforts to assess DIB risk posture "sector by sector, tier by tier" using its "fragility and criticality" (F&C) matrix. F&C assessed industrial sectors on four factors measuring supplier strength and six factors measuring products' criticality to DoD requirements. While F&C outputs are portrayed on a numeric scale, inputs rely on subjective assessments by subject matter experts. DoD recorded the results in a database, but they were not perfectly comparable across sectors due to assessment subjectivity and were soon outdated due to the rapidly changing corporate landscape (Heritage Foundation, 2021; United States Government Accountability Office, 2018). On a positive note, SCRAM and F&C agreed on many of the factors considered relevant in assessing supply chain resiliency.

The foregoing indicated an opportunity for further research in quantifying subjective risk factors used in F&C, SCRAM, and others by using publicly available data that can be structured and analyzed. The author found limited research into predicting company risk based on factor analysis and into testing the efficacy of those factors' predictive power. However, there exists a vast body of research in predicting company prospects in one domain for which there is ample quantifiable public data – finance (Appiah et al., 2015; Daubie & Meskens, 2002).

Factor-based company assessments

In their seminal 1992 paper, Fama and French proposed that three financial factors, observable from publicly available data, were statistically significant in predicting stocks' future price performance (Fama & French, 1993). The resulting "3-factor model" laid the foundation for the "factor-based" or "smart beta" investing approach that underpins hundreds of current mutual funds and ETFs today.

This author speculates that a similar approach might be used to predict the riskiness of companies within a supply chain. The author tailored further keyword searches to focus on keywords including "supply chain risk analysis", "risk prediction", "risk factors", and similar, and searched for relevant risk factors and their data sources. Table 1 summarizes the most promising and relevant supply chain risk factors addressed in the author's literature search.

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Table 1: Literature Search Summary:
Factors that increase vulnerability in DoD supply chains

Risk Types	Risk Factors	References
Financial	Bankruptcy risk Limited credit availability Small company size	(Zsidisin et al., 2004) (Ho et al., 2015) (Zsidisin, 2003)
Quality	Ability to meet product specs Constrained production capacity Limited surge capacity	(Zsidisin et al., 2004) (Ho et al., 2015) (Zsidisin, 2003)
Environmental/Geographic	Natural disaster regions Quality of regional infrastructure No close proximity to customer	(Zsidisin et al., 2004) (Ho et al., 2015) (Runde & Ramanujam, 2020) (Kumar et al., 2014)
Legal & Regulatory	Poor environmental compliance Poor labor law compliance Access to Intellectual Property	(Zsidisin et al., 2004) (Zsidisin, 2003) (Ho et al., 2015)
Customer Demand	High variability of demand	(Zsidisin, 2003) (Ho et al., 2015)
Supply	Over-dependence on customer Competing customer obligations Sole source supplier At-risk raw material supply High subcontractor concentration Few alternate suppliers	(Zsidisin et al., 2004) (Zsidisin, 2003) (Ho et al., 2015)
Information Risk	Information system quality Poor cybersecurity posture	(Ho et al., 2015)
Political	Import/Export restrictions Political instability/terrorism Labor strength/relations Government interference	(Zsidisin et al., 2004) (Kumar et al., 2014) (Runde & Ramanujam, 2020) (Zsidisin, 2003)

The literature review, including articles from finance theory, coupled with the author's knowledge of supply chain resiliency analysis tools currently under development by the DoD informed the development of a conceptual model for quantitatively assessing factors affecting supply chain resiliency. This model in turn helps establishes a framework for addressing the author's research question.

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Proposed Conceptual Model

Figure 2 illustrates the author's conceptual model for identifying and quantifying potential vulnerabilities in the supply chain supporting a DoD system.

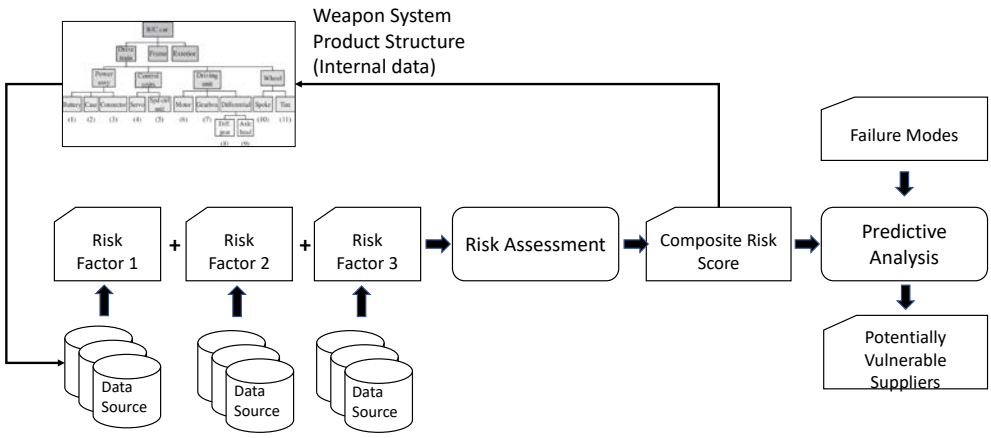

Figure 2 Proposed Conceptual Model

The model employs an "inside-outside" approach that uses the DoD's internal hierarchical product structure as a proxy for the system's supply chain. This information resides on secure government computing systems and serves as the "skeleton" or framework for capturing risk data for each element (company) in the supply chain. Data from multiple sources, both internal and external, are imported to the secure server to populate multiple risk factors at each supply chain element. The data collection from external sources is anonymized such that outside observers cannot infer the product structure or purpose of the data collection.

Risk factor data from multiple sources can be used for internal corroboration and to develop confidence levels for each risk score. The individual risk factors can be aggregated to develop a composite risk score for each supply chain element.

The author recognizes that predicting company risk is inexact. However, automated data collection, analysis, and measurement reduces human effort required to analyze risk factors, enables more frequent updates, and alerts analysts to the areas warranting further manual investigation.

Discussion

This literature review reveals that some supply chain-related topics have been addressed by substantial research and other topics are thinly covered. The bulk of the literature focuses more on traditional supply chain management and less on supply chain risk management. The Association of Supply Chain Management (ASCM) defines supply chain management as "the design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally" (Association for Supply Chain Management, 2022). This definition omits any reference to managing risk or

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creating resilience. Its focus on executing and monitoring supply chain activities might imply the use of risk management, but creating value is clearly the primary objective.

In contrast, Wieland and Wallenburg define supply chain risk management (SCRM) as "the implementation of strategies to manage both everyday and exceptional risks along the supply chain based on continuous risk assessment with the objective of reducing vulnerability and ensuring continuity" (Wieland & Wallenburg, 2012). The emphasis of SCRM is squarely on ensuring the "robustness" or "resiliency" of supply chains.

The last decade has shown increasing interest in supply chain resiliency by both the commercial sector and the government sector, especially the DoD. The majority of current SCRM research focuses on the commercial sector. The literature reviewed by this author addressed macro-views of supply chain resiliency, supply chain risk management as a strategic imperative, and stochastic modeling techniques that capture a very small number of supply chain tiers and risk drivers. The limited amount of DoD-specific literature identifies supply chain risk management and industrial base resiliency as national security imperatives. The DoD desires detailed knowledge of supplier risks, especially foreign influence and cyber risks. There exists very limited literature on quantitative assessments of DIB risk and particularly on the specific factors that might predict vulnerabilities.

This author progressively narrowed the literature search to focus on predictive risk factors, the results of which are summarized in Table 1 above. In 2022 a working group led by the Logistics directorate within the Office of the Secretary of Defense (OSD) began developing a supply chain risk framework and taxonomy. The working group's pre-publication database contains thirteen risk categories and over one hundred well-defined risk sub-categories (Office of Secretary of Defense - Logistics Directorate, 2022). The author notes that there exists considerable overlap between the factors identified in the commercial and DoD sectors. Further, few of the factors identified by OSD are so defense-specific as to be inapplicable in the commercial sector.

Table 2 summarizes the attributes of the supply chain management domain by the commercial sector and the government sector.

Table 2: Supply chain management domain attributes for the commercial and DoD sectors

Topic area	Commercial	DoD
Visibility of Supply Chain	Good	Limited
Reason for strengthening supply chains	Strategic business imperative	National security imperative
Emphasis of supply chain management	Efficiency and cost	Security and resiliency
Approach to assessing supply chain resiliency	Stochastic modeling, supplier audits	Surveys (or nothing)
Predictive risk analysis (or factors)	See Table 1	OSD framework and taxonomy

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The foregoing suggests that while the commercial sector and the DoD are motivated by different imperatives, they share a common concern about supply chain resiliency. Both sectors have considerable commonality in the factors believed to influence resiliency. Similarly, both sectors are constrained by limitations in accurately identifying their full supply chain and quantitatively measuring predictive risk factors for each element therein. This suggests that the DoD might leverage much of the current and future commercial sector SCRM research by tailoring it to its specific needs and concerns.

Limitations of the current research

The author's literature review revealed considerable depth in some areas, including definitions of "risk", the emergence of theory and practice in the field of supply chain risk management particularly as globalization has grown apace, and "supply chain resilience" as a desirable attribute, especially following economic and environmental shocks. The author noted several gaps in the literature that point to topics for further research:

- There is clearly a lack of peer-reviewed research into DoD supply chain risk analysis, especially the risk factors and mitigation options that are unique to defense industrial base.
- The author found limited research into quantitative factors used to assess individual company risks. This observation includes the factors themselves, measurement methods, and approaches for assessing their efficacy. Relatedly, the author has not yet found research into the development of composite risk measures derived from multiple factors assessed at the company level.
- The author found no substantive references to reliable, repeatable, and current data sources that could be used to quantify risk factors.
- The author found research gaps identified in some of the articles that were reviewed and agrees that they could point to further research. Notably, Khan, et. al. state that current research on supply chain risk management frequently lacks a grounding in risk theory. They also note that many supply chain risk factors identified in prior research are too broad and are not necessarily quantifiable or even measurable.

Contributions

Heightened geo-political tensions, trade wars, and a world-wide pandemic have magnified interest in supply chain risk and resiliency in both the commercial and government sectors. This article highlights the distinction between supply chain management, which focuses on efficient operations, and supply chain risk management, which emphasizes improved resiliency. The literature review indicated increasing amounts of research in SCRM since 2000 as globalization grew apace, supply chains became increasingly complex, and exogenous shocks caused world-wide impacts.

The peer-reviewed literature on both supply chain management and SCRM are heavily weighted toward the commercial sector. Conversely, literature addressing DoD supply chain risk assessment and resiliency typically derive from government reports, research conducted by private institutes (i.e. "think-tanks"), and commercial entities that summarize the aforementioned reports. There is very little peer-reviewed research on DoD supply chain risk management

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efforts. The author noted that the commercial sector and the DoD are motivated by different supply chain imperatives. Nevertheless, they share a common concern about supply chain resiliency.

Future research proposed by this article will focus on identifying risk factors that predict DoD supply chain vulnerability. The author's literature review revealed a wide range of factors that can be grouped into risk categories. Table 1 illustrated a sample of risk factors and categories. There exists significant commonality between factors from the literature, which primarily address the commercial sector, and factors identified in current and previous DoD supply chain risk assessment efforts. This overlap suggests that SCRM research in the commercial sector may serve as a useful reference for investigating risk factors that increase vulnerability in DoD supply chains.

In addition to the dearth of peer-reviewed literature on DoD supply chain risk management, the author noted other limitations and opportunities for further investigation. These include a lack of rigorous research into:

- Operationalization of supply chain risk factors so that they may be quantified
- Data sources, either publicly available or accessible by the DoD, to inform risk factors
- Methodologies for quantifying risk factors when data are available
- Quantitative assessment of risk factors' predictive ability
- Approaches to build composite risk measures or to assess risk based on factors that span multiple domains
- Risk factors and mitigation options that are unique to the DoD
- Application of big data and machine learning in quantifying risk factors

This article briefly discusses an industry with extensive research and practice in assessing risk and developing predictive models – finance. The author reviewed a single seminal article that launched an entire field of factor-based predictive modeling. The article demonstrates approaches for constructing factors from available data, building regression models, and identifying factors with statistically significant predictive capability. The literature on risk assessment and predictive analytics from the finance industry may also serve as a reference for research into supply chain risk factors.

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Appendix A: Summary of Literature Review Keyword Searches

Database	Search Criteria or Cross Ref Source	Gross Returns	Selected articles	Title	Author	Cum Total
ABI/Inform	ab("supply chain risk") OR ab("industrial base risk")	233	2	Toward a supply chain risk identification and filtering framework using systems theory	Hou, Jianrong; Zhao, Xiaofeng	2
				Supply Chain Risk Management: Literature Review	Amulya Gurtu, Jestin Johny	2
Cross-Reference	Supply Chain Risk Management: Literature Review	N/A	1	An analysis of supply risk assessment techniques	Zsidisin, George A., Ellram, McCarter,and Cavinato	3
Cross-Reference	Supply Chain Risk Management: Literature Review	N/A	1	A grounded definition of supply risk.	Zsidisin, George A.	4
Cross-Reference	Supply Chain Risk Management: Literature Review	N/A	1	Analytical framework for supply network risk propagation	Myles D Garvey, Steven Carnovaleb, Sengun Yeniyurt	5
Cross-Reference	Supply Chain Risk Management: Literature Review	N/A	1	Risk and supply chain management: creating a research agenda	Khan, Omera Burnes, Bernard	6
Cross-Reference	Risk and supply chain management: creating a research agenda	N/A	1	How to Identify Vendor Risk	Michalski, Liz	7
Cross-Reference	Risk and supply chain management: creating a research agenda	N/A	1	Risk: Analysis, Perception and Management	Royal Society (1992)	8
ABI/Inform	ab(defense) AND ab(industrial base)	29	1	Preserving the Industrial Base	Kinne, Christopher E, USAF	9
ABI/Inform	ab(supply chain) AND ab(risk) AND ab(analysis)	466	1	How to evaluate supply chain risks, including sustainable aspects	Medina-Serrano, Rubén; González-Ramírez, Reyes; Gasco-Gasco, Jose; Llopis-Taverner, Juan.	10
ABI/Inform	ab(supplier) AND ab(risk) AND ab(predict)	15	4	Survival analysis of supply chain financial risk	Scott Dellana and David West	14
				Credit Rating Prediction Through Supply Chains: A Machine Learning Approach	Wu, Jing; Zhang, Zhaocheng; Zhou, Sean X.	14
				A hybrid ensemble and AHP approach for resilient supplier selection	Seyedmohsen Hosseini · Abdullah Al Khaled	14
				The impact of risk management on the frequency of supply chain disruptions	Revilla, Elena; Maria Jesus Saenz.	14
Cross-Reference	Survival analysis of supply chain financial risk	N/A	1	Financial Ratios, Discriminant Analysis and The Prediction of Corporate Bankruptcy	Altman, Edward I.	15
Cross-Reference	Supply chain risk management: a literature review	N/A	1	Perspectives in Supply Chain Risk Management	Tang, C. S. (2006)	16
JSTOR	Supply & Chain & Risk & Factors & Resilience	1359	3	Implementing Supply Chain Resiliency	Lewis, James A.	19
				A Comprehensive Risk Assessment and Evaluation Model: Proposing a Risk Priority Continuum	Stanley E. Griffis and Judith M. Whipple	19
				Recovery with Resilience Diversifying Supply Chains to Reduce Risk in the Global Economy	Runde, Daniel F.	19

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