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Multi-factor Modeling as an Enabler of Supply Chain Risk Management

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Supply chains of large-scale, technologically complex products rely on a vast network of suppliers. While supply chain efficiency has improved with the expansion of globalization, supply chain resiliency appears to have worsened. Some would argue, in light of the effects of a global pandemic and war in Eastern Europe, that supply chains have become increasingly fragile. Suppliers to the US Department of Defense (DoD), the focus of the author's research and professional work, decreased from 71,655 to 46,180 in the ten years to 2020. The DoD is investing heavily in assessing the resiliency of its supply chains and strengthening its industrial base.

Supply Chain Management, and its focus on efficiency, has long been the subject of academic research and corporate investment. Since 2000, academic research has expanded to address Supply Chain Risk Management (SCRM) and its focus on resiliency. In this paper, the author explores the potential application of multi-factor models in identifying and assessing risk factors that impact supply chain resiliency. Specifically, the author addresses the question of identifying which factors best predict supplier vulnerability and using publicly available data to populate models that assess individual supplier risk exposure. Accurate risk assessment models would enable users to devote limited resources to in-depth analysis of the most vulnerable companies and implement preemptive mitigations.

This paper provides a brief review of the extant literature, in which the author finds a lack of peer-reviewed research in the DoD supply chain risk management, but encouragingly, finds increasing research and the application of theory into SCRM for the commercial sector. The author briefly reviews risk management theory and its application in the supply chain domain. The author draws on established risk management standards to define a taxonomy that will ensure consistency throughout the research and discussion. This paper provides an overview of multi-factor modeling common in the finance domain, including its origins and basic theoretical underpinnings. The author argues for the application of multi-factor models in assessing companies for risk exposure rather than predicting future financial returns. This novel approach could increase accuracy and efficiency in assessing the thousands of companies that supply large-scale complex products.

This article concludes with a description of the author's efforts to develop a data analytics tool to illuminate and assess supply chain risks in large-scale weapon systems procured by the US Department of Defense. This project is one of many being conducted by the DoD and illustrates the emphasis on developing innovative approaches to predict supplier vulnerability in times of increasing supply chain fragility.

In today's globalized business environment, robust supply chain risk management is imperative. Multi-factor modeling, used by financial portfolio analysts, could be used to assess supply chain vulnerabilities.

Keywords: Supply Chain Risk Management, Multi-factor Modeling, Factor Analysis, Department of Defense, DoD, Resilience, Fragility, Corporate Failure Prediction, Risk Factors.

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 production. This research defines "supplier failure" as an event or condition that precludes a supplier from delivering what is needed at the right time. These conditions include, but are not limited to, insolvency, exiting the market for a given product, ceasing to sell to the DoD, ceding ownership to prohibited entities (adversarial nations), discontinuing the desired product, and debarment from Government contracting.

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 companies. While supplier failure is not completely predictable, observable factors may indicate potential supplier risk that leads to vulnerability in DoD supply chains.

A recent study by the DoD produced a "framework and taxonomy" that included 115 factors in twelve categories that could be used to indicate supply chain risk (Office of Secretary of Defense - Logistics Directorate, 2022). Data availability from public and subscription-based databases, web scraping, and other sources have made available vast quantities of information and the identification of even more potential risk factors. Since risk analysis and prediction are imprecise, human analysis must be devoted to those companies with the greatest potential vulnerability. This leads to the following research question:

RQ: What factors are most predictive of DoD supply chain vulnerabilities?

Finance theory is accustomed to analyzing many factors to predict future stock returns. The author proposes to employ multi-factor modeling, common in securities analysis, to determine the most effective predictors of supply chain vulnerability. This approach, if proven, will give practitioners a manageable set of factors that can be assessed by automated data collection and analysis tools. By automating most of the data management, analysts can devote their limited resources to investigating suppliers exhibiting the greatest vulnerabilities.

Review of Research

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 US 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 US Government is increasingly focusing its efforts on understanding the health of the US DIB and developing initiatives to strengthen it (House Armed Services Committee, 2022; Interagency Task Force in Fulfillment of Executive Order 13806, 2018; US Department of Defense, 2022). 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 (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 new permanent circumstances. (Haimes, 2009; Han et al., 2020).

Similar to corporations' interest in supply chain resiliency measurement, the US Department of Defense (DoD) has increased its focus on identifying industrial base risks that result in supplier failure (Task Force on National Security and US Manufacturing Competitiveness, 2021).

Early research in supply chain resiliency developed conceptual supply chain models and identified factors likely to impact resiliency (Sheffi & Rice, 2005). The 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, 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. 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 (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 to supply chain resiliency. The body of literature on supply chain risk management and supply chain resiliency has expanded greatly since 2001 as shown in Figure 1 (Fan & Stevenson, 2018).

Risk Management Theory

The author observed in the research an increasing integration of risk management theory, formerly emphasized in project management, into the supply

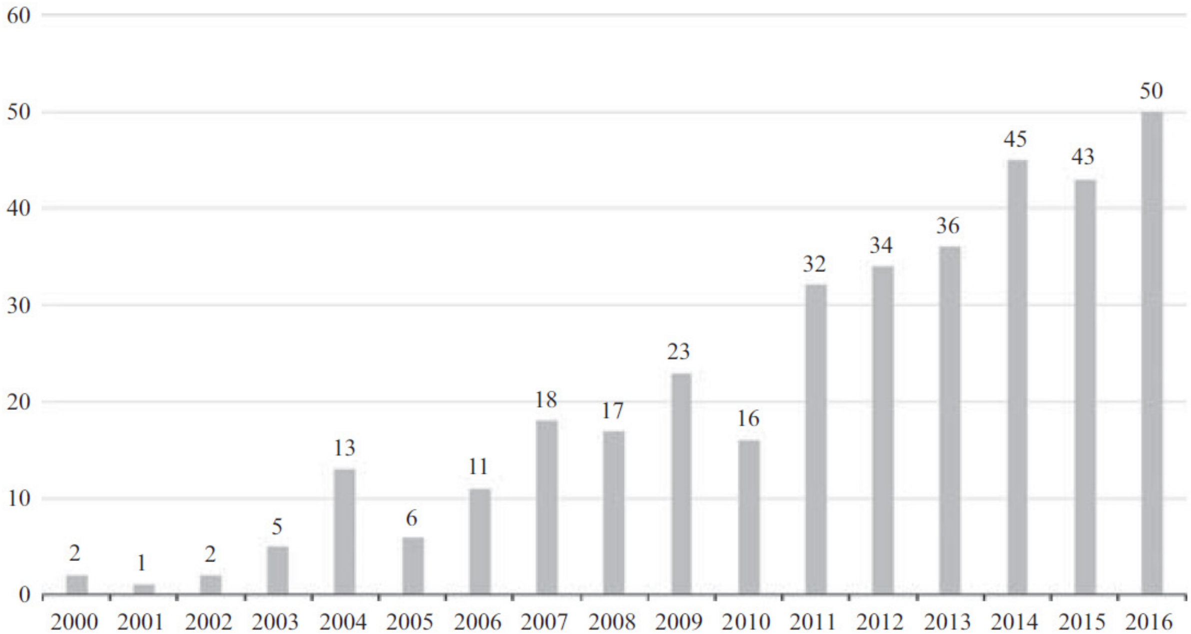

Figure 1: Number of SCRM-related Articles per Year (Source: Fan et. al. 2017)

chain management domain. The extant literature includes many worthy examples of risk taxonomies. The International Standards Organization defines risk as "the effect of uncertainty on objectives" (International Organization for Standardization (ISO), 2018). Risk gives rise to vulnerability, defined within supply chains as "an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain" (Peck, 2006). Appendix A provides additional definitions used in this article.

The author also found various risk management frameworks, with multiple researchers suggesting variations of a four-stage SCRM process that will be used in this paper: (Bak, 2018; Choudhary et al., 2023; Fan & Stevenson, 2018)

1. Risk identification
2. Risk assessment
3. Risk treatment (or mitigation)
4. Risk monitoring

The distinction blurs between Stages 1 and 2. Risk identification is normally assumed to mean the discovery of all risks relevant to the activity under analysis. The process is subjective and should entail a comprehensive approach to ensure it recognizes events with the potential to cause unintended outcomes. In their structured literature review (SLR), Fan & Stevenson (2018) discuss multiple novel approaches to risk identification and note that some have not been applied at all or have been applied only by researchers. Only a few are actually used by companies. Conversely, practitioners tend toward simpler, proven approaches like cause-and-effect diagrams. Thus there exists a gap between methods advocated by research and those used in practice (Fan & Stevenson, 2018).

Risk assessment refers to an analysis of risks for their probability of occurrence and the impact of the associated consequences (Ho et al., 2015). Risk assessment assumes the prior completion of risk identification. In practice, identification and assessment take place iteratively. Multiple authors have examined risk assessment approaches through literature reviews and documented qualitative and quantitative methods. All note that there exists no one-size-fits-all approach (Choudhary et al., 2023; Fan & Stevenson, 2018; Ho et al., 2015). The quantitative approaches that were reviewed do not provide guidance on sources of data that were used in the computations. The foregoing indicates an opportunity for further research in quantifying the subjective risk factors used in F&C, SCRAM, and other risk assessment approaches by using publicly available data that can be structured and analyzed.

Choudhary et. al. note that understanding of supply chain risk has expanded beyond purely economic parameters to include parameters capturing geopolitical, technological, social, and environmental factors (Choudhary et al., 2023). The author expanded the literature search 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. Figure 2 illustrates the author's literature review approach. Table 1 summarizes the most promising and relevant supply chain risk factors addressed in the literature search.

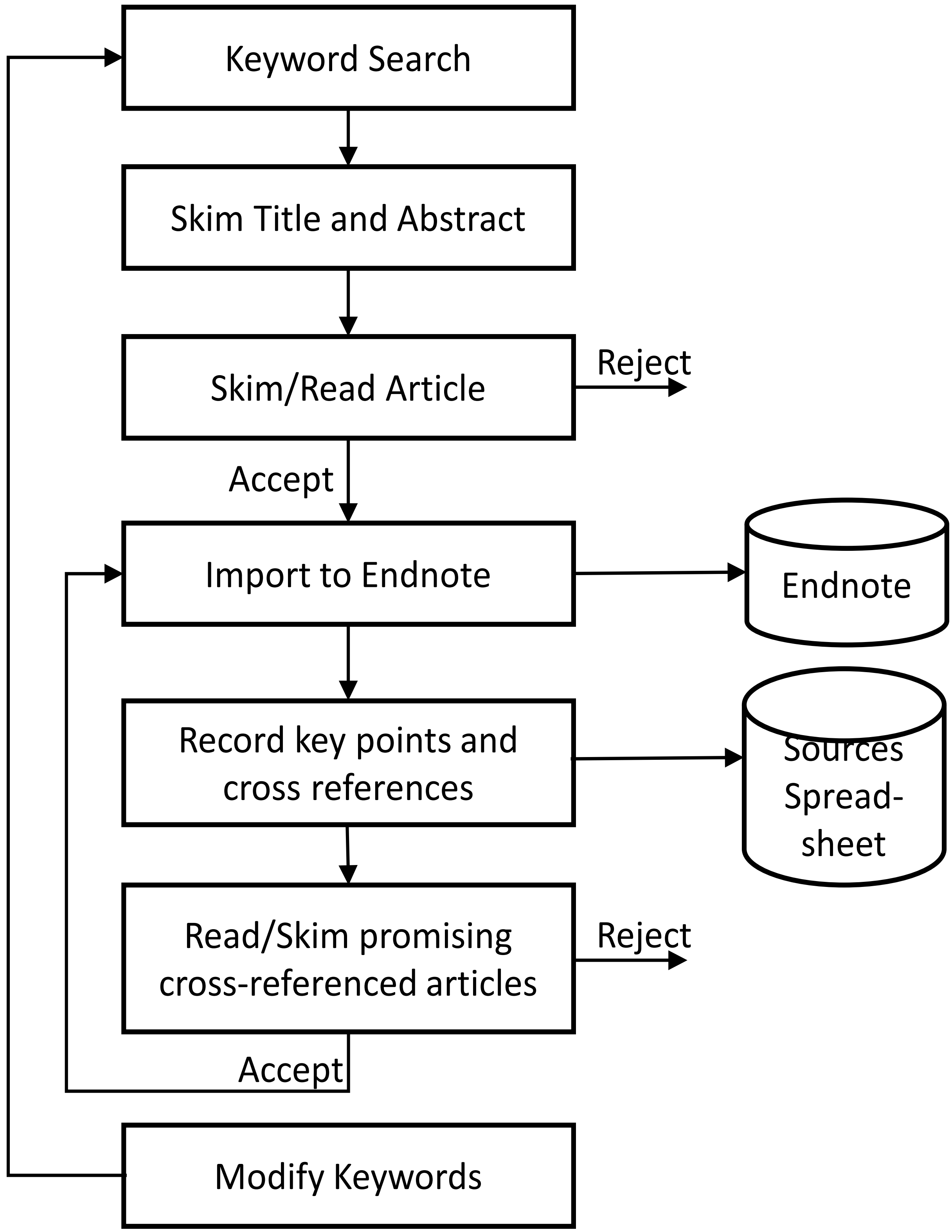

Figure 2: Keyword Search Approach

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

Risk Types	Risk Factors	References
Financial	Bankruptcy risk	(Zsidisin et al., 2004)
	Credit availability	(Ho et al., 2015)
	Company size	(Zsidisin, 2003)
	Lack of Funding Sources	(OSD Logistics, 2022)
Quality	Ability to meet product specs	(Zsidisin et al., 2004)
	Production capacity	(Ho et al., 2015)
	Counterfeit Parts	(OSD Logistics, 2022)
	Surge capacity	(Zsidisin, 2003)
Environmental/Geographic	Natural disaster regions	(Zsidisin et al., 2004)
	Quality of regional infrastructure	(Ho et al, 2015)
	Proximity to customer	(Runde & Ramanujam, 2020)
	Proximity to customer	(Kumar et al., 2014)
Technology & Cyber Security	Unsecure Networks or Systems	(OSD Logistics, 2022)
	Hardware/Software vulnerability	(OSD Logistics, 2022)
	Cyber Attack	(OSD Logistics, 2022)
	Information system quality	(Ho, et al., 2015)
	Info infrastructure breakdown	(Chopra & Sodhi, 2004)
Legal & Regulatory	Environmental compliance	(Zsidisin et al., 2004)
	Labor law compliance	(Zsidisin, 2003)
	Access to Intellectual Property	(Ho, et al., 2015)
Foreign Ownership Control or Influence (FOCI)	Weaponized M&A	(OSD Logistics, 2022)
	Industrial Espionage	
	State-owned Company	
	Nationalization	
Customer Demand	Demand variability	(Zsidisin, 2003)
	Demand variability	(Ho et al., 2015)
Supply	Over-dependence on customer	(Zsidisin, et al., 2004)
	Competing customer obligations	(Zsidisin, 2003)
	Sole source supplier	(Ho et al., 2015)
	Raw material supply	(Ho et al., 2015)
	Subcontractor concentration	(Ho et al., 2015)
	Alternate suppliers	(Ho et al., 2015)
	Part Obsolescence	(OSD Logistics, 2022)
Human Capital	Lack of Access to Capable Workforce	(OSD Logistics, 2022)
	Knowledge Management	(Wu et al., 2006)
Political	Import/Export restrictions	(Zsidisin et al., 2004)
	Interstate conflict (War)	(OSD Logistics, 2022)
	Political instability/terrorism	(Kumar et al., 2014)
	Labor strength/relations	(Runde & Ramanujam, 2020)
	Government interference	(Zsidisin, 2003)

Theory usage in SCRM research

Fan et. al. analyzed theory usage by proposing four categories of increasing robustness:

1. Informed by Theory: A framework is identified but there exists limited or no application
2. Applying Theory: A framework is specified and some/all constructs are applied in the study
3. Theory Testing: A framework is specified and some/all constructs are measured and tested
4. Theory Building: A new or expanded theory is developed based on constructs specified and analyzed

The authors note the most reviewed literature falls toward the "Informed by Theory" end of the spectrum and asserts that research is not yet realizing the potential of theory usage. Figure 3 below illustrates the broadening of theory used in SCRM research over time. In keeping with the conclusions of multiple authors, supply chain risk management is a trans-disciplinary endeavor and one would expect supporting theories to derive from a wide range of fields (Choudhary et al., 2023; Fan & Stevenson, 2018; Gligor et al., 2019).

Gaps

The author's literature review revealed considerable depth in some areas, including definitions of risk, increasing emphasis on SCRM in both research and practice as globalization has grown apace, and "supply chain resilience" as a desirable attribute, especially following economic and environmental shocks. The author noted several gaps that point to potential research areas:

- 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 the defense industrial base.
- The author found limited research into quantitative factors used to assess individual company risks. This observation includes identifying the factors themselves, measurement methods, and approaches for assessing their efficacy. Relatedly, the author has not yet found research into the development composite risk measures derived from multiple factors assessed at the company level.
- 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 & Burnes (2007) 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 (Khan & Burnes, 2007).
- Numerous researchers note the limited amount of theory usage in the extant literature on SCRM and supply chain resilience (Fan & Stevenson, 2018; Gölgeci & Gligor, 2022).

The Theory

The author proposes to use multi-factor modeling and its application in finance theory as a guide to determining the quantifiable risk factors that best predict supply chain vulnerabilities. Once identified, the set of most predictive risk factors could be used to construct composite risk profiles that prioritize suspect companies for in depth research by analysts.

Harry Markowitz developed modern portfolio theory (Markowitz, 1952) based on the idea of a risk-reward tradeoff in which reward was defined as a portfolio's expected return and risk was defined as the variance of the returns. The framework is referred to as "mean-variance analysis." Subsequent researchers extended the concept to argue that expected returns depended on a single explanatory variable – the market return. The resultant model is known as the capital asset pricing model (CAPM) and is formulated as:

$$E[R_n] - R_f = \beta_n (E[R_m] - R_f)$$

	2000				2001				2002				2003				2004				2005			
Theory use	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B
TCE									1	1							1							
Agency theory														1				1						
Systam theory																	1				1			
Institution theory																						1		
RBV																								
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KBV																								
Manufactueing Strategy theory																								
Expectation confirmation theory																								
Infomation processing theory																								
Complementarity theory																								
Total									1	1				1			2	1			1	1		

	2006				2007				2008				2009				2010				2011			
Theory use	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B
TCE		1								1							1				1			
Agency theory							1		1															
Systam theory																								
Institution theory																								
RBV		1								1			1											
Resource dependence theory									1								1							
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Total		2					1		2	2			2				2	1	1		1	3		

	2012				2013				2014				2015				2016			
Theory use	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B	I	A	T	B
TCE				1			1													
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Systam theory													1							
Institution theory																	1			
RBV																	1			
Resource dependence theory																		1		
Contingency theory					1								1					2		
Normal accident theory											1						1			
Real option theory																				
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High reliability theory																	1			
Social capital theory		1				1				1										
Modular systems theory							1													
Stakeholder theory									1	1										
Regulatory focus theory											1									
KBV															1					
Manufactueing Strategy theory																	1			
Expectation confirmation theory																		1		
Infomation processing theory																		2		
Complementarity theory																		1		
Total		1		1	1	1	2		1	3	2		2		1		5	8		

Figure 3: Theory Usage in Reviewed Articles (Source: Fan & Stevenson, 2018.)

Where:

- R_n is the return of asset n
- R_f is the return of the risk-free asset (usually assumed to be a US Government treasury bond)
- β_n is the coefficient defining the exposure to the market variable (or factor)
- $E[R_m]$ is the expected market return

While elegant and simple, the CAPM has not proved to be particularly powerful as a predictor (Gundersen, 2022). Subsequently, researchers extended the CAPM by developing multi-factor models, the best-known of which is probably the Fama-French three factor model. Fama and French observed that two classes of stock tended to outperform the market: small capitalization stocks and those with a high book value to price ratio (commonly referred to as value stocks). The resultant model was:

$$r - R_f = \beta_M \times (R_m - R_f) + \beta_S \times SMB + \beta_H \times HML + \text{alpha}$$

Where:

- r is the return of asset n
- R_f is the return of the risk-free asset
- R_m is the market's return
- β_n is the coefficient of each respective factor
- SMB is "Small minus Big" defined as a measure of a company's relative size
- HML is "High minus Low" defined as a measure of a company's relative Price/Book ratio
- alpha is the return not explained by the three factors.

The coefficients were determined through linear regression. Fama and French concluded that the model explained over 90% of market portfolio returns, compared with only 70% predicted with the CAPM alone. (Fama & French, 1993). Subsequent research also concluded that the 3-factor model is superior to the CAPM, but in varying degrees. Griffin showed that the 3 model factors are country-specific, concluded that local (country-specific) factors are more predictive, and confirmed that the 3 factor model is still more predictive than the CAPM (Griffin, 2002). This suggests that multi-factor modeling can be effective in predicting future returns but factors may be environment-dependent and warrant careful analysis and selection.

Rosenberg (1974) noted that the same multi-factor modeling procedures used to estimate returns could be used to explain portfolio risk (The Research Foundation of The Institute of Chartered Financial Analysts, 1994). While the definition of portfolio risk (variance of returns) differs significantly from the risk factors affecting supply chains, the multi-factor model seems to hold some promise.

Multi-factor models, which are based on observable (and measurable) variables, can be further enhanced through factor analysis. Factor analysis is a statistical method used to identify underlying patterns in a dataset and to use them to develop linear factor models. The method assumes that observed variables in the data can be represented through a multiple linear regression on a smaller number of latent or unobserved variables known as factors (Fabozzi et al., 2014). The explicit form of the general factor model is given by:

yNt = aN + bN1 f1t +….+ bNq fqt + εNt

Where:

- yNt is the dependent variable
- aN is the constant term
- bN1 is the coefficient called factor loading
- f1t is the hidden factor
- εNt is the error term or the residual

The model is used to systematically identify the hidden relationships (factors) between measured variables (Sreejesh et al., 2013).

Applications of the Theory

The author currently leads a project to develop a software tool to ingest internal and publicly available data to assess risk in DoD supply chains. Figure 4 illustrates the conceptual model for identifying and quantifying potential vulnerabilities in the supply chain supporting a DoD system.

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.

However, the surge in interest and research in SCRM has led to a proliferation of potential risk factors across a wide spectrum of domains that could potentially predict supplier vulnerability. In its recent "Taxonomy and Framework Final Report", the DoD identified 115 factors in twelve domains that could indicate risk (Office of Secretary of Defense - Logistics Directorate, 2022). Additionally, there exist many other measures related to the factors identified by DoD. Analysts would likely be overwhelmed by the data when attempting to assess which companies present the greatest risk. Finally, acquiring the data needed to populate the risk factors is costly, may re-

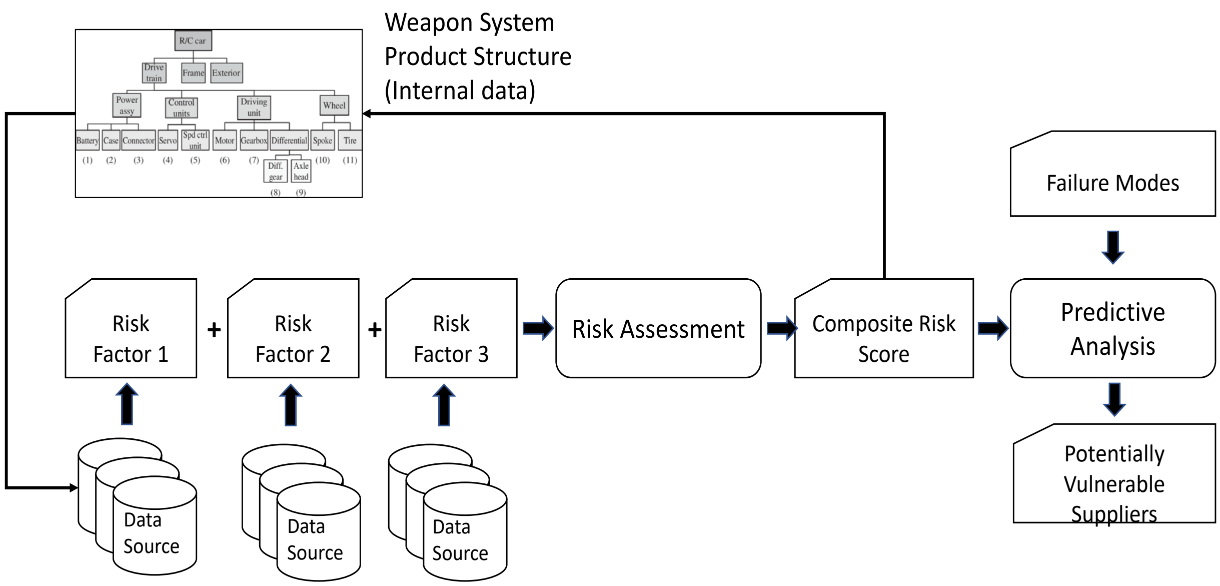

Figure 4: Proposed Conceptual Model

quire significant pre-processing, and would add significant complexity to the software architecture.

The author suggests that multi-factor modeling and factor analysis offer methodical approaches to assessing supply chain risks using the smallest number of predictive variables possible.

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

Limitations

The author's proposed application of multi-factor modeling theory to supply chain risk assessment has not yet been tested empirically. The work of this author and his colleagues for the DoD has produced a prototype risk assessment tool that evaluates companies on sixteen risk factors, develops composite scores evaluated on two dimensions (likelihood and severity), and produces a prioritized list of at-risk suppliers. The model's assessment results have not been formally evaluated nor have they yet been used to inform mitigation decisions. Nevertheless, the prototype forms the foundation for a subsequent tool currently under development that will incorporate more sophisticated risk factor selection, measurement, aggregation, and assessment. The author is aware of other tools under development that take similar approaches to supplier risk assessment. These efforts and DoD investment in related activities strongly indicate the demand for supply chain risk assessment approaches and future opportunities to assess their validity. The author believes the grounding in academic research of his project and that of other initiatives holds promise for moving SCRM tools from "informed by theory" to "application of theory" and ultimately to "theory testing."

A second key limitation in the author's research is the lack of company failures (independent variable) against which to assess the tool's effectiveness through regression testing. The limitation is compounded by the time lag between risk identification and visible consequences should the risk be realized. These limitations will likely cause model evolution to be slow and imprecise. The author believes this limitation is somewhat mitigated by the tool's inherent purpose. The author's tool, and others like it, are not intended to conclusively identify which companies will fail. Rather, the tools identify companies exhibiting high vulnerability that warrant deeper investigation by human analysts. The author believes that a well-constructed assessment tool that is grounded in research will help identify high-risk companies which, upon closer manual inspection, will warrant intervention. While the tool's developers (and the program managers who rely on the at-risk company) will never know if a failure would have occurred absent an intervention, the tool's assessment facilitates informed risk management. Specifically, program managers can compare the costs associated with analysis and mitigation with the projected impacts of failure to assess if the approach adds value.

Discussion

This article reviews the literature on supply chain risk management and notes increasing peer-reviewed research that mirrors industry's greater focus on SCRM since the turn of century. This is due in part to forces that increase supply chain complexity (globalization) and events that reveal greater fragility (terrorist events, financial crises, wars, and pandemics). The literature simultaneously observes the dearth of theory-based SCRM approaches used in practice and the expanding set of theories that have been suggested to inform SCRM research.

This article seeks to address some of the criticisms levied in the literature that SCRM does not incorporate theory by proposing the application of a multi-factor model approach that is widely used in the finance domain to selectively assess a wide range of predictive factors. Multifactor modeling shows promise in SCRM applications, especially in aggregating multiple disparate factors that likely contribute to a firm's overall risk posture. Multi-factor modeling theory could bring rigor to the development of risk assessment tools through methodical approach to factor selection, measurement, and aggregation.

While not its primary focus, this article also incorporates some aspects of risk management theory. The reviewed literature asserts that most proposed SCRM approaches have not yet fully incorporated risk theory. The author's DoD supply chain risk assessment prototype tool relies heavily the DoD's Risk Taxonomy and Framework report. The report is grounded in standard risk management processes that are common in the project management domain. This paper summarizes some of the foundational elements of risk management theory and identifies which of the competing concepts and definitions it uses.

The author notes that multi-factor modeling achieved proven success in Fama and French's three-factor model. The model identified three company-specific factors that could explain 90% of the returns in a diversified portfolio. Subsequent multi-factor models by Fama and French and others employed both company-specific factors and macro factors (interest rates, GDP growth, unemployment, and others) to predict stock returns. This author suggests that the multi-factor modeling approaches used to predict future stock returns, which can be interpreted as a proxy for company performance, are applicable in predicting company vulnerability caused by observable risk factors.

This paper suggests a conceptual model that employs multi-factor risk assessment of companies that exist in a supply chain. The conceptual model describes the use of multiple data sources to inform the risk factors of the multi-factor model, the development of composite risk scores, and ultimately a prioritized set of at-risk companies in the context of the entire supply chain. This approach expands on the multi-factor modeling used in predicting stock returns by enabling analysts to see risk concentrations in the supply chain and to make informed judgements about systemic impacts.

The author's proposition is preliminary and only scratches the surface of potentially SCRM-relevant theories. However, the paper describes a current initiative that moves the research from "informed by theory" closer to "application of theory." The prototype assessment tool under development by the DoD helps chart a course for building an artifact that can be tested and revised iteratively.

Conclusions

This paper describes the proposed application of multi-factor modeling to supply chain risk management, a relevant issue with increasing levels of practitioner and researcher interest. The SCRM field is rich with data, presents a wide range of industry applications, and is facilitated by increasing data availability and computing power. The application of theory in SCRM research and practice is still nascent and presents a great opportunity to leverage theory and approaches that have been refined in other fields including finance, marketing, and medical research. The author proposes the application of multi-factor modeling theory, in a fashion similar a proven approach from finance, to identify the most predictive SCRM factors, aggregate them to form composite risk profiles, and ultimately assess their validity. Multi-factor modeling could lead to opportunities to explore factor analysis to further enhance predictive models.

This paper points out that risk management theories are clearly relevant to SCRM and the application of those theories, while not as robust as in other domains like project management, is well underway. There exist opportunities to tailor the use of risk management theory and practice to the specific needs of the SCRM domain.

In today's globalized business environment, robust supply chain risk management is a competitive advantage and, in the DoD's case, a national imperative. This paper proposes a path toward the adoption of theory in research and application of supply chain risk analysis and management tools.

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Review

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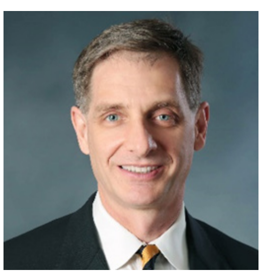

Will Cook is co-founder and CFO of QED Analytics, a privately held defense contractor that specializes in engineering, acquisition, business operations, and research in the social sciences. He has more than 20 years' experience in manufacturing, operations, financial management, and data analytics. In addition to his corporate roles at QED, Will directly supports clients by conducting industrial base and supply chain risk analyses. He has been instrumental in developing a suite of analysis tools that captures data from external sources to identify industrial base vulnerabilities. He is currently pursuing a doctorate at the University of South Florida.

Appendix A: Risk Management Definitions

Table A1. Risk Management Definitions

Term	Definition
Risk	The probability of realizing an unintended or unwanted consequence that leads to an undesirable outcome such as loss, injury, harm, or missed opportunity (Schlegel & Trent, 2015)
Risk	The effect of uncertainty on objectives (International Organization for Standardization (ISO), 2018)
Uncertainty	The condition in which outcomes and their probabilities of occurrences are not known to the decision-maker. (Park & Shapira, 2017)
Supply chain vulnerability	An exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain (Peck, 2006)
Consequence	The outcome of an event affecting objectives (International Organization for Standardization (ISO), 2018)
Supply Chain Management	The management of upstream and downstream relationships with suppliers and customers in order to create enhanced value in the final market place at less cost to the supply chain as a whole. (Schlegel & Trent, 2015)
Supply Chain Risk Management (SCRM)	The implementation of strategies to manage everyday and exceptional risks along the supply chain through continuous risk assessment with the objective of reducing vulnerability and ensuring continuity. (Office of Secretary of Defense - Logistics Directorate, 2022)
Supply Chain Resilience	The capability of supply chains to respond quickly, so as to ensure continuity of operations after a disruption, and to quickly adapt to change. (Office of Secretary of Defense - Logistics Directorate, 2022)