Research Report

Measuring and Managing Army Supply Chain Risk

A Quantitative Approach by Item Number and Commercial Entity Code

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Preface

This report was produced under a project entitled, "Diagnostic Tools for Supply Chain Risk Analysis," which developed a Supply Chain Risk identification process, including data analysis tools to support Army Materiel Command's (AMC's) implementation of strategic sourcing and supplier relationship management. This project is intended to help AMC identify supply chain risks at the enterprise level and thereby inform AMC's strategic sourcing partnership selection. The tools and processes developed in this work should also help identify supply chain risk by providing a means to assess the likelihood and consequences of supply chain disruptions.

This report presents the methodology used to estimate supply chain risk, including the databases exploited for this purpose. It also presents a general background on supply chain risk management and how it relates to strategic sourcing/supplier relationship management (SS/SRM). We made an initial analysis of supply chain risk using a list of over 9,000 parts/NIINs (National Item Identification Numbers) that are currently under contract. The report presents risk scores by National Item Identification Number (NIIN), supplier, weapon system, and Life Cycle Management Command (LCMC).

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Executive Summary

As the United States Army winds down from over a decade of contingency operations, the Army's demand for spare parts is expected to decrease. However, the amount of the decrease is uncertain, as are the parts and vendors that will be most affected. Army Materiel Command (AMC) executives are concerned that a decrease in orders to suppliers could raise the risk that either the suppliers will fail or shift production, potentially disrupting the Army's supply chain. AMC is currently implementing a Strategic Sourcing and Supplier Relationship Management initiative, to help the Army reduce supply chain costs by identifying strategic suppliers and working closely with them to improve performance. The Strategic Sourcing initiative is focused on active suppliers producing parts to maintain ground and air weapon systems and communications equipment. As part of the Strategic Sourcing initiative, AMC asked RAND Arroyo Center to determine the supply chain risk by supplier and the supply chain risk factors that are critical to AMC. This report documents a process and tool that allow AMC to assess supply chain risk by supplier, part, and weapon system. Starting with 9,300 NIINs provided by AMC, we assembled information from multiple data sources to create a database that can be used to analyze risk by NIIN. We then linked the NIIN to the Commercial and Government Entity (CAGE) code to identify the supplier. For each NIIN, we calculated a heuristic score for (1) the likelihood that a vendor could fail to supply the NIIN, and (2) a heuristic score for the consequent impact on Army weapons systems. We are most concerned with the cases where there is a high likelihood of supply chain failure and a high impact on the Army. We concluded that only a few hundred of the 9,300 NIINs have much risk, mainly because of the large inventory still on hand. This does not imply that there is no risk, but rather, that the Army has time to address the risk. The database allowed us to assess risk further by source of supply and by system type and family. We also developed a database of 14,472 additional NIINs that did not have contract actions in the past three years. Consequently, we had little or no vendor information on them and could not assess the risk by vendor. We could, however, assess system risk, which is the consequence should the external supply chain be completely unavailable.

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Summary

The Army Materiel Command (AMC) is currently implementing a Strategic Sourcing (SS) and Supplier Relationship Management (SRM) initiative. This initiative seeks to leverage industry best practices to help the Army reduce supply chain costs, improve performance, and lower risk. The Strategic Sourcing/Supplier Relationship Management Implementation Plan (2012) lays out a roadmap for a transition which leverages industry best practices to help AMC identify candidates for strategic sourcing, assess AMC's spend, segment suppliers, develop metrics for AMC and suppliers, and create enterprise SS/SRM strategies.

The implementation of the SS/SRM initiative is being carried out across the AMC enterprise, by all the Life Cycle Management Commands (LCMCs): the Army Aviation and Missile Command (AMCOM), Tactical Command (TACOM), Communications-Electronics Command (CECOM), and Army Contracting Command (ACC). The initiative includes representatives from the Defense Logistics Agency (DLA) and from the Defense Contract Management Agency (DCMA).

An essential part of the implementation plan is to determine the supply chain risk factors that are critical to AMC and the supply chain risk presented by each supplier. This report documents a process and tool that allow AMC to assess supply chain risk by supplier, part, and weapon system.

As the United States Army winds down from over a decade of contingency operations in Iraq and Afghanistan, the Army's demand for spare parts and maintenance services is expected to decrease. However, the amount of the decrease is uncertain, as are the parts and vendors that will be most affected. Army Material Command executives have been concerned that the sudden fall in orders to suppliers could raise the risk that suppliers could fail, potentially disrupting the Army's supply chain.

AMC provided a list of more than 9,300 NIINs (National Item Identification Numbers) to assess for supply chain risk. These NIINs had contract actions from January 2010 through mid-July 2013. Based on these NIINs, we assembled a database to analyze risk by NIIN, which allowed us to further assess risk by supplier CAGE code (Commercial and Government Entity code). For each NIIN, we calculated a heuristic score for (1) the likelihood that a vendor could fail to supply the NIIN, and (2) a heuristic score measuring the consequent impact on Army weapons systems. Our measures included information about vendors' change in revenue and overall size, exposure to natural hazards, and whether the vendor location was foreign. For system impact risk, we linked the NIIN to the weapon system using maintenance records,[1] and

[1] We used RAND's Equipment Downtime Analyzer (EDA) to capture the parts used on a maintenance job order, including the serial number and national stock number (NSN) of the end item.

considered whether the NIIN was nonreparable, sole-sourced, had technical documents available, had short or long resupply lead-times, and whether it caused the weapon system to remain unoperational. The formula includes factors for the number of times the NIIN was associated with a weapon system being down at the end of the duty day. The risk score also includes an estimate of the days on hand for the NIIN, based on whether the contract is still in place, a forecast of annual issues, and washout rates (for reparable NIINs, the fraction of broken parts that could not be repaired).

We concluded that only a few hundred of the 9,300 NIINs are classified as having both a high likelihood of supply chain failure and high consequence to the Army. That is because many NIINs have a large amount of serviceable inventory (relative to demand) on hand. We acknowledge that long supply may increase future vendor risk. However, this study focused on examining the risk from the perspective of the Army. That is, what is the Army's risk exposure for a particular NIIN? If the Army still has sufficient supply to ride out the demand, the Army has lower exposure and more time to react to potential vendor failure.

The first analysis measured risk by NIIN. To measure risk by supplier, we summed risk by NIIN over vendor CAGE codes. This sum calculation tends to imply greater risk for those vendors that supply more NIINs; however, the sum takes into account the risk by NIIN too, so the rank order of risk by vendor depends on the risk of the vendor's NIINs, not just the number of NIINs.

The database then allowed us to assess risk by source of supply and by weapon system type and family.

Finally, we also developed a database of 14,472 additional NIINs that did not have contract actions in the past two years. Consequently, we had little or no vendor information on them and could not assess the risk by vendor. We could, however, assess weapon system risk, which would be the consequence of a failure of the external supply chain needed to bring in new assets. For reparable items, we assumed that either organic depots or external repair capacity would allow the Army to plan for enough repair capacity to meet demand. Supplier risk for reparable items was calculated based on the assumption that vendors would only be asked to replace the items that could no longer be repaired, i.e., demand that is generated by the part washout rate.[2]

The method developed can be used to identify the reasons for the risk score. For those few hundred NIINs that rank high on the risk list, the recommendations are straightforward.

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[2] We calculated washout rate at the installation level. When parts are sent to installation maintenance by the Supply Support Activity (SSA), they must be returned to the SSA in a serviceable condition code, an unserviceable but reparable condition code, or in a condemned condition code. We estimate the washout rate by calculating the percentage of the total number of parts that are sent to maintenance and returned condemned. The washout rate calculation did not include the washout at the depot level, but washout rates at depots would be calculated in a similar fashion by counting the items sent to depot repair and calculating the percentage of those items that subsequently were sent from the depot to DLA disposition services.

Which Risks Are Most Important to the Army?

We conducted a workshop with the AMC's Strategic Sourcing Working Group (SSWG), to elicit their concerns about supplier risks facing the Army. Their responses are summarized in Table S.1.

Table S.1. Supplier Risks Faced by AMC, As Identified by the Strategic Sourcing Working Group

Labor disruptions—external strikes, internal BRAC	Funding consistency & timing
Delays in contracting awards	Lifecycle changes
Length of & scope of terms of contract	Sequester—small firms going out of business
Counterfeit parts	Long administration & production lead times/delays in contracting
Quality escapes	Business consolidations
Aging infrastructure & workforce	Unpredictability in ordering, changes in demand
Delay in receipt recording at storage facility	Acts of God: fire, quake, flood, hurricane
Raw material shortage	First article test (FAT) requirement extends delivery schedule
Foreign sources of supply, geopolitical issues	Lack of mitigation plans at prime & lower tiers
Extended development time & costs	Database inaccuracies

Following the development of this list, we asked the working group to select the top three risks. They selected demand fluctuation, funding uncertainty, and long lead-times. Based on these top three concerns, we identified data that could help measure the associated risk from a particular NIIN and a particular supplier. We found, however, that data are not available to measure all of the risks described in Table S.1.

Recommendations to Reduce the Likelihood of Vendor Supply Failure

- First, address high-risk suppliers that provide many parts, even if the average risk per NIIN is low. Efforts to improve these relationships are likely to have the biggest payoff.
- Then address high-risk suppliers that provide only a few parts. These suppliers will have a high average risk per NIIN.
- If no contract is in place, assess whether a new contract needs to be made.
- Assess whether the existing vendor has contingency plans in place to manage natural hazard.
- If the vendor is foreign and single-sourced, assess whether production can be done in the United States.

Recommendations to Reduce System Impact

- Consider obtaining technical documents where they are missing.
- Assess inventory levels, and consider ordering additional quantities.

- For reparables, assess whether the repair cycle can be improved.
- For nonreparables, assess whether the NIIN could be made reparable.

Recommendations to Reduce Risks from Internal Processes

Improving Internal Processes

The Strategic Sourcing Working Group workshop, held May 1, 2013, identified the key risks as demand fluctuation, funding uncertainty, and long lead-times (including production, but especially contract and administrative). These risks stem mainly from internal processes.

Demand fluctuation and funding uncertainty are not particularly under AMC control. However, AMC may wish to consider initiating an "internal supplier management" process, to improve demand planning and forecasting, and to reduce its internal lead-times.

Improving Inventory Management

Thus far, we have focused on risk by NIIN, and we calculated aggregate risk for different groups by summing the NIINs associated with those groups. We found that one way to reduce risk is to hold extra inventory (long supply). Unfortunately, this is an expensive way to reduce risk. And while the Army finds itself in a relative low risk position now due to current long supply, over a longer term, we expect that the long supply of many NIINs will be consumed.

In any case, the Army will always have to make choices as to *which* inventory to hold, because it cannot afford to always be in long supply for all NIINs. Our current analysis gives little advice about how to decide exactly how much of each NIIN to hold. To integrate risk management into Army processes would require analysis across NIINs, taking cost much more directly into account.

Recommendation on Implementation

Overall, we concluded that a methodology developed in this research could inform AMC management regarding its exposure to supply chain risk. Such risk should be tracked routinely. The Army has no process in place to track supply chain risk, and the SS/SRM initiative does not meet that requirement. We recognize that our process is analytically intensive and in its current form would be difficult for the Army to implement. Such an automated tool, focused on identifying supply chain risk, would need to be developed to make this a viable program. The automated tool could further calculate drivers of risk, for example, showing the number and percentage of sole-source NIINs by system. This automated tool could run relatively often, at least monthly, while sending automated alerts to AMC staff only as needed.

Acknowledgments

The research team deeply appreciates the support it received from AMC. We are particularly grateful to Mr. David Frey for his guidance and direction. We likewise benefitted significantly from the advice and insights offered by Working Group members, Mr. James Wright (ACC), Mr. Brian Woods (AMCOM), Mr. Mark Grotke (CECOM), and Mr. Dave Apel (TACOM). We would also like to acknowledge the collaboration of Mr. Johnathan Selter of Censeo and Mr. Nathan Powless of AMC, who was instrumental in providing the required data, and Mrs. Vickie Beaver for her insights on the contracting and her assistance coordinating with key stakeholders. Finally, we are indebted to the contributions to the study of Supply Chain Risk Management, Supplier Relationship Management, and Strategic Sourcing made by Dr. Nancy Moore and others at the RAND Corporation.

Abbreviations

ABF	Asset Balance File
AMCOM	Army Aviation and Missile Command
ACC	Army Contracting Command
AMC	Army Materiel Command
CAGE code	Commercial and Government Entity code, a five-character identifier used by the federal government, assigned by the Department of Defense's Defense Logistics Agency (DLA), to identify a vendor by specific location. A single vendor can have one or many CAGE codes.
CECOM	Communications-Electronics Command
CONOPS	Concept of operations
CSS	Combat Service Support
CTASC	Corps Theater ADP Service Center
DAC	Document Availability Code
DCMA	Defense Contract Management Agency
DLA	Defense Logistics Agency
EDA	Equipment Downtime Analyzer
FAT	First Article Test
FedLog	Federal Logistics Data, a catalog of NIINs published monthly by DLA on CD-ROM
FPDS	Federal Procurement Database System
GSA	General Services Administration
ILAP	Integrated Logistics Analysis Program
ISO	International Organization for Standardization
LCMC	Life Cycle Management Command
LIW	Logistics Information Warehouse
LMP	Logistics Management Program
NIIN	National Item Identification Number
NSN	National Stock Number

O&M	Operations & maintenance
OCO	Overseas Contingency Operations
RDT&E	Research, development, test, and evaluation
RNAAC	Reference Number Action Activity Code
SARSS	Standard Army Retail Supply System
SCRM	Supply Chain Risk Management
SOS	Source of supply
SRM	Supplier Relationship Management
SS	Strategic Sourcing
SSA	Supply Support Activity
SS/SRM	Strategic Sourcing and Supplier Relationship Management
SSWG	Strategic Sourcing Working Group
TACOM	Tactical Command
USGS	U.S. Geological Survey

1. Introduction: Improving Supplier Relationship Management and Reducing Supply Chain Risk

The Army Materiel Command (AMC) is currently implementing a Strategic Sourcing (SS) and Supplier Relationship Management (SRM)[3] initiative. This initiative follows industry practice in identifying important suppliers and improving those relationships in ways that benefit both the buyer and the supplier, particularly to reduce the effect of uncertainty.

This initiative seeks to leverage industry best practices to help the Army reduce supply chain costs and improve performance. The Strategic Sourcing/Supplier Relationship Management Implementation Plan ((USAMC, 2012) lays out a roadmap for a transition that leverages industry best practices to help AMC identify candidates for strategic sourcing, assess AMC's spend, segment suppliers, develop metrics for AMC and suppliers, and create enterprise SS/SRM strategies.

The implementation of the SS/SRM initiative is being carried out across the AMC enterprise, by all the Life Cycle Management Commands: AMCOM, TACOM, CECOM, and ACC. The initiative includes representatives from DLA and from the DCMA.

An essential part of the implementation plan is to determine the supply chain risk presented by each supplier in general and the supply chain risk factors that are critical to AMC. We developed a process and tool that allows AMC to assess supply chain risk by supplier, part, or weapon system. Our results are reported in this document.

Supply Chain Uncertainty Facing AMC

As the United States Army winds down from over a decade of contingency operations in Iraq and Afghanistan, the Army's demand for spare parts and maintenance services is expected to decrease. However, the amount of the decrease is uncertain, as are the parts and vendors that will be most affected.

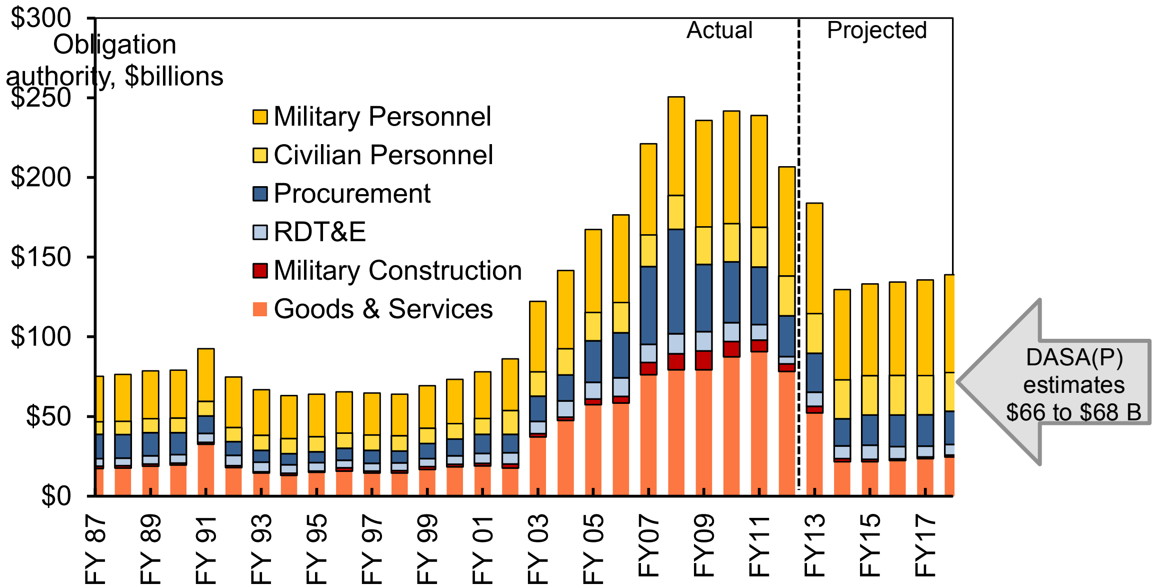
This uncertainty is influenced by factors that have yet to play out. First, in the short term, the drawdown from Afghanistan and Iraq will decrease the usage rates of certain types of equipment and thereby reduce the demand for spare parts used to support this equipment. Second, over the longer term, the proposed reduction in total Army end-strength will likely reduce peacetime spare part demands generated by training, but this will depend on which type of units take the brunt of the cuts. Third, reductions in funding of depot maintenance may reduce demand for the

[3] *Supply chain risk management* is the coordination of activities to direct and control an enterprise's end-to-end supply chain with regard to supply chain risks. (Adapted from International Organization for Standards, 2009.)

parts needed to repair, overhaul, or reset equipment returning from the field, resulting in less procurement from vendors.

Figure 1.1 shows how the Army's projected investment Operations & Maintenance (O&M) is expected to decrease to pre-2001 levels over the next few years (O&M is in the goods and services portion of the chart). Much of the reduction reflects the withdrawal of funding that had been provided by Congress to support overseas contingency operations (OCO) dollars. Further, the projected President's budget for FY14 and beyond does not include sequestration.

Figure 1.1. Army Budget, FY 1987 to 2019



SOURCE: Unpublished 2013 RAND research by Moore, Chenoweth, et al.

The projected reduction in funding creates uncertainty and increases the risk associated with repair and procurement decisions. In a more constrained budgetary environment, the margin of error associated with repair and procurement decisions decreases rapidly. Buying too much from one vendor and not enough from another can have dire implications for the latter vendor and for weapon system readiness. Additionally, uncertainty in the availability of funds causes supply chain managers to be more risk averse, putting off procurement and repair decisions in order to reserve funds in case of unforeseen demand spikes. Reductions in lot sizes and demand volatility are likely to increase price volatility, adding an additional component of risk. Research indicates that supply managers are less likely to enter into long-term contracts when they perceive increased risk of demand or price volatility (Cohen and Huchzermeier, 1999). Therefore, despite the cost improvements that may be promised by long-term contracts and strategic relationships, supply managers can be reluctant to engage in these partnerships when they perceive uncertainty and high risk.

Relationship Between SCRM and SS/SRM

The relationship between supply chain risk management (SCRM) and strategic sourcing with supplier relationship management (SS/SRM) is not always clear. In some instances, SCRM is viewed as a component of SS/SRM. In other instances, the SS/SRM process more clearly depends on SCRM. We conducted a risk assessment as part of a strategic sourcing and supplier relationship initiative; for this project, we consider SCRM a component of SS/SRM.

The Concept of Operations (CONOPS) for AMC's SS/SRM initiative (AMC, 2012) incorporates supply chain risk management in two ways. First, it recommends that monitoring and mitigating supply chain risk should be a responsibility placed on SRM managers. Specifically, it calls for managers to

- ensure that supplier risks are reported upward
- develop appropriate mitigation tactics for identified risks
- communicate risk assessment and mitigation within the organization.

Further, the CONOPS calls for a risk assessment as part of developing a partnership strategy with the suppliers. This risk assessment takes place after suppliers have been selected for a strategic relationship opportunity. Prior to this step, much of the focus of the CONOPS is on selecting strategic supplier opportunities by systematically segmenting suppliers by commodity type, conducting a spend analysis,[4] and bringing the expert judgment of Life Cycle Command (LCMC) managers to bear to select strategic suppliers.[5] Our analysis goes further than this, by assessing risk for all relevant suppliers, not only those identified through the spend analysis.

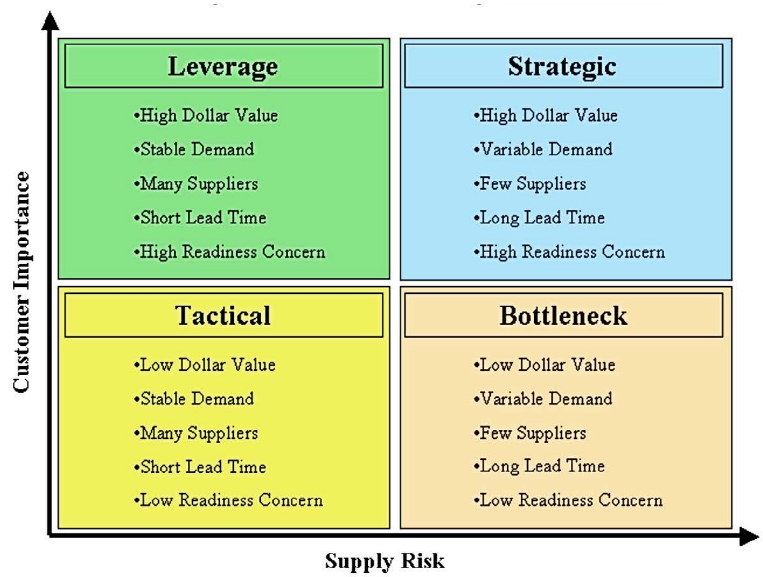
An FY2008 update on DoD strategic sourcing initiatives (DoD, 2009) mentions risk in the context of contracts and describes how DLA uses a measure of supply chain risk and customer importance to segment suppliers into four categories: leverage, tactical, strategic, and bottleneck. Figure 1.2 illustrates a segmentation matrix for the Defense Logistics Agency. By contrast, leading enterprises often segment their suppliers based on the risks and value of their products, then manage the segments differently. Best practice research (Moore et al., 2007) indicates

> . . . leading enterprises identify the suppliers who add the most value—or whose failure can pose the greatest risk—then seek to develop much closer relationships with these key suppliers than they have with less critical suppliers. Such efforts will include contracts or other agreements defining the terms of the relationship, such as performance expectations of both parties. Supplier contract structuring is part of this process; contracts should be flexible enough to enable and encourage improved performance from both parties. In some cases, there may be no contract, but the supplier relationship may still allow for rewards and other incentives to improve performance.

[4] A *spend analysis* tallies total procurement dollars dedicated to a supplier. It also includes a calculation of the total percentage of business that the buyer conducts with the supplier.

[5] By *strategic supplier*, we mean a supplier that provides a relatively large portion of the budget and whose products impact operations significantly.

Figure 1.2. DLA Supplier Segmentation Matrix



SOURCE: Report to Office of Management and Budget: Department of Defense Strategic Sourcing Initiatives FY 2008 Update.

For leading firms, understanding and managing supply chain risk is an essential first step in designing and implementing a successful strategic sourcing and supplier relationship management strategy. Supply chain risk is a measure of the effect of uncertainty along any point in the end-to-end supply chain and its objectives. Supply chain risk management (SCRM) is the coordination of activities to direct and control an enterprise's end-to-end supply chain with regard to supply-chain risks and ensure profitability and continuity (Moore, 2014, Tang 2006). Thus, SRM decisions and priorities are both affected by spend analysis and an assessment of supply chain risk. In fact, in some cases SS/SRM becomes a component of an SCRM mitigation strategy. Tang (2006) posits that it is possible to address SCRM along two dimensions:

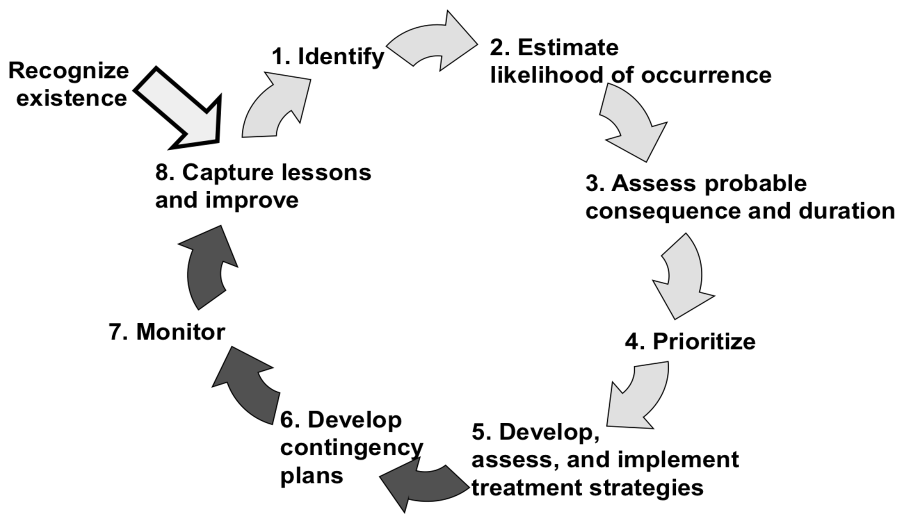
1. Supply Chain Risk—operational risks or disruption risks: These include demand or supply uncertainty, uncertain costs, disruptions due to natural or manmade disasters such as earthquakes, floods, financial crisis, etc.
2. Mitigation Approach—supply management, demand management, product management, or information management. This involves a coordination and collaboration within the firm and with the firm's suppliers to mitigate supply chain risk. Collaboration with suppliers, sharing of information, and entering into strategic partnerships are key components of the mitigation approach.

In this report we present an approach to supply chain risk management that supports AMC's SS/SRM CONOPS. However, we also expand the analysis and suggest that both a broader assessment of supply chain risk and a process to systematically manage supply chain risk are needed.

2. How Businesses Manage Supply Chain Risk

In this chapter, we present a generic eight-step process to identify, estimate, and manage supply chain risk. Figure 2.1 outlines this process. The circular design of the figure illustrates that this is an ongoing activity that must become a part of how business is conducted within a supply chain management organization.[6] While the Army has different objectives than a business, the process for managing risk will be the essentially same.

Figure 2.1. Eight-Step Process for Managing Supply Chain Risk



The process begins with recognition or awareness that supply vulnerabilities exist (Zsidisin et al., 2003). Enterprises need to be aware that their actions or lack of actions create supply chain risks.

Step 1 is identification of prospective supply vulnerabilities. Enterprises need to identify as many risks associated with a prospective supply strategy as possible. Methods for identifying risks include brainstorming, interviews, workshops, supply chain mapping/description,[7] the Delphi Method,[8] Fault or Event Tree Analysis[9] (Ziegenbein and Nienhaus, 2004), and Nominal

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[6] Nancy Y. Moore, Mary E. Chenoweth, Amy G. Cox, Clifford A. Grammich, and Judith D. Mele, "Improving Life Cycle Management Commands' Supply Chain Risk Management," unpublished 2012 RAND research.

[7] Supply chain mapping identifies all members, facilities, linkages, and flows of goods, information, and money in the end-to-end supply chain from upstream raw materials suppliers through manufacture to downstream delivery to the final customer, use, and then disposal (Gardner and Cooper, 2003).

[8] The Delphi Method relies on a series of questionnaires among a group of experts to discern a consensus as well as reasons for disagreement. For further information, see Linstone and Turoff, 2002.

Group Technique (Zsidisin, Panelli, and Upton, 2000).[10,11] Some authors recommend assessing vulnerabilities by categories of external risks, such as demand, supply (e.g., vendor failure, interruption in inbound shipments), and environment (e.g., natural disasters, accidents, terrorism/sabotage, and business environment) and internal risks (such as control, process, and contingency) (i.e., plans to mitigate and manage the impact of a risk) (Peck et al., 2003). Others recommend a less structured approach so as not to inhibit thinking (e.g., Steele and Court, 1996).[12]

Step 2 in the risk assessment and management process calls for enterprises to estimate the likelihood of occurrence of the prospective vulnerability. Some authors (e.g., Steele and Court, 1996) assign a relative weight to the probability of occurrence while others (Ziegenbein and Nienhaus, 2004) classify the possibility of occurrence into unlikely, possible, likely, and very likely.

Step 3 is to assess the relative impact or consequence of prospective loss (i.e., to calibrate the exposure of the business). The impact of a given risk is a function of its scale, scope, duration, recovery time, and total cost. A risk's total impact to the enterprise can be ranked as low or high (Steele and Court, 1996) or as low, medium, significant, or fatal (Ziegenbein and Nienhaus, 2004).

Step 4 prioritizes risks by their significance to the enterprise so as to focus available resources for risk elimination, mitigation, and management efforts on the most important risks. Because each commodity, product, or service exhibits a different risk profile (Gunipero and Eltantawy, 2004) and identifying, assessing, and planning for supply chain risks requires

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[9] Fault or Event Tree Analysis breaks down a system risk event into component failures step by step by linking failure events with their causes. Because fault tree analysis is used for qualitative and quantitative analysis of systems, it is essential that for a risk every cause is considered in the fault tree and conversely that every mentioned cause is actually needed to trigger the event (Schellhorn et al., 2002, p. 1).

[10] These definitions stem in part from those of the International Organization for Standardization (ISO). ISO (2007) does not define *supply-chain risk*, but it does define *supply chain* as a "linked set of resources and processes that begins with the sourcing of raw material and extends through the delivery of products or services to the end user across the modes of transport." As such, the supply chain "may include vendors, manufacturing facilities, logistics providers, internal distribution centers, distributors, wholesalers and other entities that lead to the end user" (ISO, 2007). Our focus, as indicated, is on "risk" in the "upstream" supply chain. As ISO (2007) defines it, upstream "refers to the actions, processes, and movements of the cargo in the supply chain that occur before the cargo comes under the direct control of the organization, including but not limited to insurance, finance, data management, and the packing, storing and transferring of cargo." ISO (2009) also defines "risk" as "the effect of uncertainty on objectives." ISO (2009) describes uncertainty in turn as "the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequences, or likelihood." Objectives, the ISO (2009) adds, "can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process)." ISO (2009) defines "risk management" as coordinated activities to direct and control and organization with regard to risk."

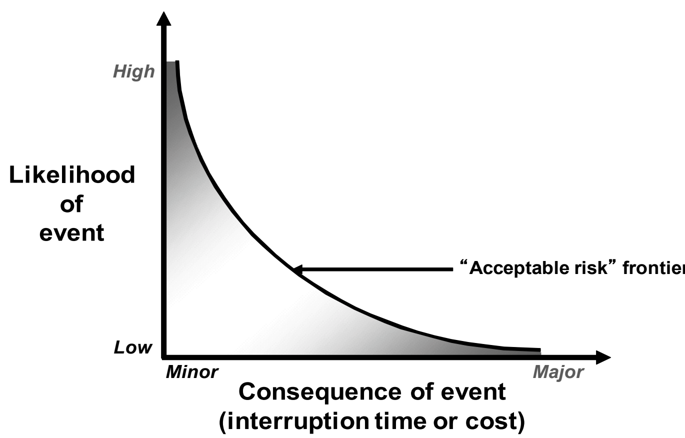
[11] NGT involves individuals first generating their own ideas then sharing them with a group, before ranking each. For more information, see Van De Ven and Delbecq, 1974.

[12] "When working through the vulnerability analysis there will be a temptation to make use of some form of checklist. This should be avoided, since experience has shown that checklists seem to inhibit entrepreneurial thinking, so essential in this exercise" (Steele and Court, 1996, p. 89).

considerable time and resources, enterprises need a way to prioritize SCRM efforts. The next few figures provide examples of alternative methods to prioritize risks.

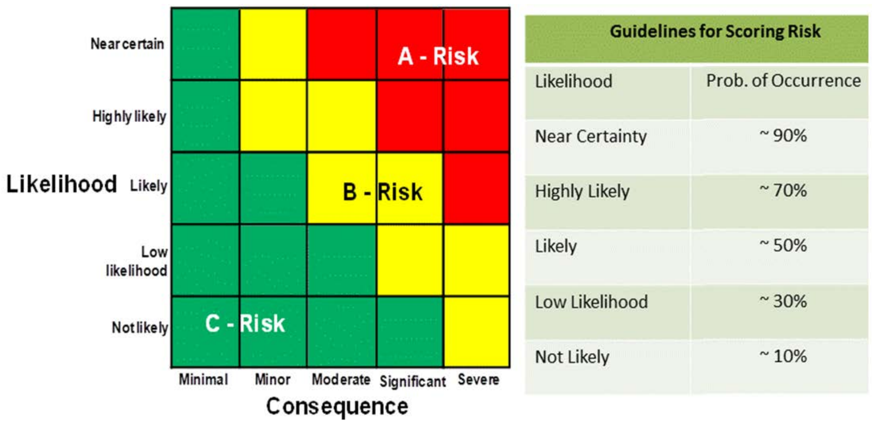
One proposed way to prioritize risks is to plot risks by probability of occurrence from low to high and consequence of event (interruption time or cost) from minor to major, and then to identify the acceptable risk frontier above which risks are unacceptable and must be managed (Zsidisin et al., 2003). Figure 2.2 notionally depicts this approach. However, many firms find this to be an artificial exercise and opt for a more qualitative approach, as depicted in Figure 2.3. The DoD Risk Management Guidebook (2006) presents a risk matrix along with guidelines for scoring risks based on a five-point scale of increasing likelihood of occurrence and consequence, shown in Figure 2.3. As with much of the DoD risk management literature, this guidebook is geared toward supporting Program Managers in managing risk during the weapon system acquisition phase. For risks in the red quadrant, Program Managers should prepare mitigation plans to reduce the potential impact on the acquisition program. A similar matrix can be created to support the setting of priorities for managing supply chain risk.

Figure 2.2. Understanding Risk Exposure



SOURCE: Adapted from Zsidisin, Ragatz, and Melnyk, 2003.

Figure 2.3 DoD Risk Management Matrix



SOURCE: DoD Risk Reporting matrix, online at https://acc.dau.mil/docs/plt/se/riskmatrix/dod_risk_matrix.htm

Step 5 of the supply chain risk management process involves developing, assessing, and executing strategies for reducing the likelihood or mitigating the consequence or duration of prospective risks (Zsidisin et al., 2003). For low-priority risks (i.e., those with low likelihood of occurrence and low consequence), an enterprise may want to ignore or accept the risk. For high-priority risks (i.e., those with high likelihood of occurrence and high consequence), an enterprise may try to avoid the loss occurrence altogether[13] or accept and reduce its likelihood, consequence, or duration. If the likelihood, consequence, or duration of a risk cannot be reduced, then an enterprise needs to identify prospective operational or risk-sharing or transfer measures to mitigate the risk (Ziegenbein and Nienhaus, 2004).

Enterprises can work with their suppliers in improving demand visibility, helping them source their sub-tier supplies, working together to improve logistics and reduce lead-times, and establishing longer term contracts to give the supplier confidence in the relationship.

To mitigate supplier risks, enterprises have a range of tools. They can hold inventory (e.g., emergency supplies), obtain design specifications (i.e., technical data enabling them to develop supplier products internally or purchase them from another source), require the supplier to develop alternative sites, use dual or multiple sourcing, develop an alternative source, and move

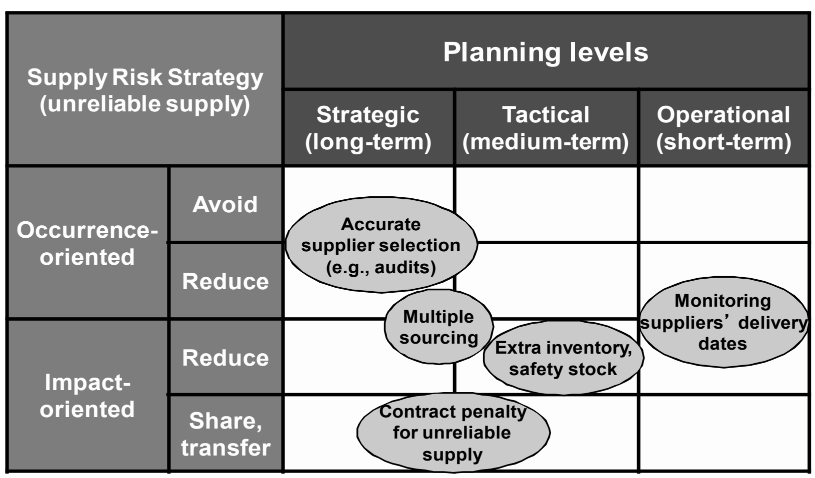
[13] To *avoid supplier disruptions*, enterprises can rigorously assess suppliers, carefully select them (using certification and prequalification), and frequently monitor or audit them for viability, quality (using statistical process control), reliability, and dependency (i.e., enterprise's percentage of supplier's total business). They can also establish multiple two-way communication channels for sharing forecasts and plans. They can gain or maintain visibility into the supplier's operations and require a quality management program and contingency plan. They can also align the supplier's incentives with theirs, penalize poor performance (using fines or reduced business), reward good performance (using gain sharing, increased business, and supplier recognition) and share financial risks. Lastly they can encourage joint improvement initiatives and direct access to knowledge workers. To *prevent demand (volatility) risk*, enterprises can develop industry standards, common product "building blocks," or collaborative forecasting. *Process risk prevention* includes using ISO 9000 standards for process control, increasing supply chain visibility, and reducing lead-times.

special tooling. To mitigate demand risk, enterprises can hold safety stock inventory or develop multiple supply sources.

To develop contingency options to reduce supplier risks, enterprises can establish a second-source contract or identify and introduce alternative sources. Contingency options for demand (volatility) risk include identifying strategies to ration supply or reduce inventory and plans for their introduction. Process risk contingency options include identifying strategies to shift production or flow and plans for their execution.

Figure 2.4 shows selected risk management strategies by occurrence and impact, and length of term; the strategies can be short-, medium-, and long-term for occurrence-oriented and impact-oriented supply events. For example, a long-term strategy for avoiding or reducing supplier problems is to have a rigorous supplier selection process followed by regular audits of supplier facilities, processes, and finances. Another strategy to reduce supply risks is to have multiple sources, if feasible. A third long-term strategy is to share or transfer the risk by including penalties in contracts for unreliable supply. One short-term strategy is to monitor supplier delivery dates and quantities to quickly discover emerging problems at suppliers. A medium-term strategy could be to have extra inventory or safety stock, but many enterprises prefer not to do this because of the added costs and risk of obsolescence or eventual disposal due to excess inventory.

Figure 2.4. Risk Management Strategies

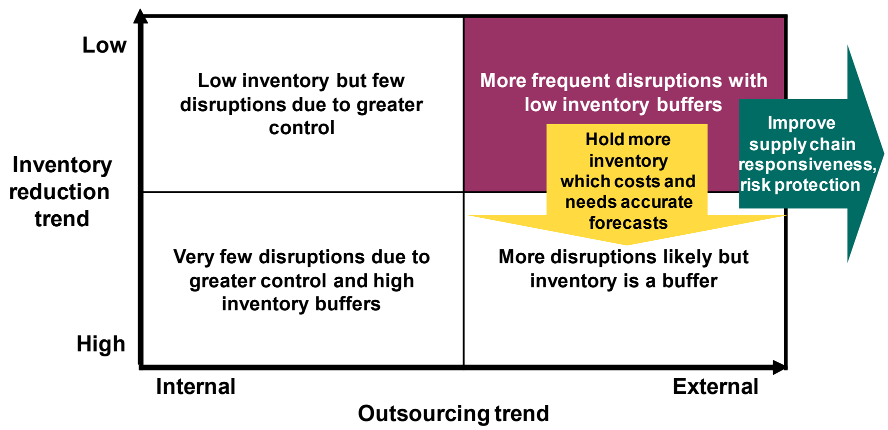


SOURCE: Ziegenbein and Nienhaus (2004). The terms “strategic,” “tactical,” and “operational” differ from the way the Air Force uses these terms. Here, “strategic” is long-term, “tactical” is mid-term, and “operational” is short-term.

Depending on probability of risk, consequence, and duration, prospective actions can range from taking no immediate action to eliminating the need or finding alternatives for a commodity. Because risk prevention or mitigation can be costly, enterprises need to evaluate each prospective strategy’s costs and benefits. They should then gain management support and implement those strategies that are cost-effective (Kiser and Cantrell, 2006), avoiding higher production and transportation costs.

Figure 2.5 outlines two prevalent supply chain improvement strategies: The upper right hand quadrant indicates that a combination of outsourcing and reducing internal inventory buffers could reduce costs, but increase the risk of supply chain disruptions, which in turn can decrease revenue due to lost sales. The lower right hand quadrant shows the tradeoff of decreased risk of supply chain disruption at the cost of increased inventory and forgoing potential savings from outsourcing. The risk of holding inventory can be mitigated if demand forecasts are accurate; however this is seldom the case. An alternative strategy is to hold fewer inventories, but improve the responsiveness of its supply chain, which reduces the need for inventory and increases risk protection through risk transfer or insurance

Figure 2.5. Risk Mitigation Strategies



SOURCE: Adapted from Enslow, 2008.

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Step 6 is focused on developing contingency plans for when disruptions occur, because not all risks can be cost-effectively avoided, adequately mitigated, or even identified. For example, companies had not developed strategies for radiation risk following the March 2011 earthquake and tsunami in Japan. Such strategies should entail detailed recovery and remediation plans, for shortening the duration of a disruption, minimizing its consequence, and identifying the resources to execute the plan (Zsidisin et al., 2003). The duration of a risk can be reduced by developing proactive risk management plans that reduce the decision latency to react to an event, reduce the reaction plan design latency, reduce the implementation latency, and reduce the execution time of a recovery plan.

Step 7 of the supply chain risk management process involves continuously monitoring the environment after a supply strategy and associated risk management plan is in place for any increases or decreases in prospective supply chain risks that warrant changing the supply strategy or risk management plan (Zsidisin et al., 2003).

Step 8 is focused on continuous learning and knowledge management. When a supply disruption occurs, an enterprise needs to conduct post-incident audits to determine its root cause and document any lessons learned for better managing future events. The audits should also address any deficiencies identified in past risk assessments, mitigation strategies, and contingency plans (Zsidisin et al., 2003).

Rather than addressing all vulnerable areas at once, enterprises can focus on those events and supplier characteristics that are likely to bring the greatest relief (Steele and Court, 1996). For example, Hewlett-Packard identifies the impact of differing risks on its supply-chain management strategies (Verstraete, 2008).[14] The country where a supplier is located has a high impact on risks for HP's globalization and outsourcing strategy, as can the internet provider, regulations, workforce practices, and quality. Sole sourcing, lean practices, and distribution hubs are subject to risks from natural and man-made hazards. Globalization and outsourcing, sole sourcing, supply tiering,[15] and returns management raise risks to quality.

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[14] *Commodity dependency* is the extent to which an enterprise depends on a particular commodity. *Demand visibility/variability* reflects the ability to see undistorted and accurate demands for a good or service within the time necessary to respond to it and the extent to which such demands vary over time. A *returns management* system manages returns of products, sometimes also called the *reverse supply chain*.

[15] In *disaggregated* or *multi-tier* supply chains, a number of different suppliers add value at different points along the supply chain (e.g., from raw materials, to sub-components, to sub-assemblies, to assemblies, to assembled final product, to delivered final product).

3. What Can Disrupt the Supply Chain? Identification of Risks

In this section, we describe our process for eliciting from the Army an identification of risks. To initiate these steps, RAND conducted a workshop with AMC's Strategic Sourcing Working Group (SSWG), on May 1, 2003. According to the SRM/SS CONOPS, "The AMC Strategic Sourcing Working Group (SSWG) is the most senior body engaged in strategic sourcing activity across AMC." The SSWG is made up of high level LCMC and ACC managers and (where appropriate) managers from DLA and DCMA. The role of the working group is to establish the processes and develop SS/SRM strategies.

The SSWG participating in this exercise included representatives from AMCOM, CECOM, TACOM, and ACC. Each member was asked to produce a list of supply chain risks that are of importance to AMC and specifically to the Commands that they represented. The working group used a brainstorming technique to develop the list of risks shown in Table 3.1 below. After the initial list was compiled, we presented the SSWG with a list of additional risks that they could consider and add to the list if they thought appropriate (Appendix A).

Table 3.1. Supplier Risks Faced by AMC, As Identified by the Strategic Sourcing Working Group

Labor disruptions—external strikes, internal BRAC	Funding consistency & timing
Delays in contracting awards	Lifecycle changes
Length of & scope of terms of contract	Sequester - small firms going out of business
Counterfeit parts	Long administration & production lead times/ delays in contracting
Quality escapes	Business consolidations
Aging infrastructure & workforce	Unpredictability in ordering, changes in demand
Delay in receipt recording at storage facility	Acts of God: fire, quake, flood, hurricane
Raw material shortage	First article test (FAT) requirement extends delivery schedule
Foreign sources of supply, geopolitical issues	Lack of mitigation plans at prime & lower tiers
Extended development time & costs	Database inaccuracies

Following the development of the list, the working group was asked to select three risks of greatest concern. The three areas of supply chain risk identified by the managers are shown below (see Appendix B for the full list).

- *Demand fluctuation:* "Variance in demand need/budget. Suppliers have to manage large fluctuations in orders. Item managers go from ordering a few parts to ordering large quantities. Suppliers may need to set up a line or tool for larger orders; this requires an investment by the supply base. Demand fluctuations are sometimes driven by funding availability of the customers; changes in demand driven by optempo and unforecasted requirements."

- *Funding uncertainty:* "The unpredictability of funding creates risks for the supplier and for the enterprise. For the enterprise, the risk is that we are not sure what we can buy and what weapon system we can support. Also funding often comes available toward the end of the fiscal year, providing very little time to execute."
- *Long lead-times:* "Long lead-times (administrative and production) either on the Army contracting or the supplier side, increase risk of backorders and limit funding flexibility because monies have to be committed to orders way in advance of execution."

The risks identified by the SSWG affect the supplier and may create a high risk for AMC. The next steps in the process call for estimating the likelihood and consequence of the risk and prioritizing them. To complete these steps, we first translated the risks into a form that can be measured. For example, it is not possible to measure funding uncertainty directly with the available data; however it is possible to estimate how susceptible a supplier might be to reductions in revenue resulting from funding uncertainty.

The risks identified by the Working Group are not easily quantifiable, so we developed a corresponding set of measures. Table 3.2 shows a translation of the risks identified into consequences that can be estimated. We endeavored to use available data on demand, supply, lead times, and information about the supplier and the part to measure the likelihood and consequence of the risk; our approach is described in the rightmost column of Table 3.2.

Table 3.2. Top Risks, Measures, and Consequence

Top 3 Risks Identified by Working Group	Consequence of Risk	How RAND Measures Risk
Funding consistency & timing, demand fluctuations	Revenue loss leads to: Supply disrupted, Vendor failure	*Days of supply on hand.* Funding consistency and demand fluctuations have the potential of reducing supplier revenue and as a consequence reducing supply. To measure the risk to the Army, we calculate the days of supply available by projecting the current demand rate and comparing it to the available inventory. More days of supply lower the risk incurred by the Army. *Potential for future sales.* For NIINs in short supply, we look at whether demand rates are increasing or decreasing. A NIIN in short supply with diminishing demand may not generate enough demand to maintain a supplier's interest. However, if demand is increasing, then the risk is related to the capacity of the supply chain to meet the required amounts. *Supplier dependence on AMC.* We estimate the suppliers' dependence on AMC by looking at AMC revenue as a percentage of their total revenue. A supplier with large portions of revenue tied to AMC is more vulnerable; but less likely to lose interest in AMC as a customer. We also identify NIINs in long supply: these present greater risk to the supplier, less risk to the Army. NIINs in short supply that are not reparable: these represent greater risk to the Army, especially if the supplier is a sole source supplier. NIINs in short supply that are reparable: reparable NIINs have an internal and external source of supply (depot & contract repair); therefore there is less risk to the Army. For these NIINs we need to factor the capacity of the repair system to provide the needed parts.
Long admin & production lead-times/ delays in contracting	Supply disrupted; risk of backorder increases	Long lead-times represent a greater risk to AMC than the supplier. To classify this risk, we identify NIINs with current demand and with contracts that are about to or have expired. We estimate the days of supply available and compare them to the number of days until the contract expires. We consider if the NIIN is available internally from repair or if it is provided by a sole source.

4. How We Measured Risk

As we indicated in Chapter 3, the risks identified by the Working Group are not easily quantifiable, so we developed a corresponding set of measures, shown in Table 3.2. These measures are days of supply on hand, potential for future sales, and supplier dependence on AMC.

The next steps in the risk management process—steps 2 and 3 in our framework—are to quantify the likelihood and consequence of the risk by combining multiple pieces of information. We want to determine the likelihood that a vendor fails to supply a NIIN, and the resulting impact on the system. Reflecting this two-part likelihood-versus-impact approach, our formula has the same two parts. We normalized the data that we describe below, so values are between 0 and 1; normalization allows us to combine components of different scale and produce risk factors that can be expressed as percentages. We defined NIIN risk as:

NIIN risk = VendorFailRisk*SystemImpactRisk/(1+DaysToRunOut/365).

NIIN risk is only one measure of importance. NIIN risk, as we measure it, creates a weight for each NIIN on the system. While it may indicate risk on its own, NIIN risk serves primarily in our measures as a mechanism to calculate system risk.

The sections that follow describe each component and the data required to calculate the risk. We selected the components of our data based on a pragmatic assessment of their availability and their applicability to the factors that we wanted to measure. Because we had no information on the relative importance of each component, we weighted them equally.

Databases Used

Our database was originally based on 6,907 NIINs listed sent by AMC on May 28, 2013. The NIINs were from the Material Master table in the Army's Logistics Management Program (LMP). Our database was later updated with additional NIINs on July 16, 2013, so that it had a total of 9,298 NIINs. AMC extracted the following files from LMP, and sent key files to us. These files contained information on NIINs with contract actions in the past three years.

- Material Master table, containing general information about each NIIN, such as price, weight, Federal Supply Class, etc. This list was used to drive the database, so NIINs in NIIN-level reports matched the NIINs in the Material Master.
- Purchase Order Header table, containing information including contract number, dates of action, and vendor CAGE code.
- Purchase Orders table, which shows the NIIN in the "Material" field, and the purchase document number.

- Purchase Requisition and MARC tables (but we did not find these useful for our analysis).

We also assembled data from the following databases:

- Federal Procurement Database System (FPDS). This database holds contract-level data, supplier, place of performance, obligated amount by year, final contract end date, and whether the contract is sole source. The data are available directly from USASpending.gov. We matched contract numbers in the AMC tables to records in FPDS.
- Federal Logistics Data (FedLog). This database contains information mainly about the NIIN, whether the part is reparable, and the availability of technical documents that describe the NIIN, the vendor's CAGE code (Commercial and Government Entity code), and company status (e.g., active, inactive, disbarred from government business). FedLog is available on CD-ROM by subscription from the DLA Logistics Information Service. We matched NIINs from the AMC tables to FedLog.
- Corps Theater ADP Service Center (CTASC) database. This database contained quantities issued and inventory on hand from CTASC. The Army's Corps/Theater Automated Data Processing Service Center (CTASC) is an Army Automated Information System employed at Corps and Echelons above Corps levels to provide automated data processing support for Combat Service Support (CSS) logistical support agencies. CTASC is often referred to as SARSS (Standard Army Retail Supply System), which is the Army's primary software application used for retail logistical support. The data were processed through RAND's Turns Analysis code, which focuses on issues representing sales from the Army revolving Working Capital Fund (AWCF).
- CTASC data are also used to calculate washout rate at the installation level. When parts are sent to installation maintenance by the Supply Support Activity (SSA), they must be returned to the SSA in a serviceable condition code, an unserviceable but reparable condition code, or in a condemned condition code. We estimate the washout rate by calculating the percentage of the total number of parts that are sent to maintenance and returned condemned. The washout rate calculation did not include the washout at the depot level; but washout rates at depots would be calculated in a similar fashion by counting the items sent to depot repair and calculating the percentage of those items that subsequently were sent from the depot to DLA disposition services.
- The RAND Equipment Downtime Analyzer (EDA), to indicate whether a NIIN had been associated with a weapons system being downed overnight. These data are downloaded from the Logistics Support Activity's ('s) Logistics Information Warehouse.
- The U.S. Geological Survey (USGS) Natural Hazard database, to indicate relative hazard for each vendor. The database shows a historical dollar value for property damage for floods, tornadoes, and hurricanes, which we converted into a relative score. For earthquakes, the database gave a "probability scale," which we converted to a relative score.

In some cases, data were missing or duplicated. We made considerable effort to determine why data were missing and to ensure that the most recent data were used when available.

The above data were then assembled into a Microsoft Access database, "Part & vendor risk analysis.accdb." This database was designed to be as simple as possible, with SQL queries only. It has no special reporting, Visual Basic code, or linked files. It could, therefore, be converted to a different format, or made part of an enterprise system. The key part of the database is simply the risk formula given below.

The overall method for the scoring was to develop a set of values between 0 and 1. These scores corresponded to binary indicators (e.g., whether a contract was expired), percentages (e.g., change in revenue), or a relative ranking on a list (where a value close to 0 was near the bottom of the list and 1 was the top of the list, as for natural hazard risk). Larger values indicated higher risk compared to others on the given list.

Our approach has several important caveats. Our database is limited to the approximately 9,300 NIINs selected. It is also limited by some missing data for these NIINs and the associated vendors. We generally treated missing data as zero. Error is likely to be one of omission, where the NIINs and vendors we observe as risky are probably indeed risky, but other NIINs and vendors that are not part of our study are also risky. We shall test this to some extent later by examining another set of NIINs that have no contract actions.

Vendor Fail Risk—Likelihood of Risk

The risk of vendor failure should be viewed independently of the impact on readiness. We wanted to identify—independent of the system impact risk— how likely a vendor would be to stop producing a NIIN. Given the available data, what information might indicate whether a vendor's supply is more or less likely to fail? Further, we sought to design a simple heuristic that could be readily understood and even extended.

To be clear about what we mean by "vendor fail risk," we do not mean the likelihood that the vendor will go bankrupt, but rather the higher likelihood that the vendor will be unable or unwilling to supply the NIIN. This measure is intended to indicate the likelihood that a risk to the Army could occur.

Our vendor fail risk score for a NIIN includes the following.

- **Vendor status.** The status of the vendor's company, as reported in FedLog. This status could be one of 15 values, such as "Active" where the company is currently in operation, "Debarred" where the General Services Administration (GSA) has debarred the company from procurements, and "Defunct" where the company is believed to be defunct. If the Federal Logistics Data (FedLog) catalog reported that the vendor's status was anything but "Active," we assessed a risk, "Status Risk." However, most status values were active, with only a few blank (and therefore treated as active). We chose values of 0, 0.5, or 1: e.g., 0 risk value for Active, 0.5 for "company discontinued or merged," and 1 for "debarred."
- **Vendor change in revenue by NIIN.** The percentage fall in the vendor's revenue for each NIIN. This was calculated from the purchase orders, using a trend formula. We calculated percentage fall as the "backcast" for the earliest data available (August 2009) compared to the "forecast" for the latest data available (April 2013). The percentage fall was then this (forecast – backcast)/backcast. This gave an "average monthly" change,

based on all the available data. We reasoned that if a vendor saw sharply decreased revenue from AMC, the vendor was more likely to stop producing the NIIN.[16]

- **Vendor's total business by NIIN.** The percentage of the vendor's 2012 revenue for this NIIN compared to its overall 2012 revenue. The overall revenue was taken from FPDS. We reasoned that if a large part of a vendor's revenue was associated with the part, then the vendor was at greater risk from falling demand.
- **Vendor's change in revenue compared to other vendors.** The percentage of the greatest revenue fall over all vendors. We reasoned that a vendor that had incurred relatively more loss compared to other vendors was at higher risk compared to other vendors.
- **The expiration date of the contract.** If the contract was currently expired (recorded as 0 or 1), we reasoned that the vendor was more likely to give up its ability to produce the part.
- **The vendor's place of performance ZIP code** (as reported in FPDS) and the associated exposure to natural hazards from floods, tornadoes, hurricanes, and earthquakes. To calculate these, we scaled each type of risk to the largest dollar value in that category, so a flood risk of 1.0 means that the zip code has the highest flood risk in the database. We have no natural hazard data for foreign locations, so we added a risk value of 1 (highest) for such NIINs.

The above logic produces a likelihood score for each vendor and part as follows:

VendorFailRisk = (StatusRisk + RevenuePercentFall + RevenuePercentFallToAllVendors
+ RevenuePercentSAM + IsContractExpired
+ Floodrisk + TornadoRisk + HurricaneRisk + QuakeRisk + ForeignRisk)/9.

We divide by 9 because ForeignRisk appears only if the other natural hazard data do not. This produces a value of between 0 and 1, with larger values meaning a higher risk. The actual values ranged from 0 to about 0.45.

Thus, by our definition, NIIN has high vendor risk if the contract is expired, if the vendor has lost significant revenue, if that lost revenue had been a large fraction of the vendor's total revenue, and if the place of performance has significant natural hazard risk or is foreign.

System Impact Risk—Consequence of Risk

System impact risk should be viewed under the assumption that the vendor has definitely failed. Given a vendor failure, what would be the impact on readiness? If the NIIN were no longer needed, or if the NIIN were in very long supply, the impact is likely to be minimal. On the other hand, if the NIIN were in short supply and regularly caused systems to go down, we would

[16] We used backcasting rather than percentage change from some baseline, to dampen effects of variability. This metric need not be between 0 and 1, but usually was.

expect a higher system impact risk. While the vendor fail risk indicates likelihood, system impact risk indicates consequence to the Army.

Our system impact risk formula contains the following factors:

- **Reparability.** 1 if the NIIN is nonreparable (i.e., FIA3 Code is 2), else 0. We reasoned that the Army had an internal source of supply or ready access to an external repair capability with a reparable item, thus reducing the system impact risk in the event of a vendor failure. The Army may have fewer options for a consumable item. Thus, supply chain risk for consumables is higher.
- **Sole source.** 1 if the NIIN is sole sourced, else 0. We reasoned that a vendor for a sole sourced item would be harder to replace than for a competitively sourced item.
- **Availability of technical documents.** The Reference Number Action Activity Code (RNAAC**)** indicates whether someone has acknowledged possession or nonpossession of a drawing or technical documentation. We assigned a factor of 0, 0.5, or 1 depending on the document availability code (DAC) in FedLog, with 1 (higher risk) for codes indicating less availability, such as "The reference number is represented by a drawing and the drawing was available to the RNAAC, which may or may not be the submitting activity at the time of submission of the reference number; however, the RNAAC cannot furnish the drawing." We reasoned that technical drawings would help the Army be able to develop a new source should the vendor fail. The lack of those drawings suggest a higher risk that a system would be impacted if the vendor's supply were to fail.
- **Lead-time.** Ratio of (production + administrative lead time)/(worst lead time for all NIINs). Failure of supply for NIINs with higher lead-time is more likely to have system impact risk than failure of supply for NIINs with lower lead-time. This data came from the AMC tables.
- **Downing a weapons system, relative to demand.** (EDA demands)/(CTASC demands for this NIIN); thus, a NIIN is riskier if it has many EDA demands in absolute, but also if it has many EDA demands compared to its CTASC demands.
- **Downing a weapons system, relative to other NIINs.** We calculated this as (EDA demands)/(worst EDA demands over all NIINs). That is, a NIIN with many EDA demands relative to other NIINs clearly has a relatively larger system impact risk.
- **Weapons system.** 0 if the NIIN is not listed as a component on any weapons system, 0.5 if the NIIN is listed as a component to at least one weapons system model, and 1 if the NIIN is listed as a component to 2 or more weapons system models. To determine whether a NIIN is listed as a component on a weapons system, we used RAND's EDA[17] database. This database has a table with fields "NIIN," "model1," "model2," "model3," up to as many as 66 system models. We could therefore easily count whether the NIIN was associated with one or more systems.

The above logic produces a system impact risk score for each part as follows:

SystemImpactRisk = (1/7)*(isNonreparable + Solesource + DACrisk + ,Factor
+ SystemCountRisk + EDA_demands_factor + EDA_ratio_factor).

[17] RAND's Equipment Downtime Analyzer data captures the parts used on a maintenance job order, including the serial number of the end item and the weapon system designator.

We divide by 7 to normalize. This calculation produces a score between 0 and 1. Actual scores ranged between 0 and about 0.67. Thus, a NIIN has a higher system impact risk score if it is nonreparable, sole sourced, if its technical documents are missing, if it has a relatively long lead-time, and if it impacts weapons systems.

Days to run-out calculation. We further reasoned that system impact risk would be greater and sooner for NIINs with low inventory, and lesser and delayed for NIINs with high inventory. This factor should be considered part of the system impact risk, but we decided to separate the calculation from the other system impact factors.

Further, this value needs to be interpreted with care. It is not intended to indicate physical inventory on hand, but rather to indicate supply chain availability. The days-to-run-out for each NIIN were calculated to include the date to the end of the latest-ending contract for that NIIN. This is the way that the risk database should work, because it indicates the supply chain risk, not simply a quantity on hand. Further, even with good forecasting tools, these run-out times are essentially speculative, because they depend on a forecasted demand. For example, in the extreme case where forecasted demand is zero, we assume 10,000 days to run-out, even if only one unit is on hand. The goal was to calculate *relative* risk across NIINs, and consequently across vendors.

As part of the days-to-run-out calculation, we wanted to account for other features of the supply chain, including the NIIN's reparability and whether the contract had expired. We therefore had a fairly complicated calculation for days to run out.

Demand forecast. First, we forecasted June 2013 issues (fulfilled demands) using a trend (linear regression) calculation by month. Multiplying by 12 gave an estimate of annual issues. This tends to overestimate demand (and therefore overestimate risk), because most demands were falling. We had previously used a smoothed calculation (e.g., 0.1*(2010 issues) + 0.3*(2011 issues) + 0.6*(2012 issues)), but this greatly overestimated demand. If the forecast was 0, we assumed 10,000 days to run out.

Days to contract run-out. Second, we calculated the days to contract run out as follows. If the contract was expired, we used 0. If the contract expiration date was in 1,500 days or more, we used 1,500 (because some contracts appeared to have unreasonable expiration dates, such as the year 2104, which may be a mistake in the database). Otherwise, we used the expiration date minus the date that the report was calculated.

Quantity on hand. We added serviceable and unserviceable on hand, on the assumption that unserviceable could be repaired, and much more quickly than bought new. The on-hand data came from DLA's QBO file, the SARSS ABF file from ILAP, and LMP Assets_All file from LIW.

Final calculation. If the NIIN was reparable, we calculated days to run-out as the days to contract run-out, plus 365 times the quantity on hand, divided by [annual issues times the wash-out rate]. (With 48 parts on hand, demand of 30, and a 40 percent washout rate, we would predict about 48/(30*0.4) = 48/12 = 4 years on hand.) We reasoned that supply would still be available if the contract is still open, but if not, the inventory would degrade at the washout rate. Where the washout rate was not available, we used a conservative value of 5 percent.

If the NIIN was not reparable, we simply took the larger value of the days to contract run-out, and the demand forecast divided by the quantity on hand, multiplied by 365.

Formula for Risk by NIIN

Risk is the product of vendor failure risk and system impact risk. At this point, we include the days to run-out in the formula, with the understanding that we consider it to be part of the likelihood. The final formula for risk by NIIN is likelihood times impact:

NIIN risk = VendorFailRisk*SystemImpactRisk/(DaysToRunOut/365 + 1).

We add 1 in the denominator to avoid a divide-by-zero.

This formula depends strongly on the inventory. The NIIN risk is a value between 0 and 1. Actual values ranged from 0 to about 0.19.

Calculating risk by NIIN allowed us to use the database to sum risk in different ways, including by vendor CAGE code, source of supply, and weapons system. Risk, then, tends to be calculated as higher for those vendors that supply more NIINs. We concluded that this was appropriate.

5. Analysis and Results

In this chapter, we examine risk by NIIN and examine what makes a NIIN risky or not risky. Following that, we examine risk by system type, to get a high-level view of how the NIINs affect system risk cumulatively. We then examine key aviation systems—the Apache, Blackhawk, Chinook, and Kiowa Warrior—and assess risk by CAGE code and source of supply. This is Step 4, prioritization, in our framework.

Note that this analysis is time-dependent because the data themselves are time-dependent. A NIIN with an expired contract is calculated to have higher risk than a NIIN with a current contract; some contracts expire every month, and some are renewed or established.

Risk by NIIN

Table 5.1 shows that the vast majority of NIINs in our database have very low risk. The average NIIN risk is about 0.005. The conclusion is that most of the risk is in 187 NIINs (bold), about 2 percent of the 9,298 in our database with risk scores ranging from 0.04 to over 0.12; we classify these NIINs as "high risk." These represent the highest-risk NIINs and should therefore be given highest priority in a risk-mitigation strategy.

Table 5.1. Distribution of NIIN Risk

Risk	# NIINs	% of total NIINS
Over 0.12	**3**	**0.03%**
0.10-0.12	**6**	**0.1%**
0.08-0.10	**22**	**0.2%**
0.06-0.08	**47**	**0.5%**
0.04-0.06	**109**	**1.2%**
0.02-0.04	260	2.8%
0.00-0.02	8,851	95.2%

The reason that the majority of NIINs have relatively low risk is related to the number of days of supply available for these NIINs. Figure 5.1 shows that more than 80 percent of the NIINs in the database had more than four years of serviceable supply relative to the current demand rate; almost 70 percent have eight years or more of supply. With so much supply on hand, the risk to the Army for these items is commensurately low.

The implication of this conclusion is that the Army has time to develop a supply chain risk management strategy while there is enough supply in the pipeline to mitigate the risk. This strategy could first focus on examining the highest-risk NIINs and determining what action, if any is warranted. For example, Table 5.2 gives provides key information on the five highest-ranked NIINs (Appendix C lists the top-100 risk NIINs).

Figure 5.1. Current Supply Availability Mitigates Risk

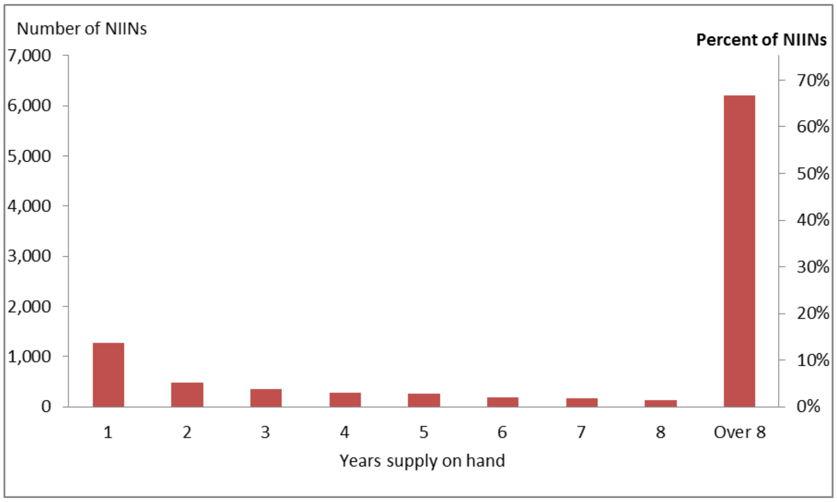


Table 5.2. Top Five Highest-Risk NIINs

NIIN	992392273	012711020	014951161	015171547	015661706
Description	GRATING, METAL	APERTURE, SIGHT	ADAPTER, POWER SUPPL	PROPELLER SHAFT,VEH	INSULATOR, PIN
Source of supply	AKZ	B14	SMS	AKZ	AKZ
Company name	W F E L LTD	Saab Dynamics AB	Ferbak Inc.	Freightliner of Savannah, Inc.	Ruta Supplies Inc.
CAGE code	K7705	SF413	0XAK6	03AZ7	0NJT4
Contract end date	2 Jan 2012	29 Jul 2013	6 May 2010	16 Jan 2012	15 Jun 2012
Vendor rev change/month	-$249	-$941	-$360	-$3,951	-$45
Vendor % rev change	-50%	-100%	-100%	-100%	-66%
Place of performance ZIP	Foreign	Foreign	91325	31407	07801
Flood risk	0.00	0.00	0.02	0.00	0.01
Tornado risk	0.00	0.00	0.00	0.00	0.00
Hurricane risk	0.00	0.00	0.00	0.00	0.00
Earthquake risk	0.00	0.00	0.50	0.05	0.04
Location hazard risk	1.00	1.00	0.52	0.05	0.05
Vendor fail risk	**0.28**	**0.33**	**0.28**	**0.23**	**0.26**
Sole source?	Yes	Yes	Yes	Yes	Yes
Reparability	Nonreparable	Nonreparable	Nonreparable	Nonreparable	Nonreparable
Tech documents available	No	No	No	Uncertain	No
Total lead-time	9	15	7	6	14
Est. annual issues	2	74	2	6	154
Est. days supply	0	20	0	0	152
System count	2	0	0	4	3
3-year EDA demands	10	0	0	11	107
System impact risk	**0.66**	**0.43**	**0.44**	**0.52**	**0.43**
NIIN risk	**0.19**	**0.14**	**0.12**	**0.12**	**0.11**

These NIINs have a relatively high vendor fail risk because the vendors' revenues have dropped significantly, the contracts are expired, two vendors are foreign, and one has earthquake risk.

In particular, NIINs 992392273, 015171547, and 015661706 have all been used on job orders that downed a weapon system in the last three years. The vendors are listed as sole source, the parts are not reparable, with technical documents not certainly available and with little on hand (using July 2013 inventory data). Subject matter expertise is needed to determine if these NIINs are indeed high risk; for example, it may not be difficult to find another source of supply or repair for the metal grating, while the propeller shaft and insulator may require a longer lead-time.

By contrast, NIINs with the *lowest* risk tend to have the opposite conditions—they have contracts still in place, and modest changes in vendor revenue and domestic production; the NIINs are from competitive sources and are reparable. They have technical documents available, many days of inventory on hand, and few impacts on systems.

Risk by System

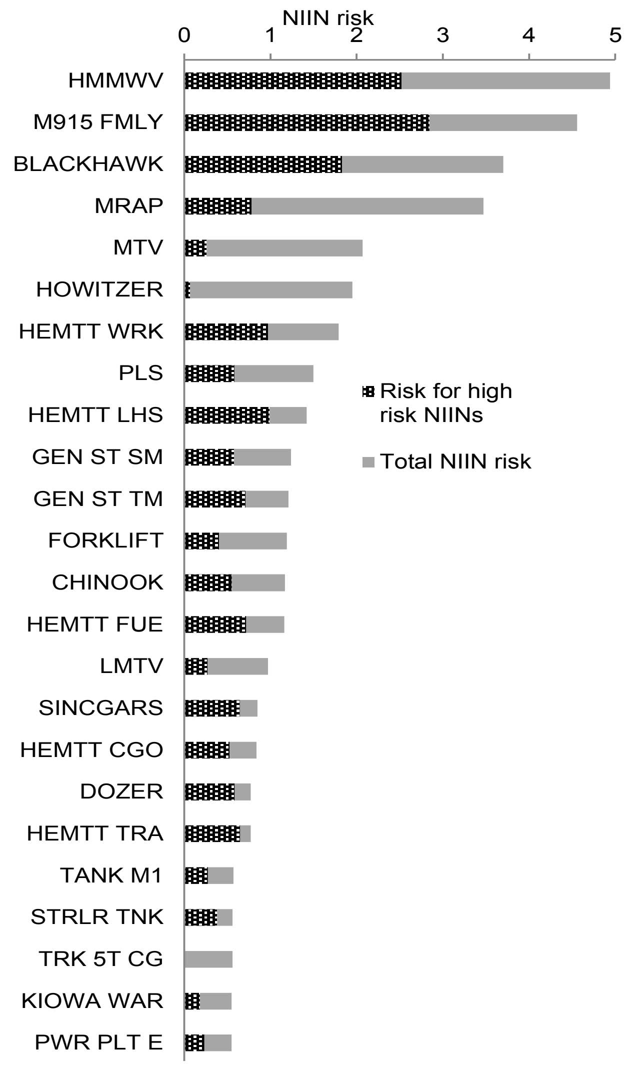
Next we examine the cumulative effect of individual NIIN risk at the weapon system level. In a previous section, we explained how NIINs can be associated with a weapon system using the EDA data set. Using the relationship between a NIIN and weapon system, we aggregate total risk and rank order the weapon systems accordingly. Thus, total system risk could be a value over 1.0.

The bar chart in Table 5.3 conveys the level of risk by weapon system family based on the NIINs in our database. The bar for each weapon system shows the total risk (summed over all NIINs supplied by each vendor), and also the contribution to risk from "high-risk" NIINs. For example the HMMWV has a total NIIN risk of 4.9; however about 50 percent of that risk is accounted for by "high-risk" NIINs. The second system on the list, the M915 family, is being retired, therefore it is not surprising that it has high-risk NIINs since current contracts are not being renewed and the risk calculation is based on historical demand. In this case, subject matter expertise would eliminate this system from consideration.

We conclude that the Army can use this method to identify and focus on the systems that have the highest supply chain risk. The following paragraphs list other systems with lower risk than these.

Table 5.3. Risk by System, Top 24

	System family	Total NIIN risk	# NIINs	# High risk NIINs
1	HMMWV	4.9	561	45
2	M915 FMLY	4.6	529	47
3	BLACKHAWK	3.7	426	26
4	MRAP	3.5	453	12
5	MTV	2.1	266	5
6	HOWITZER	2.0	203	1
7	HEMTT WRK	1.8	250	17
8	PLS	1.5	160	8
9	HEMTT LHS	1.4	127	17
10	GEN ST SM	1.2	96	10
11	GEN ST TM	1.2	90	12
12	FORKLIFT	1.2	111	7
13	CHINOOK	1.2	221	11
14	HEMTT FUE	1.2	174	11
15	LMTV	1.0	142	5
16	SINCGARS	0.9	50	9
17	HEMTT CGO	0.8	180	10
18	DOZER	0.8	20	8
19	HEMTT TRA	0.8	47	11
20	TANK M1	0.6	108	5
21	STRLR TNK	0.6	32	6
22	TRK 5T CG	0.6	117	0
23	KIOWA WAR	0.6	122	3
24	PWR PLT E	0.6	44	4



All other systems in our database had risk less than 0.34.

Key Aviation Systems

We next review four important aviation systems: the Apache, Blackhawk, Chinook, and Kiowa Warrior.

Apache

The Apache has relatively low system risk; it would have appeared 29th on the list in Table 5.3. As we shall see, the NIINs listed in our database for this system do not appear to hold much risk. Let's look at its five highest-risk NIINs.

Table 5.4. Five Highest-Risk NIINs for the Apache

NIIN	011737126	011905530	012667596	012158515	012242263
Description	RING, MATING, SEAL	BOOT, DUST AND MOIST	BATTERY BOX	KEY, MACHINE	BELL CRANK
Company name	D & R Machine Co.	Pierce Manufacturing Consulting	Federal Prison Industries Inc.	AST Associates, Inc.	SPX Corporation
CAGE code	4T853	3D3P2	90142	0WVW0	82001
Contract end date	31 May 2011	30 Apr 2011	25 Mar 2011	29 Oct 2010	30 Sep 2012
Vendor rev change/month	-$12,726	-$1,314	-$13,827	-$539	-$361,258
Vendor % rev change	-100%	-100%	-100%	-100%	-100%
Location hazard risk	0.05	0.05	0.02	0.03	0.03
Vendor fail risk	**0.23**	**0.23**	**0.22**	**0.23**	**0.23**
Sole source?	No	Yes	No	No	Yes
Reparability	Nonreparable	Nonreparable	Nonreparable	Nonreparable	Reparable
Tech documents available	No	No	No	Yes	No
Total lead-time	9	4	7	11	16
Est. annual issues	1,097	553	236	323	194
Days of supply	259	547	520	691	952
System count	3	2	5	2	1
EDA_demands	3	2	5	2	1
System impact risk	**0.26**	**0.23**	**0.18**	**0.10**	**0.11**
NIIN risk	**0.06**	**0.05**	**0.04**	**0.02**	**0.02**

These NIINs look only moderately risky. On the one hand, they all have expired contracts, and all but NIIN 012158515 “KEY, MACHINE” have missing technical documents. The vendors’ revenue has dropped for all of them. Most of these NIINs appear on multiple system models (011737126, for example, appears on both the Apache and Blackhawk; arguably, this double-counts the system risk for the each system, but the effect is small). All of these NIINs have had a few EDA demands in the past three years. However, only 011905530 “BOOT, DUST AND MOIST” and 012242263 “BELL CRANK” are sole sourced. Their lead-times are comparatively short. The location risk for each vendor is small. All are forecasted to run out in more than six months, taking into account the repair system and known washout rates. The last two do not make our cutoff of 0.04 (top 2 percent of NIINs) as being a “high-risk” NIIN.

Blackhawk

The Blackhawk is number three on the list above, so we expect its highest-risk NIINs to have higher risk than those for the Apache. Let’s look at its five highest-risk NIINs.

Table 5.5. Five Highest-Risk NIINs for the Blackhawk

NIIN	014170135	012186522	000014077	014943019	011737126
Description	BEARING, PLAIN, ROD E	ACTUATOR, ELECTRO-ME	ANTENNA	SEAT, AIRCRAFT	RING, MATING, SEAL
Company name	Lord Corporation	Eaton Corporation	Canadian Commercial Corp	BAE Systems Aerospace & Defense	D & R Machine Co.
CAGE code	76005	17472	98247	54786	4T853
Contract end date	28 Feb 2011	03 Sep 2011	23 Dec 2011	31 Dec 2011	31 May 2011
Vendor rev change/month	-$315,797	-$98,924	-$27,129	-$94,432	-$12,726
Vendor % rev change	-100%	-100%	-100%	-88%	-100%
Location hazard risk	0.03	0.02	1.00	0.03	0.05
Vendor fail risk	**0.23**	**0.22**	**0.33**	**0.21**	**0.23**
Sole source?	Yes	Yes	Yes	Yes	No
Reparability	Nonreparable	Nonreparable	Nonreparable	Reparable	Nonreparable
Tech documents available	No	No	No	No	No
Total lead-time	16	12	1	21	9
Est. annual issues	878	246	29	50	1,097
Days of supply	111	90	304	54	259
System count	5	5	1	1	3
EDA_demands	5	5	1	1	3
System impact risk	**0.46**	**0.42**	**0.27**	**0.34**	**0.26**
NIIN risk	**0.10**	**0.09**	**0.09**	**0.07**	**0.06**

What makes these risky? These NIINs for the Blackhawk are all missing technical documents. All have expired contracts. All but 011737126 “RING, MATING, SEAL” are sole source. All of them are forecasted to run out in under a year, even considering the repair cycle. In every case, the vendor’s revenue per month dropped considerably from 2010. All have had EDA demands in the past three years. So the Blackhawk appears to be much more at risk than the Apache, and our “Total NIIN risk” numbers bear this out.

Chinook

The Chinook is number thirteen on the list above. Let’s look at its five highest-risk NIINs.

Table 5.6. Five Highest-Risk NIINs for the Chinook

NIIN	011495774	015607497	013737825	013139375	009234318
Description	BOLT, CLOSE TOLERANC	SWITCH, TOGGLE	BRACKET, STRUCTURAL	BEARING,PLAIN ,ROD E	SEAT, AIRCRAFT
Company name	SPS Technologies, LLC	Mason Electric Company	Four-H Machine, LLC	Lord Corporation	Newgard Industries, Inc.
CAGE code	56878	81579	1HYV5	76005	59686
Contract end date	07 Dec 2011	06 Apr 2012	26 Jun 2011	28 Sep 2012	31 Mar 2011
Vendor rev change/month	-$39,779	-$1,379	-$16,360	-$19,391	-$33,652
Vendor % rev change	-100%	-78%	-100%	-69%	-100%
Location hazard risk	0.05	0.52	0.23	0.03	0.05
Vendor fail risk	0.23	0.26	0.25	0.19	0.23
Sole source?	No	Yes	No	No	No
Reparability	Nonreparable	Nonreparable	Reparable	Nonreparable	Reparable
Tech documents available	No	Yes	No	No	No
Total lead-time	7	7	15	18	17
Est. annual issues	1,871	35	73	535	766
Days of supply	203	409	219	218	195
System count	2	3	2	3	2
EDA_demands	2	3	2	3	2
System impact risk	0.28	0.21	0.19	0.24	0.20
NIIN risk	0.06	0.05	0.05	0.05	0.05

What makes these NIINs risky? Four NIINs for the Chinook are missing technical documents. Three are nonreparable. All have expired contracts. Vendors' revenues have dropped significantly, 100 percent from 2010. All NIINs have had EDA demands in the past three years. However, at least six months of inventory is on hand for all of them—but only one is sole source.

Kiowa Warrior

The Kiowa Warrior is number 23 on the list above. Since it is further down the list, we might expect its NIINs to be less risky, and, as with the Apache, they are.

Table 5.7. Five Highest-Risk NIINs for the Kiowa Warrior

NIIN	015007208	015572722	011268637	015253670	015253671
Description	REBOUND ASSY	E LBOW, TUBE	HANDLE, RELEASE-HOLD	BELT, AIRCRAFT SAFET	BELT, AIRCRAFT SAFET
Company name	Bell Helicopter Textron Inc.	Allied Defense Industries Inc.	Maven Engineering Corporation	Conax Florida Corporation	Conax Florida Corporation
CAGE code	60762	0GD25	46YF5	62323	62323
Contract end date	31 Dec 2010	31 Mar 2011	30 Jun 2010	31 May 2012	31 May 2013
Vendor rev change/month	-$2,722	-$220	-$1,786	$2,579	-$12,231
Vendor % rev change	-100%	-100%	-100%	100%	-93%
Location hazard risk	0.06	0.02	0.03	0.02	0.02
Vendor fail risk	**0.23**	**0.22**	**0.23**	**0.10**	**0.22**
Sole source?	Yes	Yes	No	Yes	Yes
Reparability	Nonreparable	Nonreparable	Nonreparable	Nonreparable	Nonreparable
Tech documents available	No	Yes	No	No	No
Total lead-time	14	8	5	8	7
Est. annual issues	17	106	241	102	77
Days of supply	109	321	324	143	998
System count	1	1	1	1	1
EDA_demands	1	1	1	1	1
System impact risk	**0.41**	**0.20**	**0.19**	**0.37**	**0.14**
NIIN risk	**0.09**	**0.04**	**0.04**	**0.04**	**0.03**

What makes these risky? Once again, all have expired contracts. All are sole source except 011268637. All have EDA demands, though very little. All the vendors have lost most of their revenue compared to 2010. On the other hand, none have long lead-times or significant natural hazards. All have more than three months of supply. The first NIIN, 015007208, has most of the risk for this system, 0.09 compared to 0.04 or less for the others.

Risk by CAGE Code

Top CAGE Codes

Table 5.8 shows the twenty highest-risk CAGE codes, based on sum of NIIN risk. By far, the riskiest is KB237 BAE Systems Global Combat Systems, which we shall examine in more detail later.

Table 5.8. Twenty Highest-Risk CAGE Codes by Sum of NIIN Risk

Cage code	Company name	Vendor fail risk	System impact risk	Sum of NIIN risk	NIIN count	Avg risk per NIIN
KB237	BAE SYSTEMS GLOBAL COMBAT SYSTEMS	0.15	66.3	9.7	1,431	0.007
B0897	FN HERSTAL SA	0.20	7.2	1.4	80	0.018
45152	OSHKOSH CORPORATION	0.16	7.2	1.0	162	0.006
78286	SIKORSKY AIRCRAFT CORPORATION	0.08	8.7	0.7	341	0.002
90142	FEDERAL PRISON INDUSTRIES INC.	0.17	3.4	0.7	80	0.008
0NJT4	RUTA SUPPLIES INC.	0.25	2.2	0.6	28	0.020
97499	BELL HELICOPTER TEXTRON INC.	0.06	8.8	0.5	335	0.001
7Y943	ACE ELECTRONICS INC.	0.21	2.5	0.5	79	0.006
1T1Z4	POMP’S TIRE SERVICE, INC.	0.17	2.5	0.5	35	0.015
K7705	W F E L LTD	0.29	1.8	0.5	36	0.014
31UG4	AMERICAN DEFENSE SYSTEMS, INC.	0.15	2.6	0.4	13	0.032
54786	BAE SYSTEMS AEROSPACE & DEFENSE	0.13	2.3	0.4	47	0.007
98247	CANADIAN COMMERCIAL CORP	0.21	1.9	0.4	73	0.005
51190	AEROFLEX WICHITA INC.	0.12	2.1	0.3	56	0.005
0B107	L-3 INSIGHT TECHNOLOGY INCORPORATED	0.18	1.6	0.3	20	0.013
8H994	ALABAMA FLUID SYSTEM TECHNOLOGIES,	0.15	1.5	0.3	9	0.029
4U486	P & S PRODUCTS, INC.	0.31	0.9	0.3	8	0.036
SF413	SAAB DYNAMICS AB	0.31	0.9	0.3	8	0.036
05716	RAYTHEON COMPANY	0.06	3.9	0.2	320	0.001
31550	EXELIS INC.	0.06	2.5	0.2	69	0.002

Note that the sum of NIIN risk depends on the number of NIINs—generally, a CAGE code has higher risk if it supplies a greater number of NIINs, but not completely. CAGE code 97499 Bell Helicopter Textron supplies 335 NIINs, but these are all low-risk NIINs. By contrast, B0897 FN Herstal SA supplies only 80 NIINs, but appears second on the list.

Overall, BAE system dominates the list, with over 1400 NIINs and sum of NIIN risk of 9.7. While the average risk per NIIN is low, the volume of business with BAE argues strongly for including it in any strategic sourcing initiative.

Sorting the query by average risk per NIIN gives a different picture, as seen in Table 5.9.

Table 5.9. Twenty Highest-Risk CAGE Codes by Average Risk per NIIN

Cage code	Company name	Vendor fail risk	System impact risk	Sum of NIIN risk	NIIN count	Avg risk per NIIN
0XAK6	FERBAK INC.	0.28	0.4	0.1	1	0.123
1JU97	NATIONAL SECURITY ASSOCIATES INC	0.22	0.4	0.1	1	0.098
17472	EATON CORPORATION	0.22	0.4	0.1	1	0.094
04034	GEMS SENSORS INC.	0.24	0.4	0.1	1	0.091
13859	KING NUTRONICS CORPORATION	0.18	0.4	0.1	1	0.078
65442	PELICAN PRODUCTS, INC.	0.26	0.3	0.1	1	0.078
308Z9	ELECTRIC FUEL BATTERY CORPORATION	0.22	0.3	0.1	1	0.078
5CBE0	BALLISTIC ADVANTAGE LLC DIV	0.22	0.3	0.1	1	0.076
1EAW9	TAKATA PROTECTION SYSTEMS INC.	0.25	0.3	0.1	1	0.074
1L012	MARANATHA INDUSTRIES INC.	0.27	0.3	0.1	1	0.072
59164	ELECTRICAL ASSEMBLY, INC.	0.22	0.6	0.1	2	0.069
9A017	GARDNER INC.	0.11	0.6	0.1	1	0.068
K2812	BELDAM CROSSLEY LTD	0.27	0.2	0.1	1	0.067
1P066	L-3 COMMUNICATIONS VERTEX AEROSPACE	0.22	0.6	0.1	2	0.064
56878	SPS TECHNOLOGIES, LLC	0.23	0.3	0.1	1	0.064
4HAJ0	PROJECT ENGINEERING COMPANY	0.23	0.3	0.1	1	0.064
1BZD4	TRU HITCH INC	0.19	0.3	0.1	1	0.062
14466	AERO PRODUCTS RESEARCH, INC.	0.22	0.3	0.1	1	0.061
4T853	D & R MACHINE CO.	0.23	0.3	0.1	1	0.059
0ATN7	W C WOLFF COMPANY	0.23	0.3	0.1	1	0.058

The NIINs associated with these CAGE codes are well above the 0.04 "high-risk" threshold. However, because these vendors supply only one or two parts, it is not desirable to consider them for a strategic sourcing program.

Although the risk levels do make these vendors worthy of management attention, care should be taken before pursuing these vendors and NIINs too aggressively. Consider 0XAK6 Ferbak Inc. The one part the company has supplied is NIIN 014951161 "ADAPTER, POWER SUPPL." The sole source contract expired in May 2010, implying a loss of revenue to the vendor, but of only a small amount of money. The vendor is in a severe earthquake risk zone. Demand is low, forecast at only 2.4 per year, but no parts are on hand, and the technical documents are missing. No EDA demands have been reported. So this does not look like an immediate risk, but if demand were to spike it could be. Ferbak is a small privately held business that provides photographic equipment and supplies; it does not manufacture these NIINs. (Usually, the CAGE code identifies the manufacturer, but not always.) If the power supply adapter in question is still manufactured, then it might be relatively easy to obtain it from Ferback or some other source. In this example, further information from a subject matter expert would probably eliminate this NIIN and vendor from the risk list.

Risky NIINs for BAE Systems Global Combat Systems

As noted, by far the highest risk CAGE code is KB237, BAE Systems Global Combat Systems. This CAGE code has 1,431 NIINs, about 15 percent of the NIINs on our database. Let's examine the five highest-risk NIINs for this CAGE code, as shown in Table 5.10.

Table 5.10. Five Highest-Risk NIINs for KB237 BAE Systems Global Combat Systems

NIIN	**995898526**	**998563987**	**993495740**	**999740947**	**993050111**
Description	STUD, PLAIN	HUB CAP, WHEEL	SCREW, CAP, HEXAGON H	RING, LAMINATED	SEAL KIT, ARM ASSEMB
Source of supply	B14	B14	B14	B14	B14
Contract completion date	25 Dec 2030	25 Dec 2030	25 Dec 2030	25 Dec 2030	25 Dec 2030
Vendor rev change/month	-$2	-$377	-$665	-$16	-$8,849
Vendor $ rev change	-100%	-100%	-100%	-75%	-100%
Place of performance	Foreign	Foreign	Foreign	Foreign	Foreign
Vendor fail risk	**0.22**	**0.22**	**0.22**	**0.19**	**0.22**
Sole source?	Yes	Yes	Yes	Yes	Yes
Reparability	Nonreparable	Nonreparable	Nonreparable	Nonreparable	Nonreparable
Tech documents available	No	No	No	No	No
Total lead-time	1	2	8	4	1
Est. annual issues	6	1	94	2	118
Est. days supply	0	1,521	273	1,217	335
System count	1	2	1	1	2
3-year EDA demands	10	12	84	3	22
System impact risk	**0.13**	**0.13**	**0.12**	**0.13**	**0.11**
NIIN risk	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**

The risk for each of these NIINs, 0.03 for all of them, is below our threshold of 0.04 for high-risk NIIN. The data show why: Long-term contracts are still in place and lead times are short. On the other hand, the vendor is seeing decline in revenue, all these NIINs are sole source, all the documents are missing, the CAGE code is foreign, and all these NIINs have been associated with downing a system. Finally, they are all nonreparable. Because the Army has long-term contracts for these NIINs, we assumed 1,500 days to run-out. But if BAE decided to end manufacturing of these NIINs, the Army would have an immediate difficulty with NIIN 995898526.

Risky NIINs for Sikorsky Aircraft Corporation

Sikorsky Aircraft Corporation appears fourth on the list of riskiest CAGE codes. Table 5.11 indicates that the highest risk NIINs for this CAGE code are in fact low risk overall, 0.02 and less, below our cut-off of 0.04. While the contracts are expired and they are listed as sole source, the lead-times are not long and there is ample supply based on demand history. Because Sikorsky is a provider of aircraft components, the risk is more concentrated by weapon system, as indicated by the system impact risk.

Table 5.11. Five Highest-Risk NIINs for 78286 Sikorsky Aircraft Corporation

NIIN	015485942	015856191	015856189	015742864	015864838
Description	FLOOR, AIRCRAFT	SKIN, AIRCRAFT	SKIN, AIRCRAFT	FITTING, STRUCTURALC	CHANNEL, AIRCRAFT
Source of supply	B17	B17	B17	B17	B17
Contract completion date	31 May 2012	31 May 2011	30 Jun 2011	31 May 2013	31 Jan 2013
Vendor rev change/month	-$8,145	-$663	-$612	-$407	$19,780
Vendor $ rev change	-100%	-90%	-100%	-100%	278%
Place of performance ZIP	06614	06614	06614	06614	06614
Vendor fail risk	**0.23**	**0.22**	**0.23**	**0.23**	**0.08**
Sole source?	Yes	Yes	Yes	Yes	Yes
Reparability	Reparable	Nonreparable	Nonreparable	Nonreparable	Nonreparable
Tech documents available	No	Uncertain	Uncertain	No	Uncertain
Total lead-time	13	6	12	8	15
Est. annual issues	6	4	5	20	13
Est. days supply	182	1217	1445	1,270	442
System count	0	0	0	0	0
3-year EDA demands	0	0	0	0	0
System impact risk	**0.11**	**0.08**	**0.08**	**0.07**	**0.17**
NIIN risk	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**

Highest-Risk CAGE Codes by Source of Supply

With the available data we can also examine the distribution of risk within the Army's item management organization. Table 5.12 shows the top five highest-risk CAGE codes by source of supply (SOS), the Life Cycle Management Command. The average in this list is about 0.5, so anything above that should get attention first. SOS B14, TACOM has the highest accumulation of risk, and not only because of BAE Systems Combat Systems. The SOS codes are as follows:

A12, AKZ, and B14: Tank and Armaments Command
B16: Communications-Electronics Command
B17 and B64: Air and Missile Command
B50: Appears to be orphaned
GSA: General Services Administration
N32: Naval Inventory Control Point
SMS: Defense Logistics Agency

Table 5.12. Top Five Highest-Risk CAGE Codes By Source of Supply

SOS	CAGE code	Vendor	Sum of NIIN risk
A12	1LEW5	AVON PROTECTION SYSTEMS INC.	0.2
A12	18048	SILICONE RUBBER RIGHT PRODUCTS LLC	0.1
A12	0EFR2	CONNECTEC COMPANY, INC.	0.1
A12	1W7P9	QUICK PROTECTIVE SYSTEMS INC.	0.0
A12	06421	TRUETECH INC.	0.0
AKZ	**45152**	**OSHKOSH CORPORATION**	**0.9**
AKZ	**K7705**	**W F E L LTD**	**0.5**
AKZ	**1T1Z4**	**POMP'S TIRE SERVICE, INC.**	**0.5**
AKZ	**0NJT4**	**RUTA SUPPLIES INC.**	**0.5**
AKZ	54786	BAE SYSTEMS AEROSPACE & DEFENSE	0.2
B14	**KB237**	**BAE SYSTEMS GLOBAL COMBAT SYSTEMS**	**9.7**
B14	**B0897**	**FN HERSTAL SA**	**1.4**
B14	SF413	SAAB DYNAMICS AB	0.3
B14	3A703	REMINGTON ARMS COMPANY LLC	0.2
B14	1PN61	DILLON AERO, INC.	0.2
B16	7Y943	ACE ELECTRONICS INC.	0.4
B16	0BS05	E.F. JOHNSON COMPANY	0.2
B16	90142	FEDERAL PRISON INDUSTRIES INC	0.2
B16	96214	RAYTHEON COMPANY	0.1
B16	8X691	SIERRA NEVADA CORPORATION	0.1
B17	**78286**	**SIKORSKY AIRCRAFT CORPORATION**	**0.7**
B17	97499	BELL HELICOPTER TEXTRON INC.	0.4
B17	1Q842	MARTIN-BAKER AMERICA INC.	0.3
B17	51439	FATIGUE TECHNOLOGY, INC.	0.2
B17	1T765	ROBERTSON FUEL SYSTEMS, L.L.C.	0.2
B50	48T42	BOEING COMPANY THE	0.0
B64	8H994	ALABAMA FLUID SYSTEM TECHNOLOGIES,	0.3
B64	61434	R & D ELECTRONICS INC.	0.2
B64	05716	RAYTHEON COMPANY	0.2
B64	1XFF6	FEDERAL PRISON INDUSTRIES INC	0.2
B64	24581	PRECISION CABLE OF TENNESSEE INC	0.1
GSA	1JU97	NATIONAL SECURITY ASSOCIATES INC	0.1
GSA	1P6K0	FORM FIT AND FUNCTION, LLC	0.1
GSA	46YF5	MAVEN ENGINEERING CORPORATION	0.0
GSA	1PSD4	FRANCIS TORQ/LITE INC.	0.0
GSA	8P623	DIVERSIFIED TRAFFIC PRODUCTS INC.	0.0
N32	89305	SIMMONDS PRECISION PRODUCTS, INC.	0.2
N32	07PR7	ULTRAX AEROSPACE, INC.	0.1
SMS	**90142**	**FEDERAL PRISON INDUSTRIES INC**	**0.5**
SMS	31UG4	AMERICAN DEFENSE SYSTEMS, INC.	0.3
SMS	4U486	P & S PRODUCTS, INC.	0.3
SMS	76005	LORD CORPORATION	0.2
SMS	51190	AEROFLEX WICHITA INC.	0.1

Impact of Increasing Demand

With this risk analysis, we considered whether a sudden increase in demand would change the results significantly. We therefore did a simple simulation in which we use the sum of demands from 2010 and 2011 as the basis for demand in the risk assessment. Intuitively, this should significantly raise the risk for all NIINs because this was a period of high operational tempo for the Army. Table 5.13 compares the original risk (Table 5.1) with the risk assessed using a higher demand profile.

We see that risk does increase, but not by an overwhelming amount. The higher demand has 410 NIINs considered to have a "high" risk of over 0.04, compared to 187 before. Indeed, this is likely to be an overestimate, because our simple simulation still considers that vendors' revenues have fallen. We see that risk is not only about demand. Risk increases so little because our risk assessment includes a variety of factors about the supply chain, such as the end dates of existing contracts and availability of technical documents.

Table 5.13. Distribution of High-Demand NIIN Risk

	Forecasted Demand		High Demand	
Risk	# NIINs	% of total NIINS	# NIINs	% of total NIINS
Over 0.12	3	0.03%	13	0.14%
0.10-0.12	6	0.1%	21	0.2%
0.08-0.10	22	0.2%	51	0.5%
0.06-0.08	47	0.5%	118	1.3%
0.04-0.06	109	1.2%	207	2.2%
0.02-0.04	260	2.8%	408	4.4%
0.00-0.02	8,851	95.2%	8,480	91.2%

Risk for NIINs Without Contracts

The intent of this research is to develop a method to assess supply chain risk as part of a Strategic Sourcing initiative. As such, we concentrated on a list of 9,300 NIINs provided by AMC. This is by no means the entire number of NIINs used on weapon systems. Out of concern that we may be ignoring some risk by the selection of NIINs, we also developed a second database for a larger number of NIINs without contract actions in the past three years but which had been demanded at the supply support activities (SSAs). This produced a database of 14,472 additional NIINs. Because these NIINs did not have a contract action, we had little or no vendor information for them, and could not assess the risk by vendor. We could, however, assess system risk, which is the consequence should the external supply chain be completely unavailable.

Risk by NIIN

Following the previous analysis, Table 5.14 below shows NIIN risk. It appears that these NIINs have virtually no risk. However, recall that we have very little vendor information on these NIINs, and the NIIN risk is the product of vendor fail risk and system impact risk. So we must look more closely.

Table 5.14. Table of NIIN Risk (with Little Data on Vendors)

Risk	# NIINs	% of total NIINS
Over 0.12	0	
0.10-0.12	0	
0.08-0.10	0	
0.06-0.08	0	
0.04-0.06	4	
0.02-0.04	282	1.9
0.00-0.02	14,186	98.0

Table 5.15 shows system impact risk. Recall that system impact combines several factors—reparability, sole source, availability of technical drawings, lead-time, EDA demands, and how many weapon systems on which the part is found.

Table 5.15. Table of System Impact Risk

Risk	# NIINs	% of total NIINS
Over 0.45	2	0.01
0.40 to 0.45	1	0.01
0.35 to 0.40	7	0.05
0.30 to 0.35	14	0.1
0.25 to 0.30	161	1.1
0.20 to 0.25	111	0.8
0.15 to 0.20	156	1.1
0.10 to 0.15	371	2.6
0.05 to 0.10	583	4.0
0 to 0.05	13,066	90.3

If we chose the top 2 percent of the distribution, we find that 296 NIINs could be considered as having high system impact risk, but the risk level is 0.25 or greater, compared to 2 percent of NIINs (187 of 9,298) with risk level of only 0.04 or more. The point is that this second list was not part of the original analysis, and AMC was not considering the risk associated with these NIINs. This was not because AMC is not concerned about that risk, but rather because this project was viewed as part of a supplier relationship management process, so only NIINs with recent contract actions were of interest as part of that process. The takeaway message, though, should be that as much significant system impact risk appears for NIINs without recent contract actions as for NIINs with recent actions.

So let's look at some of these high-risk NIINs (Table 5.16). Why are these risky?

. Top Five Highest-Risk NIINs

NIIN	015975557	014735029	015436120	015991927	015881366
Description	PARTS KIT, FAN RADIATOR	TRANSFER TRANSMISSI	TRAVERSING MECHANISM	DOOR, RESTOCK, REPLEN	MAINTENANCE KIT, VEH
Source of supply	AKZ	AKZ	AKZ	AKZ	AKZ
Reparability	Nonreparable	Nonreparable	Nonreparable	Nonreparable	Nonreparable
Tech documents available	Uncertain	No	Uncertain	No	No
Total lead-time	0	0	0	0	0
Est. annual issues	5	6	1	12	94
Est. days supply	0	61	0	61	39
System count	2	12	1	1	2
3-year EDA demands	38	121	3	14	6
System impact risk	0.50	0.49	0.43	0.39	0.39

These NIINs have system impact risk because they are nonreparable, with technical documents not currently available, and with little on hand (using July 2013 inventory data). They all appear on weapons systems, and have been associated with downing weapons systems over the past three years. These are high-risk NIINs.

Risk by System Category

Table 5.17 shows system impact risk by system category. For NIINs without contract actions in the past two years, we see that the Armored Carrier and Tactical Vehicle systems have the highest total system impact risk.

Table 5.17. Risk by System Category

System category	Total system impact	# NIINs
Armored carrier	93.6	1,924
Tactical vehicle	87.0	2,130
Combat vehicle	21.5	764
Rotary wing aircraft	18.9	758
Tank	6.0	297
Crew weapon	5.6	225
Power generation systems	3.7	107
Other automotive	3.4	47
Surv targ acq and observation	3.3	47
Communications	3.0	86
Artillery	2.7	100
Surface to surface missile	2.1	52
Other weapons	1.8	28
Chemical biological radiological	1.4	28
Surface-to-air missile	1.3	105
Line of communication and base support systems	1.1	64
Construction equipment	0.9	49
Other electronics equipment	0.9	12
Soldier and combat support system	0.8	34
Avionics	0.5	8
Signal intel	0.4	36
Individual weapon	0.3	10
Track	0.2	10
Missile	0.2	4
Engineer	0.0	2

Risk by System

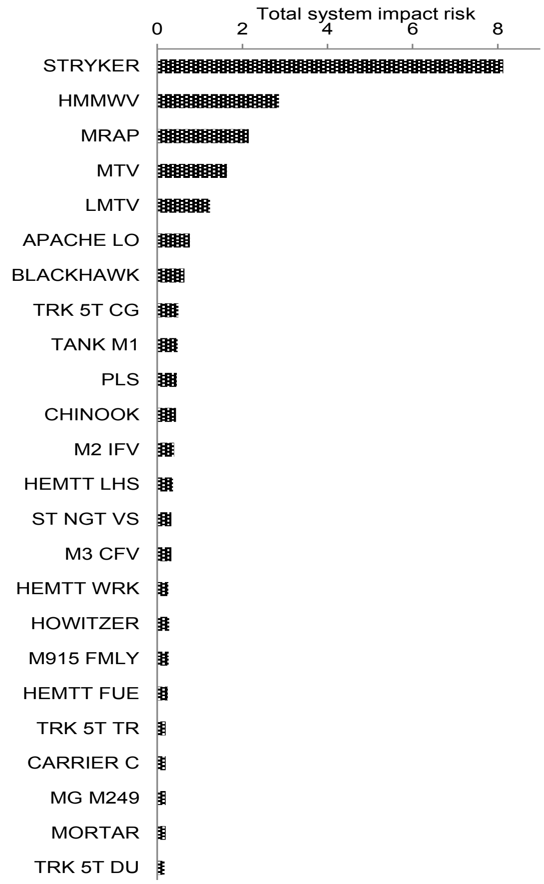
We can examine system families at a more detailed level than system category. As before, we identified system families via the RAND Equipment Downtime Analyzer.

The bar chart on Table 5.18 conveys the level of risk by weapon system family based on our database, for the top 24 systems with highest total system impact risk. Previously, we saw that the HMMWV, M915 FMLY, Blackhawk, and MRAP had the highest total NIIN risk.

Looking only at system impact risk, for NIINs with no contract actions in the past two years, we see a different story. STRYKER, HMMWV, MRAP, and MTV are at the top of the list.

Table 5.18. Risk by System

	System family	System impact risk	# NIINs
1	STRYKER	8.1	1,416
2	HMMWV	2.9	509
3	MRAP	2.2	742
4	MTV	1.6	326
5	LMTV	1.2	201
6	APACHE LO	0.8	223
7	BLACKHAWK	0.6	256
8	TRK 5T CG	0.5	178
9	TANK M1	0.5	235
10	PLS	0.5	92
11	CHINOOK	0.4	231
12	M2 IFV	0.4	204
13	HEMTT LHS	0.4	78
14	ST NGT VS	0.3	35
15	M3 CFV	0.3	119
16	HEMTT WRK	0.3	121
17	HOWITZER	0.3	100
18	M915 FMLY	0.3	121
19	HEMTT FUE	0.3	93
20	TRK 5T TR	0.2	71
21	CARRIER C	0.2	66
22	MG M249	0.2	94
23	MORTAR	0.2	53
24	TRK 5T DU	0.2	78



Highest-Risk Sources of Supply

Table 5.19 shows total system risk by source of supply for these NIINs without recent contract actions. By far, the category with highest system impact risk is AKZ U.S. Army Tank-Automotive Command, and not only because it has the largest number of NIINs. It has about triple the NIINs of the next category, B14, but almost five times the total system risk.

Table 5.19 System Impact Risk by Source of Supply

SOS	NIIN count	Total system risk
AKZ	6,019	170.5
B14	2,148	36.5
B17	1,907	27.5
B16	2,981	33.7
B64	998	8.2
A12	417	6.1
BAM	1	0
B46	1	0

6. Conclusions and Recommendations

In this research we presented an eight-step supply chain risk management process and implemented steps 1 through 4: identify risk, estimate likelihood of occurrence, assess probable consequence and duration, and prioritize. We developed and demonstrated a data-driven approach that can be used to assess and prioritize the relative risk of a supply chain disruption from the perspective of the Army, at the NIIN, vendor, and weapon system levels.

This research supported an effort by AMC to implement a strategic sourcing and supplier relationship initiative. Strategic sourcing seeks to identify suppliers of high strategic importance and invest additional time and resources in developing a relationship with that supplier. When RAND began this study, the Army had completed a spend analysis and selected candidate firms for its SS/SRM initiative. AMC asked RAND to look more broadly at supply chain risk.

Overall, we concluded that a methodology developed in this research could inform AMC management regarding its exposure to supply chain risk. Supply chain risk is dynamic, and changes as vendors move in and out of the market and as demand changes. This risk should be tracked routinely. The Army has no process in place to track supply chain risk, and the SS/SRM initiative does not meet that requirement. We recognize that our process is analytically intensive and in its current form would be difficult for the Army to implement. An analogous system is RAND's Automated Quality Management Tool (Loredo et al., 2014), which provides system engineers with near-real-time assessment of abnormal demand patterns and quality problems. Such an automated tool, focused on identifying supply chain risk, would need to be developed to make this a viable program. The automated tool could further calculate drivers of risk, for example, showing the number and percentage of sole source NIINs by system. This automated tool could run relatively often, at least monthly, while sending automated alerts to AMC staff only as needed.

More specifically, our study initially focused on NIINs that have active supplier contracts, which resulted in an analysis of about 9,300 NIINs. However, we were curious to expand the approach to all NIINs. This resulted in the addition of approximately 14,000 additional NIINs. Our analysis of NIINs with expired contracts should be highlighted. These NIINs are not associated with a current contract, and tend to be nonreparable, with no technical documentation and little on hand. If SS/SRM initiatives focus only on NIINs with current contracts, a significant supply chain risk is ignored.

For both populations of NIINs, the current serviceable on-hand balance eclipsed the projected demands (especially with the projected reduction in operational tempo)—thereby limiting the immediate risk from a supply chain disruption to the Army. Even if demand were to increase, we have some indication that the Army's supply chain would not have a spike in risk.

From a strategic sourcing point of view, the methodology identified several vendors of strategic interest; chief among them is BAE Systems.

The methodology was also used to analyze risk by weapon system, identifying the top risk weapon systems for both NIIN populations as the HMMWV, the Stryker, the Blackhawk, the MRAP and the MTV. Looking at risk by weapon system should allow AMC to focus supply chain risk management activities.

The method developed can be used to identify the reasons for the risk score. For example for those few hundred NIINs that rank high on the risk list, the recommendations are straightforward.

Recommendations to Reduce the Likelihood of Vendor Supply Failure

- First, address high-risk suppliers that provide many parts, even if the average risk per NIIN is low. Efforts to improve these relationships are likely to have the biggest payoff.
- Then, address high-risk suppliers that provide only a few parts. These suppliers will have a high average risk per NIIN.
- If no contract is in place, assess whether a new contract needs to be made.
- Assess whether the existing vendor has contingency plans in place to manage natural hazard.
- If the vendor is foreign and single-sourced, assess whether production can be done in the U.S.

Recommendations to Reduce System Impact

- Consider obtaining technical documents where they are missing.
- Assess inventory levels, and consider ordering additional quantities.
- For reparables, assess whether the repair cycle can be improved.
- For expensive nonreparables, assess whether the NIIN should be made reparable.

Recommendations to Reduce Risks from Internal Processes

Improving Internal Processes

The Strategic Sourcing Working Group workshop, held May 1, 2013, identified the key risks as being demand fluctuation, funding uncertainty, and long lead-times (including production, but especially contract and administrative). These risks stem mainly from internal processes.

Demand fluctuation and funding uncertainty are not particularly under AMC control. However, AMC may wish to consider initiating an “internal supplier management” process, to improve its demand information and to reduce its internal lead-times.

Improving Inventory Management

Thus far, we have focused on risk by NIIN, and we calculated aggregate risk for different groups by summing the NIINs associated with those groups. We found that one way to reduce risk is to have long supply. Unfortunately, this is an expensive way to reduce risk. And while the Army finds itself in a relative low risk position now due to current long supply, over the longer term, we expect that the long supply of many NIINs will be consumed.

In any case, the Army will always have to make choices as to *which* inventory to hold, because it cannot afford to always be in long supply for all NIINs. Our current analysis gives little advice about how to decide exactly how much of each NIIN to hold. To integrate risk management into Army processes would require analysis across NIINs, taking cost much more directly into account.

We implemented our method in Microsoft Access, using a range of available data sources, including the Army Logistics Management Program, Federal Procurement Database System, Federal Logistics Data, Corps Theater ADP Service Center database, the RAND Equipment Downtime Analyzer, and the U.S. Geological Survey Natural Hazard database. Some of these, such as the RAND Equipment Downtime Analyzer, depend on still other databases. Our approach has several important caveats. Mainly, the database is limited by missing data. We generally treated missing data as zero. Error is likely to be one of omission, where the NIINs and vendors we observe as risky are probably indeed risky, but other NIINs and vendors that are not part of our study are also risky.

Appendix A: Master List of Supplier Risks

RAND presented the following list of risks to the Working Group, as part of the risk identification workshop. The Working Group had the opportunity to develop its own list and also to select from ours.

External risks

Natural disasters
Epidemics
Earthquakes
Tsunamis
Volcanoes
Weather disasters (hurricanes, tornados, storms, blizzards, floods, droughts)
Accidents
Fires
Explosions
Structural failures
Hazardous spills
Sabotage, terrorism, crime, and war
Computer attacks
Product tampering
Intellectual theft
Physical theft
Bombings
Biological and chemical weapons
Blockades
Government compliance and political uncertainty
Taxes, customs, and other regulations
Currency fluctuations
Political unrest
Boycotts
Labor unavailability and shortage of skills

Availability

Quality
Cost
Unrest
Strikes and slowdowns
Industrywide (i.e., market) challenges
Capacity constraints
Unstable prices
Lack of competition
Entry barriers
Capital requirements

Specific assets
Design patents
Process patents
Shrinking industry
Low supplier profitability
Certification
Cost trends
Recessions/inflation
Lawsuits

Environmental

Health and safety
Intellectual property
Technological trends
Emerging technologies (pace/direction)
Obsolescence
Other technological uncertainty
Supplier Risks: external, DLA, organic
Physical and regulatory risks
Key suppliers located in high risk areas

Material Unavailability/Poor Planning

Raw materials
Other materials
Legal Noncompliance
Labor practices
Environmental practices
Tax practices
Regulatory Noncompliance
Customs/trade
Security clearance requirements
FAA or other certification
Production problems

Capacity

Too little, too much, or diminishing
Order and shipping times
Out of stock (i.e., no/low inventory)
Repair cycle time
Inflexible production capabilities

Technological Inadequacies or Failures

Incompatible information systems
Slow adoption of new technology
Critical disclosure—ITAR

Poor Quality

Defects in manufactured product
Failure to maintain equipment

Lack of training or knowledge
Lead-times
Backlogs
Unresponsive
Unreliable
Variable

Financial losses and premiums

Degree of competition/profitability
Downstream integration or too much competition
Little/no competition – sole source
Financial viability
Inability to sustain in a downturn
Bankruptcy
Withdrawal from the market

Management Risks

Inadequate risk management planning
Management quality
High turnover
Dishonesty
Substituting inferior or illegal materials/parts
Failing to perform required treatments/tests
Submitting inaccurate/false invoices
Lack of continuous improvement
Unwillingness
Cost escalation
Opaque processes
Opportunistic behavior
Inflation of purchase costs
Dependence on one or a few customer(s)

Poor Communication

Internal
External
Upstream (i.e., subcontractors and their subcontractors) supply risks
Any of the above external/supplier risks
Lack of visibility into subcontractors
No or poor relationships with subcontractors

Diminishing sources of supply

Transition "costs" for new suppliers
Distribution risks/disruptions: inbound or outbound

Infrastructure Unavailability

Roads
Rails
Ports
Air capacity/availability

Assets - lack of capacity or accidents
Containers
Trucks
Rail cars
Ships
Airplanes
Labor unrest/unavailability
Truck drivers
Rail operators
Longshoremen
Pilots
Cargo damage/theft/tampering
Physical damage
Theft and other security problems
Tracking the damage
Warehouse Inadequacies
Lack of capacity
Inaccessibility
Damage
Lack of security
IT system inadequacies/failures
Long, multi-party supply pipelines
Longer lead-time

Buying Enterprise Risks

Demand variability/volatility
Drawdown of the stockpile
Exceeding maintenance replacement rate
Shelf life expiration
Surges exceed production, repair, or distribution
Shortfalls
Longer fleet life-cycle
Shorter fleet life-cycle
Personnel availability/skills shortfalls
Sufficient number
Sufficient knowledge, skills, experience
Design Uncertainty
Changes to requirements
Lack of technical detail
Lack of verification of product
Changes to product configuration
Poor specifications
Reliability estimates of components
Access to technical data
Failure to meet design milestones
Planning failures
Forecast reliability/schedule availability

Contract risks
Deferred procurement
Competition/bid process
Acquisition strategy
Manufacturability of a design
Program maturity
Subcontracting agreements
Financial uncertainty/losses
Funding availability
Workscope/plan creep
Knowledge of supplier costs
Strategic risk
Facility unavailability/unreliability

Organic availability

Facility breakdown
Mechanical failures
Testing Unavailability/Inferiority
Unreliable test equipment
Operational test qualifications
Operational test schedule
Integration testing
Transition from first test to mass production
Enterprise underperformance/lack of value
Customer satisfaction/loyalty
Liability
Cost/profit
Customer demand
Uniqueness
Substitutability
Systems integration
Other application/product value
Inventory obsolescence
Supplier relationship management use
DCMA availability and expertise
In-house SRM expertise
Lack of internal and external communication/coordination

Appendix B: Workshop to Identify Enterprise-Wide Supply Chain Risks, May 1, 2013

RAND conducted a workshop with AMC's Strategic Sourcing Working Group (SSWG), on May 1, 2003. The role of the working group is to establish the processes and develop SS/SRM strategies. The SSWG participating in this exercise included representatives from AMCOM, CECOM, TACOM, and ACC. Each member was asked to produce a list of supply chain risks that are of importance to AMC and specifically to the Commands that they represented. This Appendix gives the full list of risks, as found by the Working Group.

AMC Attendees/Participants: SSWG Working Group Members

Instructions: Participants were asked to list any potential cause of supply chain disruption. Each participant took turns reading a cause, which was then discussed and recorded.

Comments:

1. Funding Uncertainties—The unpredictability of funding creates risks for the supplier and for the enterprise. For the enterprise, the risk is that we are not sure what we can buy and what weapon system we can support. Also funding often comes available toward the end of the fiscal year, providing very little time to execute.

   Internal (government) and external (supplier) considerations.
   – Consistency of funding: Timing and uncertainty.
   – Depends on type/color of money.

2. Lifecycle changes—Development, fielding, sustainment. Identify and balance risks. Integrate requirements. Unique and common considerations at prime and subcontractor level, second, third, and lower tier.

   ECP Approval and induction.
   Component parts driven by commercial rather than government.
   – Technology requirements and changes.

3. Sequester—small businesses have gone out of business due to reduced government business. (related to funding issue)
4. Bankruptcies, especially at lower tiers of the supply chain. It may be a critical component; the supplier goes out of business, but no one is aware. Higher-tier suppliers then need to scramble to find parts and production is delayed.
5. Long lead-times—administrative and procurement. Unique, production setup, etc.

6. Merger and acquisition issues. External side—business consolidations, mergers and acquisitions issues, e.g., Lockheed Martin may take over a Boeing subsidiary and may decide to drop some line of its business. "Last supper issue." Less competition. May not continue to develop certain systems. May choose to go out of business.
7. Acts of God—fire, quake, flood, hurricane. "We've had all of those." Quake in Mexicali. Floods in the northeast. [How did you find out about the disruption?] Whenever they hear about an act of God, they review the "Suppliers Reference Guide" to determine which suppliers are in the area, do they have active contracts, then reach out to DCMA to get quick feedback, who takes a proactive stance in informing customers.
8. Production capability—keeping up with requirements. First article test (FAT) requirement extends delivery requirement. Needed for new items, and when they change production facilities, but also if a lapse in time since their last production. An engineering requirement.
9. Lack of mitigation plans at prime and lower levels, internal and external. AMC is very reactive.
10. Contracting considerations—delays in contracting associated with the BRAC. Reorganization—administrative lead-time for DLA went up substantially, then more than doubled. DLA hired other people.
11. Awarding of contract can take considerably longer than doing the contract.
    Things stack up until the end of year, then rush in September. Money can evaporate with contracts not awarded. Pretty regular occurrence. Can have contract terms still uncertain late in the process.

    Different review levels, differences in DLA vs. AMCOM, e.g., single year contract rather than long-term. ACC has repair and new buys on same contract, contracts that incorporate multiple requirements. DLA has a single function. May be able to leverage ACC contracts, e.g., ACC have repair and new spare buys, and other service elements. Leverage PM buying power.

    Broader risk area—Competition between DLA and ACC for particular supplier. All (including Air Force and Navy) competing for the same components from lower tier suppliers.
12. Counterfeit parts.
13. Quality escapes. May not catch bad parts, which get into the field.
14. Aging infrastructure and aging workforce. Tooling bought in the 1950s wearing out with no replacement insight. Some commercial tooling that is very rare and very large. AMC "Global Logistics 2020," understand base capacity and capabilities.
    Aging workforce—AF1 —Only a few people in Wichita Falls.
15. Receipting issues of the storage facility—it is there but hasn't appeared in the system. Can't issue until receipt shows up in the system.
16. Raw material shortages, certain types of steel that China is buying up.
17. Foreign sources of supply, introduced geopolitical issues.

18. Extended development time and costs, e.g., F-35—funding shortages, strategic partners dropping out.
19. Database inaccuracies. LMP implementation helped expose some database problems.

Table B.1 Risks Found by the Working Group

Supply Chain Risk	TOP RANK
Funding consistency & timing	1
Lifecycle changes	
Sequester—small firms going out of business	
Long admin & production lead-times/delays in contracting	2
Business consolidations	
Unpredictability in ordering, changes in demand	3
Acts of God: fire, quake, flood, hurricane	
First article test (FAT) rqmt. extends delivery schedule	
Lack of mitigation plans at prime & lower tiers	
Labor disruptions - external strikes, internal BRAC	
Delays in contracting awards. (Same as 4.)	
Length of & scope of terms of contract	
Counterfeit parts	
Quality escapes	
Aging infrastructure & workforce	
Delay in receipt recording at storage facility	
Raw material shortage	
Foreign sources of supply, geopolitical issues	
Extended development time & costs	
Database inaccuracies	

Appendix C: Top 100 Highest-Risk NIINs

	NIIN	Description	Source of supply	Company name	CAGE code	Vendor Fail Risk	System Impact Risk	NIIN Risk
1	992392273	GRATING, METAL	AKZ	W F E L LTD	K7705	0.28	0.66	0.19
2	012711020	APERTURE, SIGHT	B14	SAAB DYNAMICS AB	SF413	0.33	0.43	0.14
3	014951161	ADAPTER, POWER SUPPL	SMS	FERBAK INC.	0XAK6	0.28	0.44	0.12
4	015171547	PROPELLER SHAFT, VEH	AKZ	FREIGHTLINER OF SAVANNAH, INC.	03AZ7	0.23	0.52	0.12
5	015661706	INSULATOR, PIN	AKZ	RUTA SUPPLIES INC.	0NJT4	0.26	0.43	0.11
6	015529537	FRAME, STRUCTURAL, VE	SMS	AMERICAN DEFENSE SYSTEMS, INC.	31UG4	0.23	0.47	0.11
7	015812107	WINDOW, VEHICULAR	AKZ	AM GENERAL, LLC	34623	0.20	0.54	0.11
8	014170135	BEARING, PLAIN, ROD E	SMS	LORD CORPORATION	76005	0.23	0.46	0.10
9	015827803	KIT, BLANKET, FIRE SU	AKZ	HAZARD PROTECTION SYSTEMS INC	4MY97	0.20	0.51	0.10
10	015677321	ADAPTER, PRESSURE TE	B64	ALABAMA FLUID SYSTEM TECHNOLOGIES,	8H994	0.23	0.44	0.10
11	014853068	BRACKET SET, ANGLE	SMS	CENTRAL METAL FABRICATORS INC	1NZU4	0.23	0.44	0.10
12	015190652	POUCH, EXPLOSIVE ORD	GSA	NATIONAL SECURITY ASSOCIATES INC	1JU97	0.23	0.44	0.10
13	993680690	GRATING, METAL	AKZ	W F E L LTD	K7705	0.28	0.35	0.10
14	014289119	CABLE ASSEMBLY, RADI	SMS	AEROFLEX WICHITA INC.	51190	0.26	0.37	0.10
15	015096012	INSTALLATION KIT, EL	B16	NORTHROP GRUMMAN ITALIA SPA	A3379	0.45	0.21	0.10
16	012186522	ACTUATOR, ELECTRO-ME	SMS	EATON CORPORATION	17472	0.22	0.42	0.09
17	015007208	REBOUND ASSY	B17	BELL HELICOPTER TEXTRON INC.	60762	0.23	0.41	0.09
18	013496669	FLOAT, SIGHT INDICAT	SMS	GEMS SENSORS INC.	04034	0.24	0.38	0.09
19	000014077	ANTENNA	SMS	CANADIAN COMMERCIAL CORP	98247	0.33	0.27	0.09
20	012100523	KIT, DECAL	B14	SAAB DYNAMICS AB	SF413	0.27	0.34	0.09
21	014676748	HORN, SIGNAL	SMS	RUTA SUPPLIES INC.	0NJT4	0.34	0.27	0.09
22	015217883	PROCESSOR, DISPLAY A	B14	L-3 COMMUNICATIONS CORPORATION	1NZ85	0.23	0.39	0.09
23	013341205	ROBODRILL	SMS	AIRCRAFT DYNAMICS CORPORATION	29701	0.23	0.39	0.09
24	014768971	PUMP, FUEL, METERING	SMS	WESTERN DIESEL SERVICES, INC.	3Z7L8	0.23	0.37	0.09
25	014553370	JACK, SCREW, HAND	SMS	SIMMONDS PRECISION PRODUCTS, INC.	12511	0.23	0.38	0.09
26	007556697	SOCKET, WRENCH, FACES	GSA	FORM FIT AND FUNCTION, LLC	1P6K0	0.19	0.44	0.09
27	013068095	POWER SUPPLY	SMS	FEDERAL PRISON INDUSTRIES INC	90142	0.22	0.39	0.09
28	015549546	TURBOSUPERCHARGER, E	AKZ	CRITICAL SOLUTIONS INTERNATIONAL INC	1N5S7	0.33	0.24	0.08
29	998331252	GRATING, METAL	AKZ	W F E L LTD	K7705	0.33	0.24	0.08

	NIIN	Description	Source of supply	Company name	CAGE code	Vendor Fail Risk	System Impact Risk	NIIN Risk
30	012865186	SPACER, PLATE	SMS	O. F. MOSSBERG & SONS, INCORPORATED	41758	0.23	0.36	0.08
31	010709574	LIGHT, NAVIGATIONAL,	SMS	GRIMES AEROSPACE COMPANY	72914	0.23	0.36	0.08
32	014523355	HOLDER, SLIPPAGE, TOR	B14	ALLIANT TECHSYSTEMS OPERATIONS LLC	1YQE8	0.23	0.36	0.08
33	015642389	ARMOR, SUPPLEMENTAL,	AKZ	OSHKOSH CORPORATION	45152	0.21	0.38	0.08
34	013549430	JUNCTION BOX	AKZ	RUTA SUPPLIES INC.	0NJT4	0.34	0.23	0.08
35	015173990	ADAPTER, BATTERY TER	SMS	ELECTRIC FUEL BATTERY CORPORATION	308Z9	0.23	0.35	0.08
36	014925816	LANTERN, ELECTRIC	SMS	PELICAN PRODUCTS, INC.	65442	0.26	0.30	0.08
37	015672781	SEBACATE OIL	B64	KING NUTRONICS CORPORATION	13859	0.18	0.43	0.08
38	015057561	TIE ROD END, STEERIN	SMS	BADGER TRUCK CENTER, INC	06YZ5	0.22	0.34	0.08
39	014745772	BRAKE SHOE	SMS	BAKER & ASSOCIATES INC.	5S670	0.16	0.49	0.08
40	015682561	HOTBOX CONTAINMENT	AKZ	BALLISTIC ADVANTAGE LLC DIV	5CBE0	0.23	0.34	0.08
41	015059182	STRAP, WEBBING	B17	TAKATA PROTECTION SYSTEMS INC	1EAW9	0.25	0.29	0.07
42	015572544	TOOL, OBTURATOR REMO	B14	PINES AUTOMOTIVE, INC.	3B0Y2	0.25	0.29	0.07
43	014926186	CONTROL-DISPLAY, OPT	SMS	THE BOEING COMPANY	3A768	0.23	0.32	0.07
44	014943019	SEAT, AIRCRAFT	SMS	BAE SYSTEMS AEROSPACE & DEFENSE	54786	0.21	0.34	0.07
45	015668982	LIGHTING KIT, VEHICU	AKZ	TRUCK-LITE CO., INC.	13548	0.23	0.32	0.07
46	015496390	HANDSET	B16	MARANATHA INDUSTRIES INC	1L012	0.27	0.27	0.07
47	012314338	HEAT GUN	SMS	ELECTRICAL ASSEMBLY, INC	59164	0.22	0.32	0.07
48	014562740	PIN, SHOULDER, HEADLE	SMS	BRIGHTON CROMWELL LLC	3NNX8	0.23	0.31	0.07
49	015569015	WIRING HARNESS, BRAN	SMS	FEDERAL PRISON INDUSTRIES INC	90142	0.19	0.37	0.07
50	015534588	WINDOW, VEHICULAR	SMS	AMERICAN DEFENSE SYSTEMS, INC.	31UG4	0.23	0.31	0.07
51	014959856	CYLINDER ASSEMBLY, A	AKZ	BRIGHTON CROMWELL LLC	3NNX8	0.21	0.33	0.07
52	015064131	WHEEL, PNEUMATIC TIR	AKZ	POMP'S TIRE SERVICE, INC.	1T1Z4	0.23	0.31	0.07
53	010616941	ANTENNA	SMS	WADE ANTENNA INC	78702	0.33	0.21	0.07
54	013338433	SOUND CONTROLLING B	SMS	TRIUMPH FABRICATIONS-ST. LOUIS, INC.	0TLW4	0.23	0.29	0.07
55	014462035	ENGINE, DIESEL	AKZ	GARDNER INC.	9A017	0.11	0.60	0.07
56	015281747	WIRE ROPE ASSEMBLY,	AKZ	CANADIAN COMMERCIAL CORP	98247	0.21	0.32	0.07
57	015321759	WIRING HARNESS, BRAN	B17	COMMUNICATIONS & EAR PROTECTION	1JGL0	0.23	0.29	0.07
58	015693629	RING, OBTURATOR	B14	BELDAM CROSSLEY LTD	K2812	0.27	0.25	0.07
59	015534573	WINDOW, VEHICULAR	SMS	AMERICAN DEFENSE SYSTEMS, INC.	31UG4	0.23	0.30	0.07
60	007851162	HEAT GUN, ELECTRIC	B14	ELECTRICAL ASSEMBLY, INC	59164	0.22	0.30	0.07
61	012795318	BACK PANEL	SMS	CANBERRA INDUSTRIES INC.	06442	0.23	0.30	0.07
62	011051838	TERMINAL BOARD	SMS	HONEYWELL INTERNATIONAL INC.	02LU7	0.23	0.30	0.07
63	014123019	BELT, AIRCRAFT SAFET	SMS	PACIFIC SCIENTIFIC COMPANY	45402	0.28	0.24	0.07
64	015067315	M860A1 WHEEL ASSEMB	AKZ	POMP'S TIRE SERVICE, INC.	1T1Z4	0.23	0.29	0.07

	NIIN	Description	Source of supply	Company name	CAGE code	Vendor Fail Risk	System Impact Risk	NIIN Risk
65	015494673	TOOL KIT, TRANSMISSI	AKZ	SPX CORPORATION	45225	0.22	0.29	0.07
66	015734423	CABLE ASSEMBLY, SPEC	B17	L-3 COMMUNICATIONS VERTEX AEROSPACE	1P066	0.23	0.29	0.07
67	014283233	DETECTOR, BORE OBSTR	SMS	PROJECT ENGINEERING COMPANY	4HAJ0	0.23	0.28	0.06
68	011495774	BOLT, CLOSE TOLERANC	SMS	SPS TECHNOLOGIES, LLC	56878	0.23	0.28	0.06
69	011634642	RING, RETAINING	SMS	MACHINE TECHNOLOGY, INC.	0FW73	0.23	0.28	0.06
70	014194985	BATTERY, NONRECHARGE	SMS	FEDERAL PRISON INDUSTRIES INC	90142	0.23	0.28	0.06
71	015710255	ARMOR, SUPPLEMENTAL,	AKZ	BAE SYSTEMS AEROSPACE & DEFENSE	54786	0.23	0.28	0.06
72	015734421	CABLE ASSEMBLY, SPEC	B17	L-3 COMMUNICATIONS VERTEX AEROSPACE	1P066	0.23	0.28	0.06
73	015657841	CABLE ASSEMBLY, SPEC	B64	B.J.G. ELECTRONICS, INC.	0DTU2	0.21	0.29	0.06
74	014952850	CYLINDER ASSEMBLY, A	AKZ	TRU HITCH INC	1BZD4	0.19	0.32	0.06
75	015204798	EYEPIECE ASSEMBLY, O	B16	RAYTHEON COMPANY	96214	0.22	0.28	0.06
76	013594770	STARTER, ENGINE, ELEC	SMS	SOUTHEAST POWER SYSTEMS OF ORLANDO	3L018	0.23	0.27	0.06
77	015881407	MAINTENANCE KIT, VEH	AKZ	OSHKOSH CORPORATION	45152	0.11	0.58	0.06
78	010597989	PLOTTING BOARD, INDI	B14	AERO PRODUCTS RESEARCH, INC.	14466	0.22	0.29	0.06
79	015527695	RETAINER, BATTERY CA	SMS	L-3 INSIGHT TECHNOLOGY INCORPORATED	0B107	0.23	0.27	0.06
80	012622817	SCOPE, FOCUS DIAL	B14	REMINGTON ARMS COMPANY LLC	3A703	0.23	0.27	0.06
81	015183659	WHEEL, PNEUMATIC TIR	AKZ	POMP’S TIRE SERVICE, INC.	1T1Z4	0.22	0.27	0.06
82	015642385	ARMOR, SUPPLEMENTAL,	AKZ	OSHKOSH CORPORATION	45152	0.11	0.55	0.06
83	011737126	RING, MATING, SEAL	SMS	D & R MACHINE CO.	4T853	0.23	0.26	0.06
84	015356961	RELAY, ELECTROMAGNET	SMS	L-3 COMMUNICATIONS CORPORATION	06401	0.29	0.20	0.06
85	015393412	CASE, DISPLAY UNIT	B14	J.G.B. ENTERPRISES, INC.	61125	0.23	0.26	0.06
86	015407183	SPRING, HELICAL, COMP	B14	WOLFF, W C COMPANY	0ATN7	0.23	0.26	0.06
87	015678078	ADAPTER, PRESSURE TE	B64	ALABAMA FLUID SYSTEM TECHNOLOGIES,	8H994	0.23	0.26	0.06
88	015676573	CASE, ELECTRONIC COM	B16	E.F. JOHNSON COMPANY	0BS05	0.23	0.26	0.06
89	131162311	PIN, FIRING	B14	FN HERSTAL SA	B0897	0.22	0.26	0.06
90	012882332	FUEL CELL REPAIR KI	SMS	RELIANCE AEROPRODUCTS INTERNATIONAL	0TAN3	0.23	0.26	0.06
91	014493240	ANTENNA	SMS	TRIVEC-AVANT CORPORATION	60188	0.26	0.22	0.06
92	014396422	CAP, PROTECTIVE, DUST	SMS	SPECTRUM PLASTICS GROUP INC.	5K650	0.22	0.26	0.06
93	015147909	WHEEL, PNEUMATIC TIR	AKZ	POMP’S TIRE SERVICE, INC.	1T1Z4	0.23	0.25	0.06
94	015284215	GASKET	B14	BASIC RUBBER AND PLASTICS CO.	6K404	0.22	0.26	0.06
95	131162154	PIN, RETAINING	B14	FN HERSTAL SA	B0897	0.22	0.26	0.06
96	131162139	SPRING, COVER EXT.	B14	FN HERSTAL SA	B0897	0.22	0.26	0.06
97	015831809	BUSHING, SLEEVE	B17	LANFORD MANUFACTURING CORPORATION	3GSM1	0.21	0.28	0.06

	NIIN	Description	Source of supply	Company name	CAGE code	Vendor Fail Risk	System Impact Risk	NIIN Risk
98	131165037	SPRING, HELICAL, COMP	B14	FN HERSTAL SA	B0897	0.22	0.26	0.06
99	131162134	SPRING, HELICAL	B14	FN HERSTAL SA	B0897	0.22	0.26	0.06
100	014525904	WRENCH, SPANNER	B14	ACCUTECH MOLD & MACHINE	5FZC2	0.23	0.25	0.06

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