Supply Chain Risk Management
(Redefining the Audit Function within a Large Industrial Company)

by

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Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Logistics

at the

Massachusetts Institute of Technology

June 2005

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Abstract

As supply chains become more sophisticated, difficulties with their operation can become more complex as well. An organization must ensure the flow of goods and services end-to-end across the supply chain at the promised level and at the anticipated cost. This thesis describes the redesign and centralization of the supply chain operating model of a large industrial company, and suggests a structure capable of mitigating supply chain risk subsequent to the change. The appropriate organizational framework suggested for ensuring an uninterrupted flow of goods and services through the supply chain is the company's internal audit department. A redefinition of the audit department is explored, with the transformation of the audit role suggested to take the form of a process design centered on the Supply Chain Operations Reference (SCOR) model of Plan, Source, Make and Deliver.

Executive Summary

Supply chains are rapidly increasing in complexity. Companies no longer rely solely on manual processes or enterprise resource planning systems; they are deploying sophisticated advanced planning and scheduling applications to optimize their supply chain networks. Difficulties with deploying these networks are immense and companies may not be prepared to cope with the changing nature of risk arising from such a strategic shift. Who is to possess the deeper understanding of supply chain design, planning and operations necessary to manage risk in a more integrated, centralized and intricate environment? The most appropriate organization may be the internal audit department.

Role of the Internal Audit Department

The evolution of internal auditing over the years provides a basis for rooting supply chain risk mitigation efforts within this function. No longer focused merely on providing a check over accounting transactions, the internal auditor now applies risk-based auditing techniques to management activities that span the enterprise. This enterprise-wide view makes internal auditing primed to analyze risk associated with operating highly interconnected supply chain networks. Internal auditors can identify problems that cross organizational boundaries. The internal audit department also has the professional responsibility to provide objective assurance in the evaluation and improvement of risk management, identifying and reporting problems that can impact the economic health of the company. But is internal auditing positioned to take on the added responsibility of shepherding their organization's supply chain risk mitigation efforts?

Section 404 of the Sarbanes-Oxley Act could be a force against the internal audit profession's advancing into the area of supply chain operations. The law requires publicly traded companies to establish, document and maintain internal controls and procedures governing financial reporting. With the Act's emphasis on financial controls and extensive reporting requirements, internal audit could easily revert to being purely an internal checking mechanism over accounting transactions. Internal auditors may narrow their scope to financial controls and not focus on supply chain issues. Outside of some

recent high-profile breakdowns in corporate governance, however, are the large scale day-to-day risks within a company seated in finance or in the way the supply chain is executed?

Corporations have lost billions of dollars when faced with supply chain disruptions including natural disasters, demand and production miscalculations, software malfunctions and numerous other failures. Even companies extolled for supply chain effectiveness can encounter difficulties if not fully prepared, and the very actions intended to strengthen the supply chain can be perversely problematic.

Supply Chain Risk Mitigation Framework

Review of a $35 billion global manufacturer identifies a possible framework for mitigating supply chain risk. The company was redesigning its supply chain operating model to capture $500 million in annual cost savings. A critical part of achieving the cost savings goal was centralization of supply chain activities; however, with centralization came the increased potential for operational disruption as supply chain risk was no longer distributed across multiple businesses. The suggested framework redefines the internal audit role in terms of organizational structure and the way supply chain risk is identified and mitigated.

The organizational structure being explored forms four distinct internal audit teams based on supply chain processes. These processes are supply chain planning, strategic sourcing, manufacturing and deliver. Each team would audit its respective process wherever it resides within the enterprise. This contrasts to the traditional approach of assigning internal audit teams to individual business units. Teams would now be managed to review how work flows through the supply chain (e.g. the strategic sourcing team would look at the activities from selecting vendors and placing orders all the way through paying the vendor's invoice). In addition to the four teams looking at supply chain processes, two additional teams would specifically target the finance function (e.g. corporate treasury) and information technology (e.g. large data processing centers). These two teams would focus on Sarbanes-Oxley compliance.

Vulnerability mapping is suggested as essential to the internal audit department's supply chain risk mitigation efforts. This mapping consists of understanding and defining supply chain risk, planning for supply chain risk contingencies, and war gaming supply chain risk scenarios. Vulnerability mapping combines work from System Dynamics, Failure Mode Event and Criticality Analysis, business continuity planning and stress testing. This approach captures the causal impacts across the supply chain where an insignificant disruption builds upon itself creating a significant disruption that impacts the organization's ability to deliver goods and services at anticipated costs. A classic example is demand amplification (bullwhip effect) across supply chain partners where stable demand manifests into erratic order and production behavior. The dynamic nature of vulnerability mapping contrasts with traditional tools for diagramming risk such as flow-charts, transactional flow analysis, questionnaires and other static approaches.

Organizing the Internal Audit Department

Organizing internal audit teams around supply chain processes brings a high degree of consistency to the supply chain network. Each team can focus on supply chain planning, strategic sourcing, manufacturing or deliver to provide expertise within that area. This approach negates the probability that multiple teams will audit the same process but take a different approach, thereby creating process variance within the operation of the supply chain. In this scenario the likelihood increases that highly trained managers have been tasked to help ensure the supply chain does not face a crisis, but if a crisis does occur, the supply chain can effectively respond. Critical areas for instituting a supply chain risk mitigation program are as follows:

- **Coordination.** The task of ensuring that touch points within the supply chain are accounted for within the internal audit department's risk mitigation strategy. Coordination integrates supply chain planning, strategic sourcing, manufacturing and deliver to mitigate the risk arising from hand-offs between different supply chain processes.

- **Organizational Design:** The task of hiring, supervising and motivating staff within each internal audit team. Inherent in this task is the need to build teams with backgrounds in finance, operations, information technology and data analysis.

- **Vulnerability Mapping:** The task of understanding and defining supply chain risk, planning for supply chain risk contingencies, and war gaming supply chain risk scenarios.

- **Metrics:** The task of using indices to help determine where resources should be directed in conducting on-site reviews of supply chain processes. This includes establishing which metrics to monitor, identifying the data source for the metrics and incorporating the use of metrics with supply chain vulnerability mapping for determining risk levels.

- **Training:** The task of educating the internal audit department on supply chain methodology and instructing teams on supply chain planning, strategic sourcing, manufacturing or deliver. This task also includes teaching internal auditors how to execute vulnerability mapping, monitor supply chain metrics, perform supply chain audits and facilitate supply chain peer reviews.

- **Audits:** The task of implementing a strategy to mitigate supply chain risk effectively and efficiently. This task includes risk-based reviews of processes, enabling technology and strategic/master planning/operational documentation to provide assurance that adequate operational controls are in place and working as designed.

- **Reviews:** The task of facilitating supply chain peer evaluations within the business units. This task includes quality assurance activities to ensure peer reviews follow an approved methodology, maintain rigor, obtain management agreement on action items to address deficiencies, and provide follow-up to ensure agreements were implemented on time and in the prescribed manner.

Having the appropriate organizational structure is not sufficient, in itself, to institute an effective supply chain risk mitigation program. The internal audit teams must have the ability to understand and define supply chain risk, plan for supply chain risk contingencies, and war game supply chain risk scenarios (vulnerability mapping and metrics). These abilities are needed in addition to the administrative expertise necessary to manage an internal audit department (e.g. coordination and training).

Understanding and Defining Supply Chain Risk

A twelve-month cyclical process for administering vulnerability mapping is a recommended element of the internal audit department's supply chain risk mitigation efforts. This process includes modeling the supply chain to understand the causes of supply chain risks during months one through three (System Dynamics), identifying the critical failure modes and creating action plans for mitigating these supply chain risks in months four through six (Failure Mode Event and Criticality Analysis), contingency planning for business interruptions in months seven through nine (business continuity planning), and war gaming of contingency plans in months ten through twelve (stress testing). The process should repeat itself each annual cycle with any required updates being fused with the prior year's work. The tools needed to implement vulnerability mapping are defined as follows:

- **System Dynamics:** A tool developed by Jay Forrester at MIT that helps managers to understand the structure and dynamics surrounding complex systems. Computer simulations model system evolution over time and demonstrate how internal feedback loops can influence and shape behavior.

- **Failure Mode Event and Criticality Analysis:** A tool developed by the National Aeronautics and Space Administration to identify and assess critical failure modes and to gauge subsequent impact on system performance. Identified failure modes must be considered when modeling the supply chain in conjunction with System Dynamics.

- **Business Continuity Planning:** A tool that helps managers build contingency plans after an analysis of supply chain risk has been performed and its impact assessed. This tool leverages System Dynamics modeling and Failure Mode Event and Criticality Analysis. Contingency plans prepare for unlikely events that could occur in the supply chain so that operations can continue uninterrupted.

- **Stress Testing:** This tool war games business continuity plans to see if the plans work as intended. These games simulate real-life supply chain disruptions to ensure the plans are robust and can continue the end-to-end flow of goods and services across the supply chain.

The twelve-month cyclical process for administering vulnerability mapping was suggested as an instrumental element in redefining the audit department of the company being studied. Senior risk managers for supply chain planning, strategic sourcing, manufacturing and deliver are targeted to shepherd vulnerability mapping across the company. These managers would work in concert with line management. Together, they could mitigate supply chain risk arising from control, supply, demand or process uncertainties.

Closing

Any corporate initiative that requires resources but does not demonstrate a clear return-on-investment is difficult to justify and supply chain risk mitigation falls into this category. Managers win plaudits for cutting costs and increasing revenues, but are not usually applauded for mitigating risk and preventing a failure before it happens. The large-scale day-to-day risks within a company, however, are often seated in the way the supply chain is executed. This strategic issue must be confronted to ensure the economic well-being of the organization. The organizational structure and vulnerability mapping techniques described here provide a framework for mitigation of supply chain risk.

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Acknowledgements

This thesis is the culmination of my experience at the Massachusetts Institute of Technology, an experience that has been both challenging and rewarding. With any undertaking of great magnitude, success does not come about as the result of an individual journey but as the offspring of a network of supporters who encourage your development and assist you in crossing the finish line. It is to these supporters that I owe my deepest and sincerest gratitude.

First, I would like to give a heartfelt thank-you to my significant other and soul-mate, Judy Caldwell, for her love and encouragement are what brought me to MIT and sustained me through my time away from home. She helped me to set a standard for dedication in completing my studies and to set a purpose in what I have done. To her, I am forever indebted.

As my thesis advisor, Dr. Chris Caplice deserves my gratitude for shepherding me through the completion of this research project. Dr. Caplice has worked to ensure that the knowledge was imparted to me that would allow this paper to come to fruition. To him, I extend my deepest appreciation.

I would also like to recognize my cohorts within the Master of Logistics Program. Now that we have completed this endeavor together I consider them not only classmates but friends. This sentiment arises from my belief that an education is not about the four walls in which we study but is about the interaction, and sharing of ideas, with fellow students. Since each person in the program is world-class, I consider my experience at MIT to have been world-class.

Finally, I dedicate this thesis in memory of a beautiful lady from Mississippi, Catherine Savage Palmertree. I did not know her long but I will never forget her. Quite often in life a person is not recognized for just being a wonderful human being. Today, I do that for her.

1 Introduction

Supply chain risk management was applied to a large industrial manufacturing company. The company studied was in the midst of designing an enterprise-wide supply chain operating model in order to capture annualized cost savings of several hundred million dollars. Achieving this cost savings goal required the centralization of supply chain activities; however, centralization increased the potential for operational disruption because supply chain risk was no longer distributed across multiple businesses or facilities. A strategy was needed to deal with the increased level of supply chain risk. This strategy needed to ensure the flow of goods and services end-to-end across the supply chain, at the promised service level to the customer, at anticipated cost. Research noted here assisted the company in creating such a strategy. In compliance with the confidentiality agreement governing this research project, the researcher has referred to the company under study as the "ABCD" company.

1.1 Company Introduction

ABCD has manufacturing operations in more than 40 countries and maintains a sales presence in more than 120 nations. Global operations of the company are located primarily in the United States, Europe, Latin America, Canada and Asia. ABCD is ranked largest within its industry in annual sales, asset base and number of employees. For fiscal year-end December 2003, annual sales for ABCD were in excess of $25 billion, the asset base was greater than $35 billion and the company employed a workforce of close to 100,000 employees (Hoover's Online, 2004).

ABCD operates within an industry that has consolidated since the mid-1990s. Keeping with this trend, the company made over $17 billion in acquisitions in 1999 and 2001 alone. ABCD made another sizable acquisition of an undisclosed amount in 2004. Because of an industry-wide slowdown in sales and earnings, major acquisitions were not made by the company in 2002 and 2003. The acquisitions made by ABCD have been partially offset by divestures as the company focused on its core businesses and shed non-strategic and non-performing assets.

Value creation has been elusive with consolidations due to the nature of the industry in which the company operates. It has been challenging to achieve acquisition synergies within the industry because most plants operate at optimum production levels. As a result, network benefits and additional savings are difficult to obtain. ABCD is attempting to buck this dire assessment by designing an enterprise-wide approach to its global supply chain that will allow it to extract enterprise-wide value from the acquired businesses.

1.2 Research Scope

Research scope concentrated on the organizational structure necessary within ABCD to mitigate supply chain risk. An organizational design was identified for the internal audit department of ABCD that would provide a control and governance process over supply chain risk mitigation efforts. This structure would add value to the organization by helping to maintain a balance between the benefits of centralizing supply chain activities and the threat of business disruptions that concentrated supply chain risk introduces. The research included an analysis of how the structure would be developed around the Supply Chain Operations Reference (SCOR) model. In addition, the necessary process and system knowledge (e.g. vulnerability mapping) needed to successfully enable this organizational transition was explored.

1.3 Research Methodology

The research approach was a combination of original exploration conducted by the researcher through field work along with a synthesis of past ideas applied within a new framework. In addition, the research referenced the operating model of ABCD. This reference was done to ensure that research work aligned with, and thus complemented, ABCD's enterprise-wide global supply chain design. The company's supply chain design is referred to, but not explored in depth, within this paper due to a confidentiality agreement in effect.

- Exploration through Field Work: Research was conducted in order to lay out ideas as formulated by the researcher. These ideas included the identification of an approach to supply chain operational risk management, the application of best practices in a new and innovative way and the critical analysis of existing research applied in a business setting.

- Investigation of Existing Approaches: Research leveraged existing frameworks where available and applicable. This work included frameworks related to the evolution of the audit role across companies and the Supply Chain Operations Reference (SCOR) model.

1.4 Literature Review

As the importance of managing supply chain risk has grown within companies, research within the supply chain field has increasingly centered on this strategic issue. Researchers to date have concentrated on identifying the nature of supply chain risk and on contrasting traditional supply chain risk mitigation approaches to more recent strategies. Their research has not dealt comprehensively with the organizational aspect of supply chain risk mitigation.

Definitions of supply chain risk have been developed by several authors. Chopra and Sodhi (2004) have categorized supply chain risk as arising from areas controlled internally by the organization including manufacturing disruptions and delays, systems, forecast, intellectual property, procurement, receivables, inventory and capacity. Hutchins (2003) takes a view of supply chain risk coming from areas controlled externally to the organization. These risks are defined as the supply chain partners' abilities to meet contract, process and product requirements, the possibility of harm or loss if requirements are not achieved, the probability of an event with undesirable consequences, and the variation away from a specified set of requirements and how this is monitored and controlled. In the context of changing a supply chain process, Buchanan and Connor (2001) categorize supply chain risk in four areas: performance dips, project fights, process fumbles, and process failures. Buchanan & Connor break down process risk further into a people risk category and an operations component. Figure 1 incorporates major risk sources that have been delineated by cited researchers.

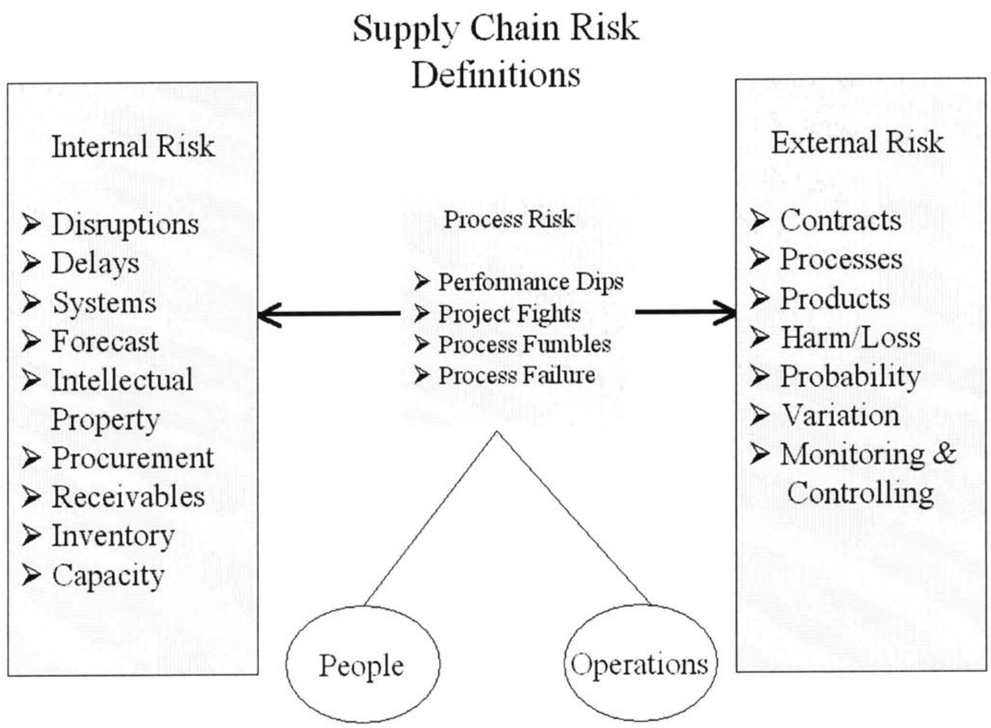

Figure 1. Supply chain risk definitions from areas controlled internally to the organization, arising externally from supply chain partners and resulting from a change in a supply chain process.

The area of study needed to build upon the work of these authors and others is to place the theoretical definitions within a strategy that would enable a company to identify risks particular to their operations. This strategy would help the company answer the question "what exactly are the specific risks posed to my supply chain?" Research conducted with ABCD helped identify an organizational structure capable of handling that question.

Just as there is an abundance of supply chain risk definitions, approaches to supply chain risk mitigation have been put forth encompassing numerous techniques. Zsidisin, Carter and Cavinato (2004) look at supply chain risk mitigation from the perspective of the purchasing organization. Zsidisin et al discuss supply chain risk mitigation techniques in terms of tackling issues arising from processes external to the organization including strengthening supplier quality, lessening the chance that supply disruptions will occur, and improving the process by which goods and services are supplied by vendors. Finch (2004) looks at supply chain risk management from the perspective of inter-organizational networking in pressing the need for companies to adequately plan for business continuity. This includes issues coming from processes external and internal to the organization. On an even more strategic basis, Christopher and Lee (2004) look at methods controlled internally including the need to improve supply chain confidence by improving end-to-end visibility across the supply chain as a mechanism for mitigating supply chain risk. An example of this is the sharing of demand forecasts in order to coordinate production and reduce the impact of demand amplification (bullwhip effect). Figure 2 compiles focus areas for risk mitigation from researchers noted above.

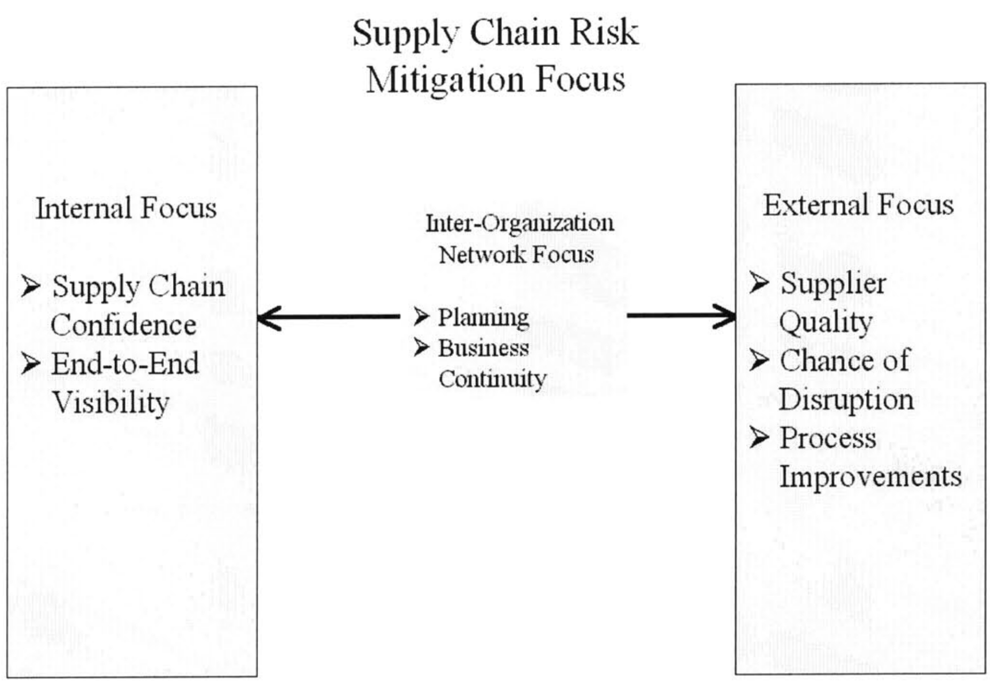

Figure 2. Focus of supply chain risk from areas controlled internally to the organization, arising externally from supply chain partners and resulting from inter-organizational supply chain processes.

As with defining supply chain risk, the approaches to supply chain risk mitigation presented by researchers need to be placed within the framework of a specific strategy. This strategy would help a company answer the questions of who should be involved as well as what actions should be taken concerning a specific supply chain operational risk mitigation effort. Although not addressing who should implement the strategy, Chopra and Sodhi (2004) do contrast the traditional risk mitigation approaches to more sophisticated supply chain techniques. These include the following:

- Traditional Approaches
  - Excess Capacity
  - Additional Inventory
  - Redundant Suppliers

- Supply Chain Approaches
  - Increased Responsiveness
  - Increased Flexibility
  - Aggregated or Pooled Demand
  - Increased Capability
  - Added Customer Accounts

Supply chain risk has become a growing concern. The current research in this area needs to be expanded to provide direction to companies on how to define supply chain risk within their particular operations. In addition, research needs to identify roles and responsibilities within a company that can best implement supply chain risk mitigation efforts. The current literature is intellectually stimulating and does provide a broad context to address these issues but is limited in answering the "who" surrounding this critical topic. The work that follows sets out a framework for the company under review to redefine its internal audit function to include the responsibility for supply chain risk.

1.5 Chapter Previews

Chapter Two provides a general overview of supply chain risk, beginning with defining what supply chain risk is. The current status of supply chain risk mitigation efforts at the ABCD Company is reviewed. The chapter concludes with an identification of the key supply chain challenges faced by ABCD along with their efforts to plan and act in response to these challenges.

Chapter Three grounds the reader in the basics of the Supply Chain Operation Reference (SCOR) model as administered by the Supply-Chain Council. The SCOR-model management processes of Plan, Source, Make, Deliver and Return are reviewed. This chapter also references how the SCOR-model was selected by ABCD to guide construction of their supply chain network and to monitor its effectiveness.

Chapter Four deals with the organizational aspect of addressing supply chain risk. The evolution of the internal audit role across companies is explored as well as the current state of the audit function within ABCD. This chapter also examines the process, business/process and directed designs in approaching organizational structure, with an analysis of key trade-offs to determine the most appropriate design.

Chapter Five provides an example of vulnerability mapping based upon a pilot of one of ABCD's regional distribution centers. A model for a single-item inventory policy for non-stationary demand is provided. In addition, supply chain risk associated with forecast bias is reviewed along with process controls to limit the amount of bias encountered. This chapter presents vulnerability mapping in terms of a supply chain structure incorporating the competitive and supply chain strategy of ABCD.

Chapter Six provides a summary of observations regarding supply chain risk management. This chapter reviews the overall need for internal audit involvement in supply chain risk mitigation.

2 Supply Chain Risk

In 2001, ABCD began its transition to a more centralized enterprise-wide supply chain operating model. This transition was an integral part of a multi-year project to achieve substantial cost savings. Three of the key business areas that were transitioned from a de-centralized business and/or facility locus of control, and were integrated into the company's global supply chain organization, were strategic sourcing, regional product distribution, and transportation planning. Although significant cost advantages were identified with the transformation, this strategic shift also changed the nature of supply chain risk confronted by the company. ABCD was now challenged with a different type, frequency and complexity of supply chain risk as a result of its move to a more centralized operating model. The company needed a strategy to ensure the flow of goods end-to-end across the supply chain, at the promised service level, at anticipated costs.

2.1 Supply Chain Risk Impact

Supply chain disruptions can significantly impact a company's earnings. Erickson in 2001 lost an estimated $400 million in sales when a factory fire in New Mexico cut off its supply of components. While Nokia responded effectively to the same supply chain disruption by locking up available supplies and capacity, Erickson is no longer in the cell phone market (Virtual-Corp, 2004). Nike reported a $100 million negative sales impact in 2001 due to problems with a planning system implementation (Karpinski, 2001). In the same year Cisco Systems wrote down $2.25 billion in excess inventory when their contract manufacturers grossly overproduced components (Kaihla, 2002). Even actions intended to strengthen the supply chain can cause problems. K-Mart initiated a large-scale supply chain software project in 2000 to get product into stores for sales promotions. Within two years, K-Mart abandoned its efforts and took a $130 million write-off because the software implementation did not mesh with its supply chain strategy (Silwa, 2002). Companies extolled for their supply chain effectiveness can nevertheless encounter difficulties if not fully prepared. In 1997 Toyota was forced to shut its Japanese production down for a week when a fire at a supplier cut off its shipments of just-in-time brake components (Rushton, Oxley & Croucher, 2000). Dell's stock sharply declined in 1993 as a result of inaccurate demand forecasts and subsequent inventory write-downs. These events demonstrate the pressing need for a company to address supply chain risk.

2.2 Definition of Supply Chain Risk

The literature review noted earlier highlighted the volume of work that has been done in categorizing and defining supply chain risk. However, it appears that consensus on these categories and definitions has not been achieved across supply chain practitioners, academicians, and technology providers. Since establishing a common language is often the first challenge in tackling any problem, the current researcher set out to establish baseline classifications and definitions at ABCD. To do this, the work of White (2003) was leveraged.

White provides definitions for risk management and supply chain risk management. Risk management encompasses the systematic process of identifying, quantifying and managing all risks--comprehensive challenges that can adversely impact the achievement and/or financial goals of the organization. In general, risk management includes the steps taken to plan for the possibility of a disruption in order to ensure the organization can continue with uninterrupted operation. Another way of saying this is that business continuity plans need to be in place to ensure operations can be carried out without change if a crisis hits.

White defines supply chain risk management as the "end-to-end management of the flow of goods and services in the supply chain to ensure uninterrupted service at the promised level to the customer at known cost." In essence, supply chain risk management is broader than risk management in that it encompasses the overall management of the supply chain. The Supply Chain Operations Reference (SCOR) model, covered in the next chapter, demonstrates the breadth of the supply chain that must be traversed in mitigating supply chain risk. Figure 2 demonstrates the five distinct SCOR management processes noted, including supply chain planning, strategic sourcing, manufacturing (make), and delivering. Where applicable, reverse logistics to handle returns is also included. The figure shows how the management processes not only cover operations internal to the company but also cover external operations managed by the organization's suppliers and customers.

Five Distinct Management Processes

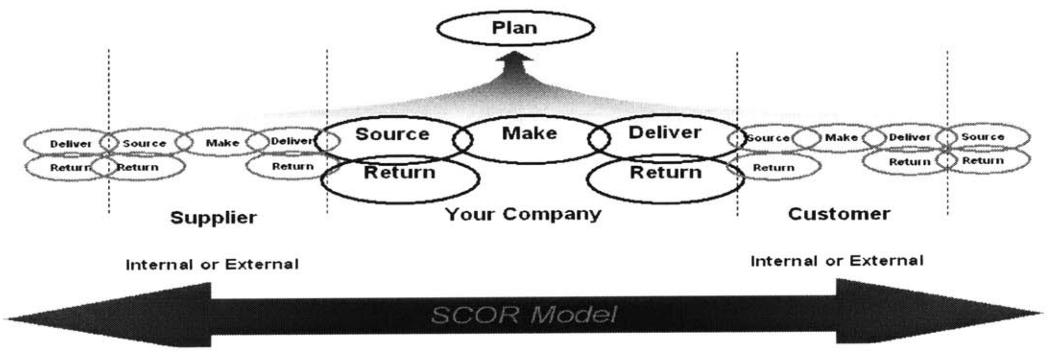

Figure 3. Five distinct management processes that must be traversed in mitigating supply chain risk (SCOR Version 6.1, 2004).

White's definition has more than theoretical value at ABCD. As the company has moved to an enterprise-wide supply chain operating model, the scope of end-to-end management of the flow of goods has taken on a level of breadth and depth that it did not possess before. The complexity of controlling supply chain risk has substantially increased as that risk is not isolated within disparate business and/or facilities but is now concentrated in centralized supply chain functions, with any disruptions now possibly being felt throughout the value chain. Therefore, White's definition of supply chain risk management is adopted for sake of this thesis.

White categorizes supply chain risk into the areas of process uncertainties, supply uncertainties, demand uncertainties and control uncertainties. These categories are presented in reference to an organization's implementation of a robust supply chain. A further explanation of the uncertainties identified by White along with examples is as follows.

- Process Uncertainties: Uncertainties arising from execution variability within the supply chain.
    - Manufacturing disruptions resulting in an inability to meet customer delivery requirements.
    - Manufacturing variances resulting in a failure to meet customer quality requirements.

- Supply Uncertainties: Uncertainties arising from a disruption in supply or manufacturing capability that result in a shutdown or slowdown in production at later stages of the supply chain.
    - Supply disruptions causing a complete shutdown of a just-in-time manufacturing environment.
    - Supply quality variances causing excess waste and rework during manufacturing.

- Demand Uncertainties: Uncertainties arising from surges in demand that abruptly raise the requirements on a particular part of the supply chain network.
    - Unanticipated customer orders or order changes resulting in excess manufacturing cost to produce or an inability to meet customer delivery requirements.
    - Unanticipated downstream demand resulting in excess manufacturing costs to produce or an inability to meet customer delivery requirements.

- Control Uncertainties: Uncertainties resulting from the trade-offs of managing risk within the supply chain.
    - Inventory reductions to lessen the potential impact of inventory write-downs to the detriment of customer responsiveness in not being able to fill orders.
    - Delivery lead time reductions to improve customer responsiveness to the detriment of supply chain efficiency in not selecting a low cost carrier.

The definition of supply chain risk has been highlighted by White as threats impacting the end-to-end flow of goods and services. There are numerous non supply chain risk management activities including financial, performance, compliance, system security, and due diligence engagements. However, this thesis focuses on the four uncertainties put forth by White. The need to mitigate these uncertainties will help guide the formation of an organizational structure within the internal audit department of ABCD.

2.3 Supply Chain Risk Mitigation - Current Status at ABCD

The current status of supply chain risk mitigation efforts at ABCD was examined to see if a case could be made that a specific supply chain risk mitigation strategy did indeed need to be developed. In addition, the reviewer sought to ensure the existing best practices of ABCD would be uncovered and considered within the supply chain risk mitigation framework as set forth by this thesis. The methodology chosen in understanding the present-day activities at ABCD was a survey of key supply chain professionals within the company. This survey included questions pertaining to the types of supply chain risk faced by the company's global supply chain organization, the global sourcing organization and each of the three major business groups within ABCD. Also included in the survey was a scan for practices being employed to mitigate supply chain risks.

Interviewees:

- Vice President of Supply Chain for North America
- Vice President for Global Sourcing
- Division Controller for Global Sourcing/Finance
- 3 Supply Chain Directors (each covering one of ABCD's three major business groups)
- Manager for Supply Planning (covering one of ABCD's three major business groups)

Questions:

- Risk: What is the greatest supply chain risk facing your organization today?
- Organization: What position, if any, within your organization is tasked with spearheading supply chain risk mitigation efforts?
- Identification: What process, if any, is utilized to determine what the key supply chain risk areas are within your organization?
- Mitigation: What tools, if any, are leveraged to help define the key supply chain risk areas identified within your organization and determine what actions will be taken to mitigate these supply chain risks?
- Metrics: What metrics, if any, are followed to trigger the execution of business continuity plans or trigger audits/reviews within your organization's supply chain?

	Questions/Responses				
Area	Risk	Organization	Identification	Mitigation	Metrics
Global Supply Chain	Control Uncertainties	Center of Excellence	Process Mapping	Process Mapping	Key Indicators
Logistics	Supply Uncertainties	Buyers	Spend Analysis	Supplier Scorecards	Source Metrics
Business Group 1	Demand Uncertainties	Supply Chain Manager	None	None	Key Indicators
Business Group 2	Process Uncertainties	Deployment Team	Compliance Assessments	None	Key Indicators
Business Group 3	Demand Uncertainties	None	None	None	Key Indicators

Figure 4. Survey responses from supply chain professionals at ABCD concerning current status of the company's supply chain risk mitigation efforts.

Figure 4 summarizes the survey responses of ABCD's key supply chain professionals and includes the following:

- The business area of ABCD represented by the interviewees.
- The risk area expressed as a primary concern by the interviewees.
- The organization tasked with supply chain risk mitigation by business area.
- The process for identifying key supply chain risk.
    - Business process mapping whereby supply chain execution is flow charted with key control points highlighted.
    - Spend analysis focusing on supplier quality, delivery performance, service and use of technology.
    - Compliance assessments to gauge adherence to supply chain business rules.
- The tools leveraged to define and mitigate supply chain risks.
    - Business process mapping whereby supply chain execution is flow charted with key control points highlighted.
    - Scorecards to monitor supplier performance.
- The metrics used to monitor supply chain performance.
    - Key indicators over each supply chain business process to include the measurements of supply chain effectiveness, supply chain responsiveness and working capital management.
    - Source metrics covering supplier performance.

In the area of supply chain risk, several key challenges for ABCD were identified. A supply chain risk consistently stressed by the interviewees concerned the deployment of ABCD's enterprise-wide supply chain operating model. These issues included consistency, integration and training. The needs to ensure that the operating model would be executed in a consistent fashion across the company and be integrated in an effective manner, and that an appropriate amount of time would be spent training users regarding the integration of the model's components, were emphasized. Without this, there was a general expectation that process discipline would not be maintained and thus process excellence would not be achieved (process uncertainties). In addition to this challenge, the ongoing need to build into the operating model the right controls, on the front-end, that would mitigate supply chain risk but still allow the company to cost effectively meet their customers' expectations (control uncertainties) was noted. This included a substantial reduction in finished goods inventory while still maintaining agreed upon service levels for on-time performance and order fill rate.

Business groups within ABCD that had recently gone through lean transformations discussed their struggle to meet customer demand in a just-in-time environment. This struggle was due to the scaling back of production capacity and inventories. The company was meeting this challenge by including the collaborative forecasts of key customers into their sales and operations planning process (S&OP). The S&OP process was relied upon to reduce production upsets resulting from unexpected demand surges (demand uncertainties). Additionally, ABCD was operating in a business environment where specialty chemicals required by manufacturing were becoming hard to get (supply uncertainties). These material shortages resulted from increased demand within the company as well as supplier shutdowns. In addition, the company lacked negotiating leverage to secure these specialty chemicals because the company was not a large consumer of these types of products.

ABCD interviewees expressed that the challenges they faced were of a nature and complexity that supported the need for a coordinated supply chain risk mitigation strategy. Whether this strategy currently existed was the focus of the questions concerning organizational responsibilities, supply chain risk identification activities, supply chain risk mitigation techniques and the use of metrics. The interviewees' responses indicated that a comprehensive strategy had not yet been formulated. The interviewees exhibited recognition of the growing importance of managing supply chain risk, an importance increasing in large part because of risk now concentrated as a result of the company's enterprise-wide supply chain operating model. Figure 5 illustrates how risk in the areas of strategic sourcing, regional distribution and transportation planning is no longer managed at the business and facility level but rather on an enterprise level. The benefit to ABCD is an increase in customer service and substantial cost savings; the challenge is the changing nature of risk as to its type, frequency and complexity. An example of newly concentrated risk is inventory. By centralizing finished goods inventory into regional distribution centers and closing down warehouses, ABCD can meet cycle service levels while maintaining less safety stock. This is accomplished by aggregating demand. However, if a regional distribution center were shut down by a natural disaster, strike, fire, etc., the impacts would be greatly increased over the same occurrences happening at a much smaller warehouse. Risk at a regional distribution center changes type, frequency and complexity as demonstrated by the following examples:

- The types of risk change in that regional distribution centers employ more sophisticated supply chain management techniques. These include cross-docking, vendor-managed inventory, postponement, etc. If these processes are disrupted there is a more immediate impact on customers than would occur in basic warehousing of finished goods.

- The frequency of risk changes in that the absolute number of warehouses potentially impacted by a disruption is reduced but the percent of total inventory at jeopardy increases. This results from fewer inventory locations with larger quantities of finished goods. If these larger warehouse locations are disrupted a more immediate impact on the customer will be felt.

- The complexity of risk changes in that identifying which customers to continue to serve after a disruption at a regional distribution center becomes more difficult. Servicing customers becomes more expensive because the next closest location in a regional distribution center configuration is farther away than in a network of multiple warehouse locations. Therefore, issues of customer stratification and protocol on whom to serve, what to provide and from where the product will come require detailed business rules to be established for product allocation in case of a supply disruption.

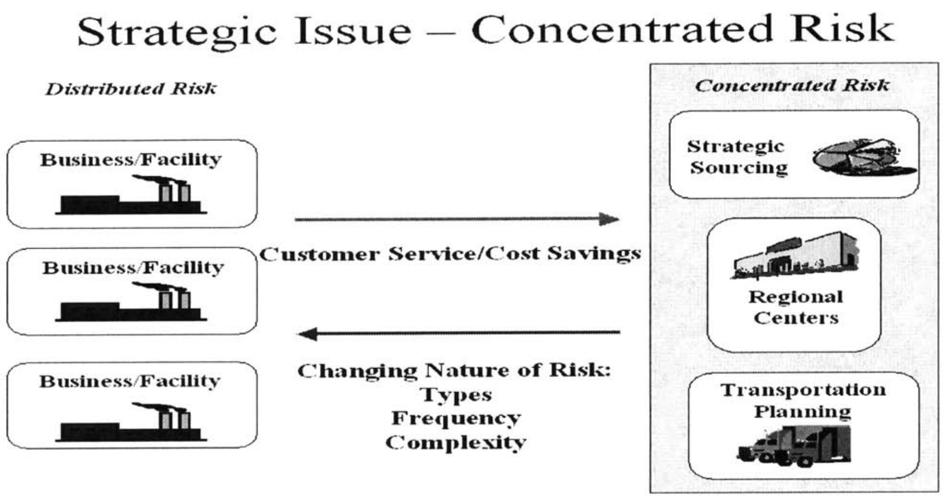

Figure 5. Changing nature of risk from a distributed environment to a concentrated environment based upon survey of key supply chain professionals at ABCD.

ABCD was following disparate approaches to supply chain risk mitigation. The most refined of these approaches was found within the global supply chain organization (GSC). Here, the interviewee outlined the company's plan to embed in the GSC a Center of Supply Chain Excellence (COE). The COE would address supply chain risk at the enterprise level, utilizing business process software to map supply chain risk areas. The COE would also monitor supply chain risk through the use of well defined metrics covering supply chain customer experience and supply chain effectiveness. Complementing the work of the COE, the logistics organization was also focusing on risk at the enterprise level. Here, the interviewees detailed how supply chain risk mitigation had been positioned as part of each buyer's responsibilities when analyzing strategic expenditures. These reviews concentrated on evaluating each vendor's quality, delivery performance, service capabilities and use of technology. The buyers would subsequently monitor the chosen vendor's performance through the use of supplier scorecards and the use of source management metrics.

Supply chain risk management was noted to be unstructured in areas other than the global supply chain and global sourcing organizations. Interviewees for the three major business groups of ABCD expressed that supply chain risk management had not been formally defined within their businesses. Interviewees did cite a supply chain manager and a project deployment manager as having some duties over supply chain risk management; however, these duties were not a primary responsibility. Supply chain performance metrics had been placed on the businesses' balanced scorecard. The key indicators were, however, directed more at management reporting than at identifying potential supply chain risk areas.

The survey of ABCD's key supply chain professionals illuminated the need for a comprehensive strategy to mitigate supply chain risk. This need became evident as the managers discussed key challenges facing ABCD. It also became apparent that a unifying strategy laying out organizational responsibilities, incorporating definitive supply chain risk identification activities and supply chain risk mitigation techniques, had not been formulated. Although these activities were beginning to take form within the Center for Supply Chain Excellence, they had not yet fully evolved. The question thus became who should ensure that a final strategy comes to fruition.

2.4 Summary

For the purpose of research at ABCD supply chain risk management is defined as ensuring the flow of goods and services end-to-end across the supply chain, at the promised service level to the customer, at anticipated costs. The uncertainties associated with maintaining this flow are shown as process, supply, demand and control uncertainties. The current status of supply chain risk mitigation at ABCD was examined to see if a case could be made that a specific supply chain risk mitigation strategy did indeed need to be developed. The survey of key supply chain professionals within ABCD supported a conclusion of "yes" in answer to this question. Hence, the argument for redefining the audit department to spearhead this task was substantiated.

3 Supply Chain Operations Reference (SCOR) Model

ABCD Company launched a multi-year project beginning in 2001 to build its enterprise-wide supply chain network with a goal of capturing annualized cost savings of several hundred million dollars. Within this project, the Supply Chain Operations Reference (SCOR) model was selected to help guide ABCD in constructing its supply chain. A critical objective of this thesis was to ensure that research was complementary to, and not contradictory with, ABCD's supply chain architecture. In keeping with this objective the SCOR-model as it relates to organizational structure became the basis for research regarding supply chain risk mitigation.

3.1 Background of the Supply Chain Operations Reference (SCOR) Model

The Supply Chain Operations Reference (SCOR) model represents agreement by the Supply Chain Council concerning supply chain management in the areas of business processes, metrics, best practice and technology. As described in SCOR Version 6.1, the SCOR-model is a unified structure to "support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities" (SCOR Version 6.1, 2004). The SCOR-model deals with the processes of Plan, Source, Make, Deliver and Return.

The SCOR-model encompasses all aspects of satisfying customer demand including customer interactions, material transactions and market transactions. The SCOR-model can be seen as not only dealing with the internal supply chain of an organization, but also unifying an organization with its external suppliers and customers. This unification extends even further to an organization's suppliers' suppliers and to an organization's customers' customers. In essence, the SCOR-model provides supply chain practitioners with a common set of supply definitions that can be used to push supply chain improvement on either a global (across the extended enterprise) or local (within the organization's own enterprise) basis.

At ABCD local enterprise improvements centered around establishment of a global supply chain organization (Plan), creation of a global sourcing department (Source), centralization of planning and scheduling functions (Make), and ramp-up of a center for transportation excellence for the central tendering of loads as well as the formation of regional distribution centers (Deliver). These SCOR-model management processes are covered in more detail in the sections that follow. Essential components of the processes as contained in the company's SAP supply chain applications are noted in each section. Figure 6 outlines the SCOR-model in terms of supply chain processes that occur among suppliers, the producing company and customers. These processes include Plan Supply Chain, Source, Make, Deliver, Return and Enable. Figure 6 also maps the sub-processes (e.g. P2 Plan Source, P3 Plan Make, etc.).

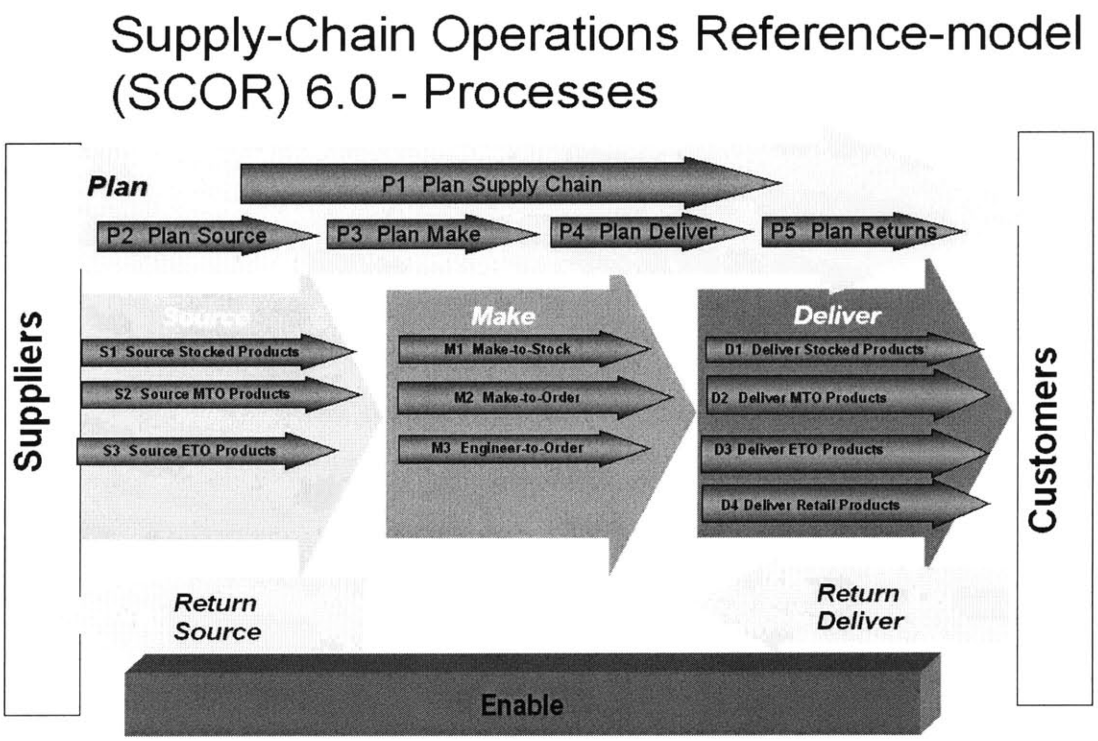

Figure 6. Supply Chain Operations Reference (SCOR) model version 6.0 showing the business processes of Plan, Source, Make, Deliver and Return (SCOR Version 6.0, 2003).

3.2 Description of Plan Business Process

The Plan management process within the SCOR-model encompasses Plan Supply Chain, Plan Source, Plan Make, Plan Deliver, and Plan Returns. As discussed by Stephens (2004), Plan has two important functions which are to provide "the mechanism for balancing demand requirements and available sources" and to provide the "integrating function between other process elements and suppliers/customers." In essence, Plan serves as the vehicle that brings together each piece of the value chain into a cohesive enterprise-wide strategy.

The key areas within ABCD's enterprise-wide strategy were the design of the company's supply chain (Plan Supply Chain) by their global supply chain organization, the development of yearly procurement plans (Plan Source) by their global sourcing organization and the planning of a distribution network (Plan Deliver) by their center for transportation excellence. Reverse logistics had not been formalized within ABCD's operating model. Supply chain planning within SAP includes the following (SAP 2005):

- Plan Supply Chain
    - Supply Network Planning & Outsourcing
        - Heuristics
        - Capacity Leveling
        - Optimization
        - Multilevel Supply and Demand Matching
        - Subcontracting
        - Scheduling Agreements
        - Aggregated Supply Network Planning
    - Supply Chain Definition
    - Supply Monitoring
    - Supply Chain Alert Monitoring
    - Supply Chain Analytics

        - Key Performance Indicators
        - Strategic Performance Management
        - Operational Performance Management
        - Supply Chain Analytical Applications
        - Collaboration Performance Indicators

- Plan Source
    - Long-Term Planning
    - Bid Management
    - Contract Management
    - Catalog Management
    - Source Determination

- Plan Deliver
    - Collaborative Shipment Forecasting
    - Load Consolidation
    - Mode and Route Optimization
    - Carrier Selection
    - Collaborative Shipment Tendering

3.3 Description of Source Business Process

The Source management process within the SCOR-model includes Source Stocked Products, Source Manufacture-to-Order (MTO) Products and Source Engineer-to-Order (ETO) Products. The Source management process serves as the locus of control for procuring goods across the supply chain to enable the satisfaction of customer demand. Stephens characterizes Source as including the "activities that connect an organization to its suppliers."

Source activities for ABCD were managed within the company's global sourcing organization for the goods and services used widely across the enterprise. Goods and services used primarily within the businesses and/or facilities were still managed on a local level. The global sourcing organization managed the Source activities for the enterprise-wide buys including the activities of acquiring materials and services, certifying vendors, managing in-bound freight, negotiating contracts, establishing business rules for sourcing and also intervening on vendor payment issues. The tasks of receiving, inspecting, holding and issuing of materials were managed by the company within the Deliver function at the applicable receiving locations.

Source was a key part of ABCD's deployment of its enterprise-wide supply chain operating model. Hence, Source improvements were instrumental in the company's drive to capture several hundred million dollars in annualized cost savings. These Source improvements were targeted as a result of increased purchasing leverage associated with becoming a larger enterprise after the sizable acquisitions made in the last 5 years. Sourcing within SAP includes the following (SAP 2005):

- Purchase Order Processing
    - Conversion of Demands to Purchase Orders
    - Confirmation and Monitoring Purchasing Activities

- Receipt Confirmation
    - Acknowledgement of Receipt within Logistics
    - Material Valuation

- Invoice Verification
    - Receiving an Incoming Invoice
    - Verifying an Incoming Invoice
    - Release of Blocked Invoices

- Supplier Collaboration
    - Data Transfer
    - Release Processing
    - Inventory Visibility and Simulation
    - Advanced Shipment Notification

3.4 Description of Make Business Process

The Make management process within the SCOR-model includes Make-to-Stock, Make-to-Order and Engineer-to-Order. The Make management process covers the internal workings of an organization as the organization receives materials, manufactures these materials into a product and then tests, packages, and subsequently releases for shipment the finished product to either an internal or an external customer. Stephens explains that Make documents how an organization "transforms/converts raw materials into finished goods" and does not "imply a change of location but a qualitative transformation of the raw materials."

Important Make initiatives for ABCD included adherence to the demand planning forecast to develop the block-schedule and detailed production plans by a centralized production scheduling department. Additionally, the initiatives embodied the control of non-conforming product within the manufacturing process and the improvement of inventory control through more efficient cycle counting and inventory visibility. ABCD sought to obtain network benefits from their industry acquisitions via these pushes for improving Make. In general, the Make improvements were geared toward improving capacity within the company's combined supply network, capacity obtained by wringing out manufacturing inefficiencies. Manufacturing within SAP includes the following (SAP 2005):

- Production Planning and Detailed Scheduling
    - Production Planning
    - Detailed Scheduling
    - Multilevel Supply and Demand Matching
    - Materials Requirement Planning

- Manufacturing Visibility
    - Manufacturing Tracking and Monitoring
    - Alerts & Follow-Up for Manufacturing
    - Manufacturing Analytics

3.5 Description of Deliver Business Process

The Deliver management process within the SCOR-model includes Deliver Stocked Products, Deliver Make-to-Order Products, Deliver Engineer-to-Order Products and Deliver Retail Products. The Deliver management process covers the activities necessary to manage a customer account in addition to packing, and then delivering, a final product to the customer's receiving location. Stephens distinguishes Deliver as "the activities that connect an organization with its customer." These activities are the associated order management tasks of entering and maintaining orders, generating quotes and creating and maintaining databases. These activities also encompass invoicing as well as the other related accounts receivable functions. Stephens outlines how Deliver further entails finished goods warehouse management, finished goods transportation and the management of Deliver business rules.

Strategic Deliver initiatives for ABCD involved the improvement of customer service levels by utilizing customer relationship management (CRM) software to enable one-question one-call service. The initiatives also concentrated on the reduction of warehouses by developing a network of regional distribution centers and on the improvement of transportation performance by the centralized tendering of loads. These improvements were further measures taken by ABCD to gain advantage from becoming a larger enterprise, size obtained after making acquisitions over the last several years. Deliver within SAP includes the following (SAP 2005):

- Transportation Execution
  - Shipping
  - Collaborative Shipment Tendering
  - Express Ship Interface
  - Distance Determination

- Freight costing
  - Freight Cost Calculation
  - Freight Conditions
  - Freight Cost Settlement
  - Freight Costing Extension

- Warehousing
  - Inbound Processing
  - Outbound Processing
  - Cross Docking
  - Warehouse and Storage
  - Physical Inventory

- Consensus Demand Planning
  - Data Handling
  - Collaborative Demand Planning
  - Planning with Bills of Materials
  - Characteristic Based Forecasting
  - Statistical Forecasting
  - Causal Forecasting

- Sales Order Processing
    - Rules Based Available-to-Promise
    - Product Allocation
    - Capable-to-Promise
    - Multilevel Available-to-Promise Check
    - Backorder Processing

- Billing
    - Creation and Cancellation of Invoices
    - Transfer Billing Data and Financial Accounting

3.6 Summary

The SCOR-model management processes of Plan, Source, Make and Deliver represent a unified structure for communication across supply chain partners. The SCOR-model was selected by ABCD to guide the construction of its supply chain and to monitor supply chain effectiveness. ABCD's efforts related to establishment of its global supply chain organization, creation of a global sourcing department, centralization of planning and scheduling functions and the ramp-up of its center for transportation excellence were aimed at improving customer service and capturing cost savings. Implementation of these improvement processes indicated a path for utilizing the SCOR-model to construct an organization capable of mitigating supply chain risk.

4 Organizational Structure

Supply chain processes and their enabling technology have become more and more complex. With this change, identification and mitigation of supply chain risk have become increasingly more difficult and sophisticated. This challenge is evident at ABCD in its transition to a more centralized enterprise-wide supply chain operating model. No longer relying solely on manual processes or enterprise resource planning (ERP) systems to control the movement of manufactured goods across the internal organization, the company is now deploying sophisticated advanced planning and scheduling (APS) software focused on managing the extended supply network across its trading partners. Substantial benefits are forthcoming from such steps but the question must be addressed of who is to cope with the changing nature of supply chain risk arising from this strategic shift. Who is to possess the deeper understanding of supply chain design, planning and operations necessary to handle the supply chain risk of operating in a more integrated, centralized and intricate environment?

The appropriate organization to oversee supply chain risk mitigation efforts is posited to be the audit department of ABCD. The evolution of the internal audit role within companies supports this conclusion. To further buttress the argument, the current state of the audit function within ABCD is assessed. This look at the audit department's capabilities sets the stage for an examination of three possible organizational structures in redefining the audit department to manage supply chain risk. Key trade-offs must be analyzed to choose the most appropriate organizational design for ABCD, a design that ties in the SCOR-model processes of Plan, Source, Make and Deliver. Additionally, vulnerability mapping is examined as a key responsibility within the audit department's supply chain risk mitigation efforts.

4.1 Internal Auditing Best Practices

The argument made here that supply chain risk mitigation should be led by internal auditing is in keeping with the Institute of Internal Auditors' (IIA) definition of the internal audit role and with the development of internal auditing over the last 20 years. In addition, the Operations Management Roundtable has identified the inclusion of internal audit in supply chain governance as a best-in-class practice.

The role of internal audit as laid out by the IIA stresses the consultative nature of the department in risk management as well its contribution in bringing a systematic approach to control and governance processes. The IIA makes no distinction between types of risk but refers to risk in its general nature. Therefore, it should be deduced that supply chain risk is within the scope of internal auditing. The Institute of Internal Auditors (IIA) has defined the internal audit role as follows:

> Internal auditing is an independent, objective assurance and consulting activity designed to add value and improve an organization's operations. It helps an organization accomplish its objectives by bringing a systematic, disciplined approach to evaluate and improve the effectiveness of risk management, control and governance processes (IIA, 1999).

The evolution of internal auditing over the last 20 years also bolsters the argument for rooting supply chain risk mitigation within internal audit. No longer focused merely on providing a check over accounting transactions, the internal auditor now applies risk-based auditing to the management of activities that span the enterprise. This enterprise-wide view makes internal auditing primed to analyze risk associated with operating highly interconnected supply networks. Internal auditors have the opportunity to identify problems that cross organizational boundaries. The internal audit department has the professional responsibility to provide objective assurance in the evaluation and improvement of risk management, identifying and reporting problems that can impact the economic health of the company. The expanded scope allows internal audit to focus on strategic areas that move a company towards its goals. Within the realm of supply chain risk mitigation, the goal is to ensure uninterrupted service to customers, at known costs, and at promised service levels. Pickett outlines the evolution of internal audit as follows (Pickett, 2003):

Evolution of Internal Audit Profession in Last 20 Years

1. Internal Check Procedures: Providing a continuous examination over accounting transactions.
2. Transaction-Based Approach: Streamlining the tests that cover accounting transactions in order to apply the tests during a specific audit visit versus providing a continuous check.
3. Statistical Sampling: Checking samples of accounting transactions in order to reduce the level of detailed testing.
4. Probability-Based Work: Transitioning from being the check over accounting transactions to testing for financial propriety across the organization.
5. Spot Checks: Creating a deterrent to financial irregularity by making unannounced checks across the organization.
6. Risk Analysis: Targeting audit resources to high risk areas based upon risk analysis.
7. Systems-Based Approach: Advising management on internal controls and then testing the way management controls activities.
8. Operational Audit: Including operational areas outside of the financial arena in order to identify cost saving efficiencies.
9. Management Audit: Addressing control issues arising from managing an activity to help move an organization toward its objectives.
10. Risk-Based Auditing: Auditing based upon the way an organization perceives and manages risk.

The above list is not mutually exclusive and most companies do some of each. The list does show the general progression of internal auditing. The most advanced internal audit departments focus on the important areas driving an organization (management audit) whether they are corporate, managerial or operationally centered. These departments emphasize how a control environment is executed across the organization (risk-based auditing) in terms of risk perception. ABCD's enterprise-wide supply chain operating model has corporate, managerial and operational components. Each of these components acquires an increased potential for operational disruption as supply chain risk becomes more centralized at the company. Thus, establishing a strategy to deal with ABCD's changing supply chain risk profile fits within the current evolution of internal auditing (management and risk-based auditing).

Where has internal audit become a best-in-class element of supply chain management? The Operations Management Roundtable studied how companies create best-in-class supply chain operations. In this study, General Electric's (GE) internal audit activities were identified as a best practice for expanding "from traditional financial audit to internal consulting and best practice transfer" (Mitchell, Horne, Evans & Hoek, 2002). GE's internal audit department took a lead role in creating alignment between the direction of GE's business units and the overall strategy of the company by spreading supply chain best practices across the enterprise. Just as GE's internal audit team disseminated supply chain best practices, ABCD's internal audit department can spread supply chain risk mitigation best practices. As noted earlier a strategy for mitigating supply chain risk had not been implemented across ABCD in conjunction with its centralization initiative. The internal audit department has the opportunity and ability to chart the course in this area.

4.2 Current Status of Internal Auditing at ABCD

The internal auditing function at ABCD is in a position to transform itself. Organizational changes need to be made in order to address control issues arising from the company's global supply chain implementation (management audit). In addition, the audit department can benefit from building competencies in understanding and defining supply chain risk (risk-based auditing).

ABCD's internal audit department has evolved in a manner that closely resembles the progression outlined by Pickett. In the 1980's the company tested business units for financial propriety (probability-based work). The audits during this time were conducted by relatively large teams, at fixed periods of time, and were geared toward being a deterrent to financial irregularity (spot checks). The internal audit department sought to improve efficiency in the early 1990's by assigning resources based upon risk assessments carried out at the beginning of each audit (risk analysis). In addition, the internal audit department sought to build partnerships with ABCD's business groups by delivering internal control seminars and other non-audit consulting engagements (systems-based approach). The mid-1990's brought an emphasis on operational areas outside of the financial arena. This focus was geared toward identifying cost saving efficiencies during the course of an audit (operational audit). The audit department has not made the transition to risk-based management auditing. Figure 7 shows how ABCD made a significant shift away from probability-based work in the early 90's and then shifted again to performing operational audits in the mid 90's. The company in 2004 is on the cusp on being able to progress into management audits using a risk-based approach.

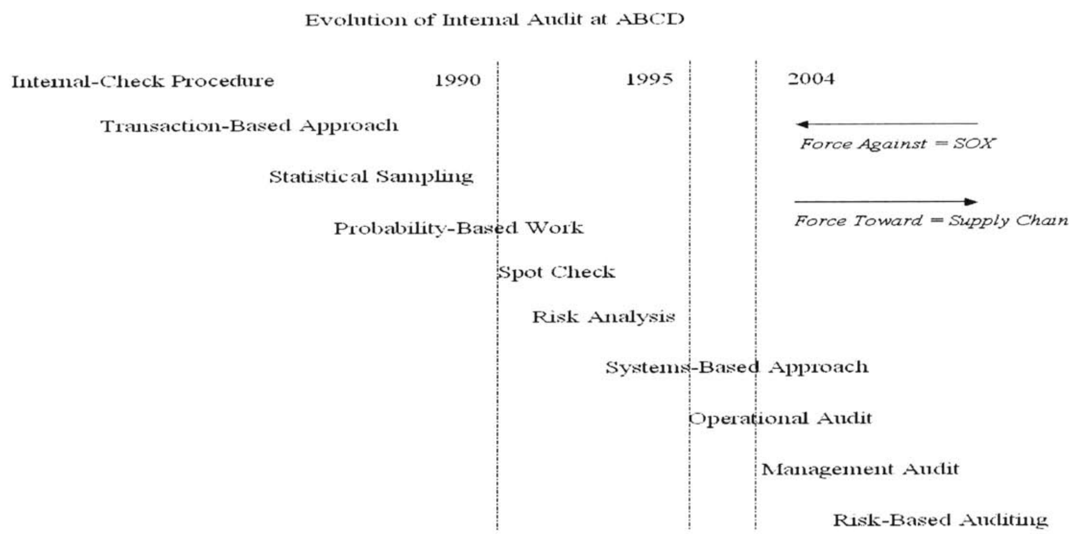

Figure 7. Evolution of internal auditing at the ABCD Company showing transitions to spot-checking, operational auditing and management auditing based upon conversations with internal auditors at ABCD.

Internal auditing at ABCD is poised to advance to the next level of development. However, Section 404 of the recently passed Sarbanes-Oxley Act can be a force against the company's ability to accomplish this. The Act requires publicly traded companies to establish, document and maintain internal controls and procedures governing financial reporting. As a result, ABCD's audit organization has placed renewed emphasis on increasing staff experience in the areas of finance and accounting, a move back toward probability-based work. This shift is due to the Act's emphasis on financial controls and extensive financial reporting. The audit staff has accordingly had to narrow their scope to financial controls and not focus on supply chain issues. The company's transition to a more centralized enterprise-wide supply chain operating model supports the audit department's need to progress to risk-based management auditing. The complexity of supply chain processes and enabling technology has driven the need to populate the internal audit staff with members better schooled in supply chain management and information technology, not only in finance and accounting. The need to balance these conflicting forces affects the timing for redefining the audit function of ABCD. It does not, however, change the need for the redefinition to occur. The need to ensure the flow of goods and services end-to-end across the supply chain will not go away. This flow must continue at the promised service level and at anticipated costs.

4.3 Approaches to Organizational Design for Internal Auditing

Three organizational structures were explored in order to recommend a redefinition of ABCD's internal audit department. These structures were centered on the Supply Chain Operations Reference (SCOR) model and consisted of a process design, a business/process design, and a directed design to staffing the department.

- Process Design: Four teams are developed with each team focusing on one of the SCOR-model processes of Plan, Source, Make and Deliver. Two additional teams are created with one team focusing on finance and one team focusing on information technology. Each team would audit its respective process wherever it resides within the enterprise. Teams would be managed to review how work flows through the supply chain (e.g. the strategic sourcing team would look at the activities from selecting vendors and placing orders all the way through paying a vendor's invoice).

- Business/Process Design: Three teams are organized with each team focusing on one of ABCD's three major business groups. Three additional teams are formed with one team focusing on the global supply chain organization, one team focusing on finance and one team focusing on information technology. Under this blueprint, the SCOR-model processes of Plan, Source, Make and Deliver are not concentrated into self-contained teams but are fully represented within each of three teams assigned to a major business group.

- Directed Design: The department is kept at status-quo except for the addition of one team directed to the global supply chain organization. This team would represent all of the SCOR-model processes of Plan, Source, Make and Deliver. This team would limit their scope to activities that had been centralized within ABCD's enterprise-wide operating model and would not be involved with auditing the three major business groups.

Figure 8 shows the organization structure following the process design, Figure 9 shows the business/process design and Figure 10 shows the directed design. Each figure also highlights the cross-functional teams needed within each organizational structure. These teams include risk consultants specializing in supply chain operations (e.g. Plan), information technology, finance and data analysis. These figures also outline the high level management structure of internal auditing including the reporting relationships to the director and senior vice president of internal auditing. Figure 10 details only the team assigned to the global supply chain. Under Figure 10, teams managed by business would be staffed according to the individual needs of each business unit and thus are not mapped out in the figure. However, the overall number of team members for each organizational structure would be roughly equivalent.

Organizational Structure – Process

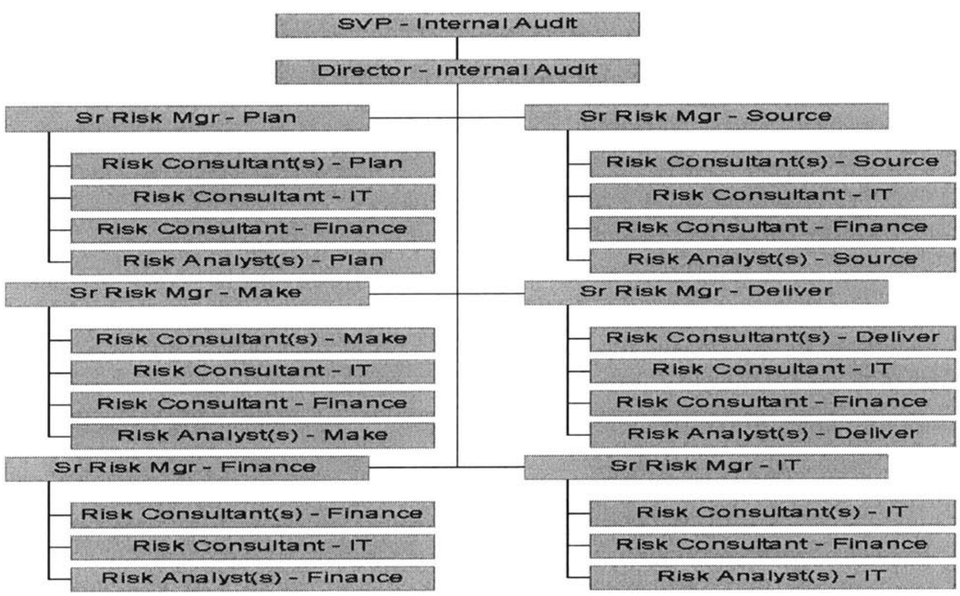

Figure 8. Process design organizational structure where teams are formed around the SCOR-model of Plan, Source, Make and Deliver as well as the areas of Finance and Information Technology

Organizational Structure – Business/Process

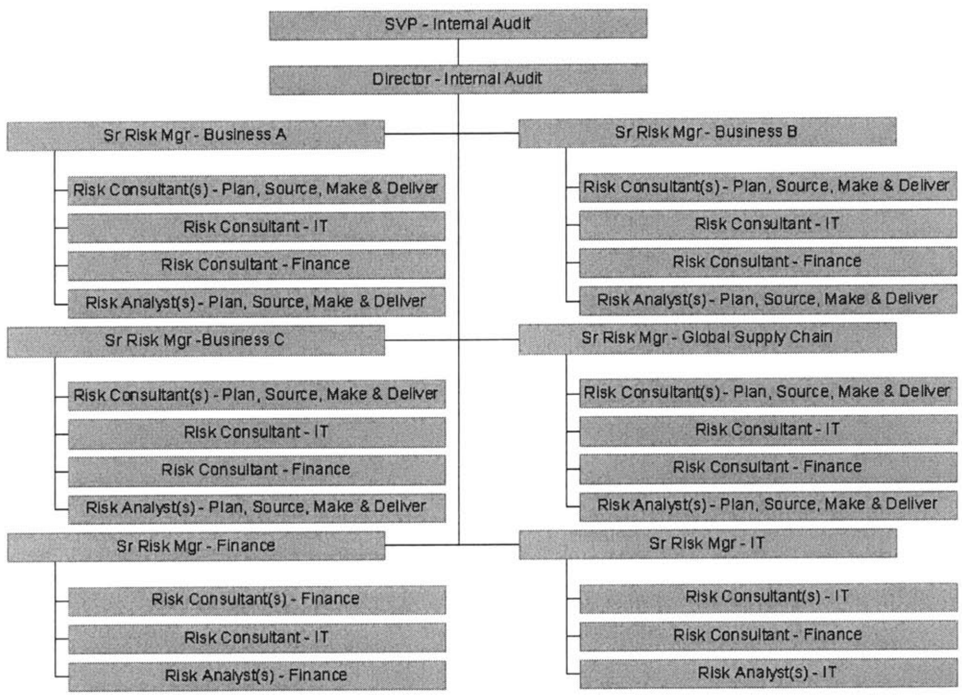

Figure 9. Business/Process design organizational structure where teams are formed around ABCD's three major business groups with each team representing the SCOR-model of Plan, Source, Make and Deliver. This structure also includes teams covering the areas of Finance and Information Technology.

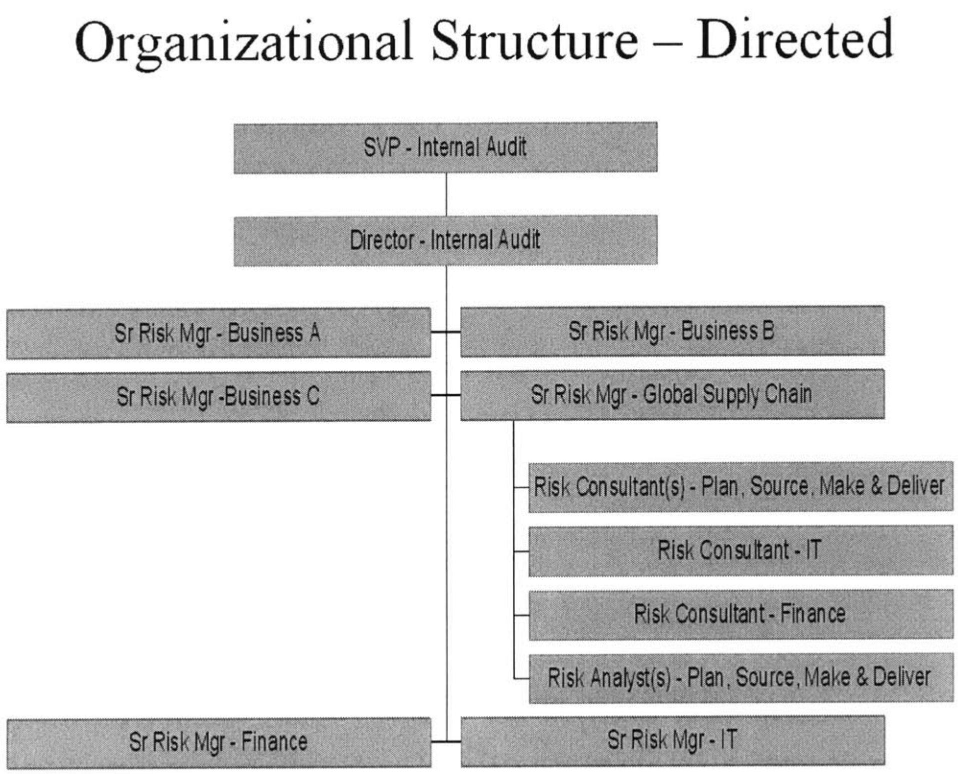

Figure 10. Directed design organizational structure where a team representing the SCOR-model of Plan, Source, Make and Deliver is assigned to the global supply chain organization. The remainder of ABCD's internal audit department is kept at status-quo.

Which of the three organizational structures is most appropriate for ABCD? Total number of employees is expected to be similar under all three designs. The decision lay in the trade-offs between the degree of standardization and supply chain risk mitigation achieved versus the degree of coordination and complexity required to implement the structures. In essence, the higher the standardization the greater amount of supply chain risk mitigation. However, in order to achieve this standardization the organizational designs become more complex and thus harder to coordinate. These trade-offs are diagrammed in Figure 11.

Figure 11 is the basis for choosing which organizational structure is mot appropriate for ABCD. The axes form an assessment between the need to achieve greater standardization/risk mitigation and the need to manage complexity/coordination. ABCD expressed the need to execute its supply chain operating model in a consistent fashion across the enterprise. There was a general expectation that a lack of consistency would result in a lack of process discipline and hence a lack of process excellence (process uncertainties). Therefore, the degree of standardization that could be pushed by internal auditing was imperative to the company's success. The counterbalance to this argument is the degree of integration necessary across the internal audit department to deliver standardization. As the need to integrate activities across the department increases, so does the complexity necessary to manage the department. Since complexity conflicts with standardization, trade-offs have to be weighed. Figure 11 shows where the process, business/process, directed and status-quo organizational structures rank in terms of standardization, risk mitigation, complexity and coordination levels. The rankings are explored further in the sections that follow.

Organizational Structure – Comparison

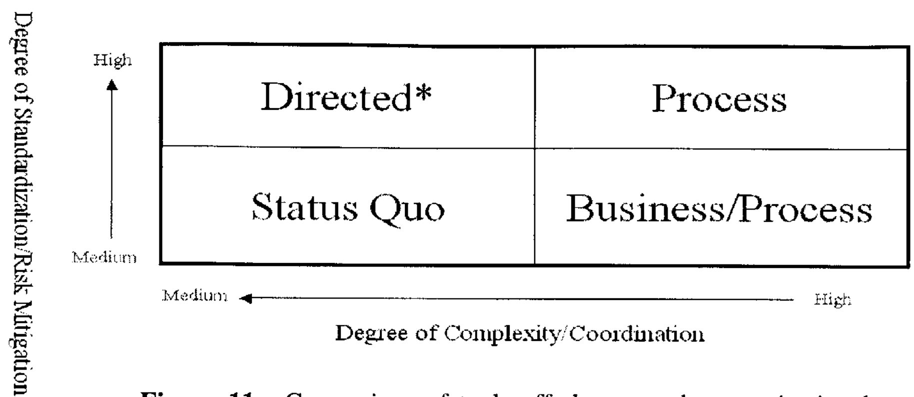

Figure 11. Comparison of trade-offs between the organizational designs of Process, Business/Process, Directed and Status Quo. *The directed design only applies to the global supply chain organization.

- Process Design: Organizing teams around the SCOR-model brings a high degree of standardization. Each team focuses on only one SCOR business process and provides expertise within that field. This negates the probability of multiple teams auditing the same business process but taking a different approach. However, teams need to coordinate their activities to ensure that the same business/location is not audited simultaneously (e.g. a Make audit and a Deliver audit being conducted at the same time at the same place) unless conditions warrant a multi-team approach. This configuration significantly increases the level of coordination needed within the internal audit staff.

- Business/Process: Organizing teams along the three major business groups lessens the amount of coordination needed within the internal audit staff. The possibility of multiple teams auditing the same business/location is eliminated. Each business/location is assigned to one team which reviews all SCOR business processes. However, with each team handling all four SCOR business processes, the possibility of teams taking different approaches increases. This reduces the likelihood that standardization will be achieved.

- Directed: Organizing a team along the SCOR-model assigned to the global supply chain organization results in the highest degree of standardization requiring the lowest level of coordination. All four SCOR business processes are contained in only one team. This team focuses on the supply chain activities that have been centralized at the enterprise level. The remainder of the audit department is staffed at status-quo. As a result, the lack of supply chain risk mitigation would not be addressed at ABCD's three major business groups.

- Status Quo: Currently the internal audit department assigns teams by business group. These teams primarily have a financial and accounting focus with little supply chain emphasis. Remaining at status-quo would contradict the need to redefine the audit department in order to deal with the changing nature of supply chain risk at ABCD.

The process design model is recommended by the researcher as most appropriate for the internal audit department due to ABCD's need for standardization. For ABCD, the need for standardized practices and metrics across the entire enterprise is more important than customization within each business unit. This standardization will be critical in capturing the savings associated with moving to a more centralized enterprise-wide supply chain operating model and in mitigating the supply chain risk this centralization created. Although important, the coordination and complexity aspects of the process design are outweighed by the benefits achieved through standardization. Moving to a process design entails the same number of employees as the status-quo model; therefore, a material amount of additional cost is not anticipated. The transition would occur over time to take into account the normal level of staff turnover and expenditures for training. The additional risk mitigation benefits thus are achieved with a minimal outlay of funds.

4.4 Critical Areas within Internal Auditing

Having the appropriate organizational structure is not sufficient, in itself, to institute an effective supply chain risk mitigation program. The organization must be comprised of teams possessing the requisite skills in the areas of supply chain design, planning and operations (organizational design). In addition, these teams must have the ability to understand and define supply chain risk, plan for supply chain risk contingencies, and war game supply chain risk scenarios (vulnerability mapping and metrics). These abilities are needed in addition to the administrative expertise necessary to manage an internal audit department (e.g. capability to administer a quality assurance program). Figure 12 shows the critical areas within the internal audit department including training, quality assurance, reviews, audits, organizational design, vulnerability mapping, metrics and coordination.

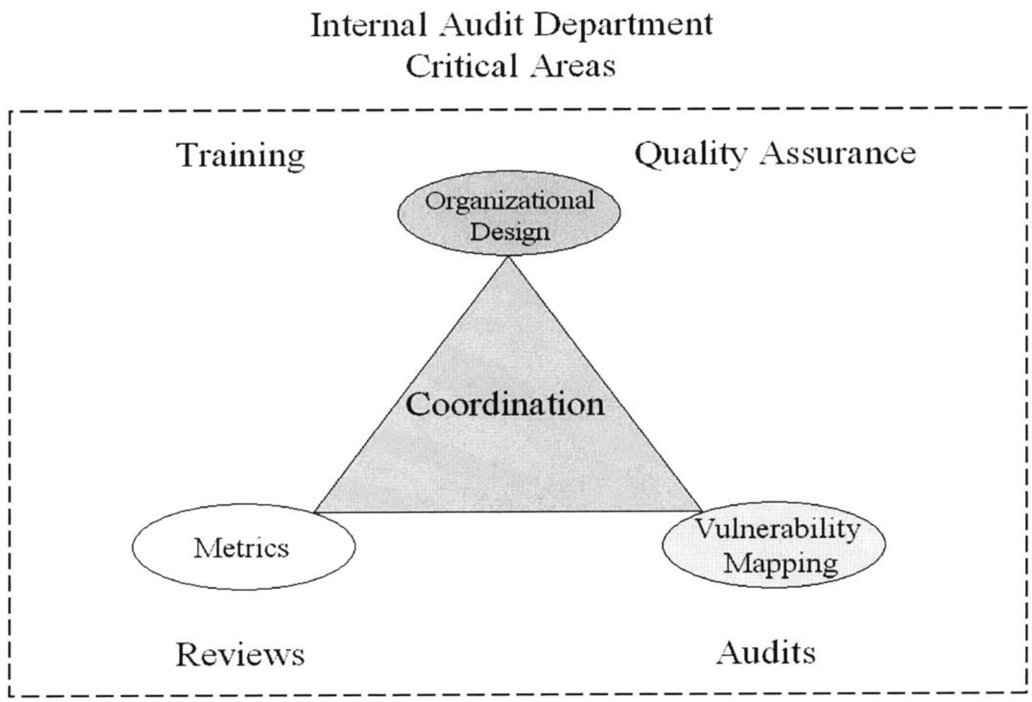

Figure 12. Critical areas within an internal audit department necessary to institute an effective risk mitigation program.

The coordination of supply chain risk mitigation activities across the internal audit department, and the implementation of an internal quality assurance program, rest primarily with the Senior Risk Manager for Plan. In essence, this manager serves as the vehicle that brings together all supply chain internal audit efforts (Plan, Source, Make and Deliver) into a cohesive enterprise-wide strategy. The remainder of the critical areas within internal auditing are shared equally by each senior risk manager.

Definitions of Critical Areas

- Coordination: The task of ensuring that touch points within the Supply Chain Operations Reference (SCOR) model are accounted for within the internal audit department's supply chain risk mitigation program. This function integrates the activities of Plan, Source, Make and Deliver into a cohesive enterprise-wide strategy to address supply chain risk arising from hand-offs between different business processes. In addition, this task involves the coordination of activities to ensure that the same business/location is not audited simultaneously (e.g. a Make audit and a Deliver audit being conducted at the same time at the same place) unless conditions warrant a multi-team approach.

- Organizational Design: The task of hiring, supervising and motivating staff within each internal audit team (Plan, Source, Make, Deliver, Finance and IT). Inherent in this task is the need to build teams with backgrounds in finance, operations, information technology and data analysis.

- Vulnerability Mapping: The task of understanding and defining supply chain risk, planning for supply chain risk contingencies, and war gaming supply chain risk scenarios.

- Metrics: The task of using indices to help determine where resources should be directed in conducting on-site reviews of supply chain processes. This includes establishing which metrics to monitor, identifying the data source for the metrics and incorporating the use of these metrics with supply chain vulnerability mapping for determining levels of operational risk. In addition, this task encompasses the setting of trigger-points and time-line sequencing to help determine where the audit department would implement pre-determined on-site supply chain reviews when metrics warn of a possible operational crisis.

- Training: The task of educating the internal audit department on the SCOR methodology and instructing individual teams, as appropriate, on the specific business processes of Plan, Source, Make and Deliver. This task also includes teaching internal auditors how to execute vulnerability mapping, monitor supply chain metrics, perform supply chain audits and facilitate supply chain peer reviews.

- Audits: The task of implementing a strategy to effectively and efficiently mitigate supply chain risk. This task includes risk-based reviews of processes, enabling technology and strategic/master planning/operational documentation to provide assurance that adequate financial and operational controls are in place and are working as designed.

- Reviews: The task of facilitating supply chain peer evaluations within the Center of Supply Chain Excellence (COE). This task includes quality assurance activities to ensure peer reviews follow an approved methodology, maintain rigor, obtain management agreement on action items to address deficiencies, and provide follow-up to action items to monitor whether agreements were implemented on time and in the prescribed manner.

Figures 13 and 14 highlight how the critical areas within the internal audit function align with the organizational structure of the process design. The audit teams for Plan and Source are utilized to illustrate alignment. The key difference between Figures 13 and 14 is that the Plan team has additional responsibility for the overall SCOR-model along with responsibility for the Plan supply chain process. These added functions include transition planning to the new organizational design, coordinating the activities of each internal audit team and performing quality assurance over the internal audit effort.

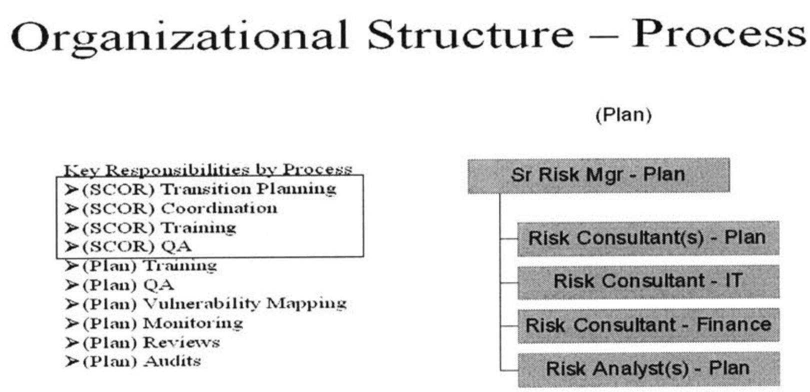

Figure 13. Plan audit team staff make-up and key responsibilities.

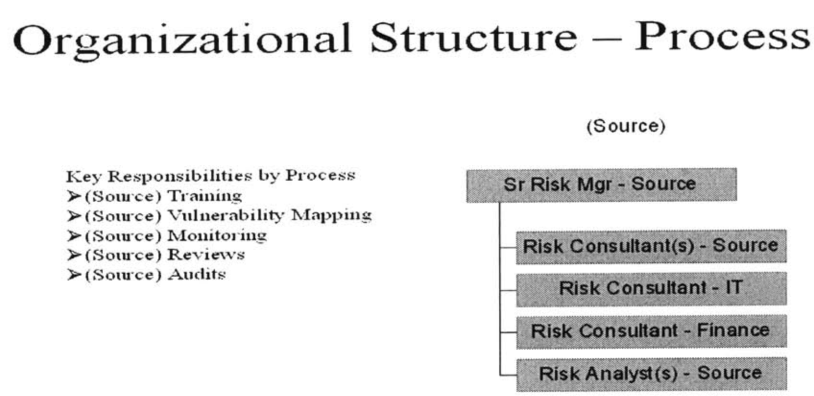

Figure 14. Source audit team staff make-up and key responsibilities.

The building blocks of an effective supply chain risk mitigation strategy are coordinated integration of the organization, execution of vulnerability mapping and use of metrics. A process design comprised of four teams with each team focusing on one of the SCOR-model processes of Plan, Source, Make and Deliver suggests the best organizational model.

4.5 Overview of Vulnerability Mapping

Vulnerability mapping is an essential component within an internal audit department's supply chain risk mitigation efforts. This methodology consists of understanding and defining supply chain risk, planning for supply chain risk contingencies, and war gaming supply chain risk scenarios. Vulnerability mapping brings together work from System Dynamics, Failure Mode Event and Criticality Analysis (FMECA), business continuity planning and stress testing. A summary of these tools is presented as follows:

- System Dynamics: A tool that helps managers to understand the structure and dynamics surrounding complex systems and subsequently build computer simulations of these models in order to design effective policies (Sterman, 2000). This tool relies on understanding how complex systems evolve over time and how internal feedback loops within the system being studied can influence and shape behavior.

- Failure Mode Event and Criticality Analysis: A tool developed by the National Aeronautics and Space Administration to identify and assess critical malfunction modes and to gauge their subsequent impact on system performance (FMECA, 2004). This tool is now being applied to supply chains in order to detail and track recommended actions for addressing supply chain risk. The identified failure modes, however, must be considered when modeling the supply chain in conjunction with System Dynamics modeling. This incorporates factors affecting the probability and severity of supply chain risk.

- Business Continuity Planning: A tool that helps managers build contingency plans in order to integrate the actions identified as necessary after an analysis of supply chain risk has been performed and the supply chain risk impact has been assessed (GAO, 1998). This tool is an outgrowth of System Dynamic modeling and FMECA. In essence, contingency plans prepare for the unlikely events that were identified as possibly occurring in the supply chain so that operations can continue uninterrupted.

- Stress Testing: This tool war games business continuity plans to see if the plans work as intended. These games simulate real-life supply chain disruptions to ensure the plans are robust and can ensure the end-to-end flow of goods and services across the supply chain.

A twelve-month cyclical process for administering vulnerability mapping was reviewed with ABCD. This process included modeling the supply chain to understand the causes of supply chain risks during months one through three (System Dynamics), identifying the critical failure modes and creating actions plans for mitigating these supply chain risks in months four through six (FMECA), contingency planning for business interruptions in months seven through nine (business continuity planning), and war gaming in months ten through twelve (stress testing). This process would repeat itself each annual cycle with any required updates being fused with the prior year's work. Figure 15 outlines the 12 month cyclical process of understanding the causes of supply chain risk, defining supply chain risks, planning for the contingency that a supply chain disruption may occur and war gaming business plans to ensure the end-to-flow of goods and services across the supply chain, at the promised service level, at anticipated costs.

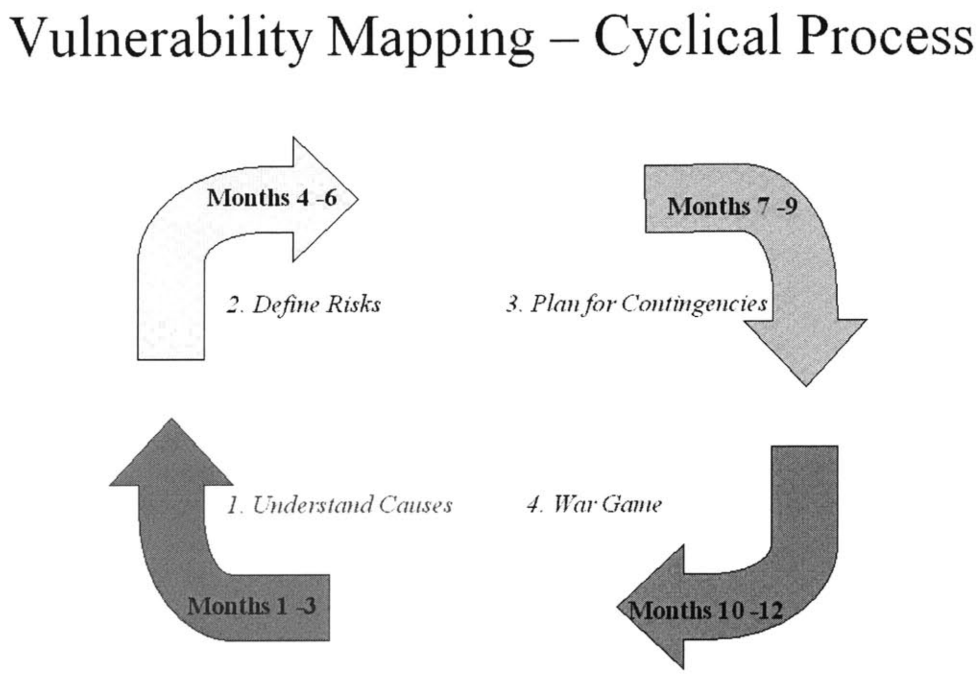

Figure 15. Twelve month cyclical process for performing vulnerability mapping.

This research does not provide an in-depth study of System Dynamics and Failure Mode Event Criticality Analysis; however, a high-level overview is warranted. The System Dynamics modeling process as outlined by the System Dynamics Society (System Dynamics, 2005) and the FMECA approach as outlined on the FMECA web-site (FMECA, 2004) is furnished as follows:

<u>System Dynamics Modeling Process:</u>

1. Identify a problem.
2. Develop a dynamic hypothesis explaining the cause of the problem.
3. Build a computer simulation model of the system at the root of the problem.
4. Test the model to be certain that it reproduces the behavior seen in the real world.
5. Devise and test in the model the alternative policies that alleviate the problem, and implement this solution.

Failure Mode Event Criticality Analysis Process:

1. Identity functions.
2. Identify failure modes.
3. Identify effects of the failure mode.
4. Determine severity.
5. Apply procedures for potential consequences.
6. Identify possible causes.
7. Determine occurrence.
8. Calculate criticality.
9. Identify design of controls.
10. Determine detection.
11. Perform final risk analysis and take actions to reduce risk.

The twelve-month cyclical process for administering vulnerability mapping was suggested as an instrumental element in redefining ABCD's audit department. Senior risk managers for Plan, Source, Deliver and Make were targeted to shepherd vulnerability mapping across the company. These managers would work in concert with the supply chain directors for each of ABCD's three major business groups as well as the controllers for the North American supply chain and global sourcing organizations. Together, they could mitigate supply chain risk whether it be from control, supply, demand or process uncertainties.

4.6 Summary

Internal auditing brings independence, the vested interest in accurate reporting and the broad organizational focus necessary to add enormous value to supply chain risk management. More so, internal auditing straddles organizational boundaries. This last point is important for any organization set on mitigating the risk of moving to a more centralized supply chain network. The process design is the recommended approach for expanding the purview of the internal auditing department with vulnerability mapping being the necessary tool to get the job done.

5 Pilot

A vulnerability mapping pilot was conducted for ABCD's Dallas regional distribution center (RDC). The Dallas RDC is a 308,500 SF facility with average on-hand inventory of 20,000 tons consisting of 1,800 stock keeping units totaling $18 million. The facility is managed by a third part logistics (3PL) provider servicing 350 customers on behalf of ABCD. The facility is replenished approximately 75% by rail and ships to customers 100% via truck. Over 90% of the outbound truck shipments are handled by a dedicated carrier which is also managed by the 3PL. The pilot team consisted of representatives from corporate audit, supply chain inventory management, supply network planning and from the operational site of the Dallas RDC. The following section gives examples to show how the vulnerability mapping process worked using System Dynamics and Failure Mode Event and Criticality Analysis. This section is not intended to be a detailed review. The examples used are a combination of actual work performed during the pilot and examples used for illustrative purposes only.

5.1 Framework

Vulnerability mapping for the Dallas RDC was executed in consideration of ABCD's competitive strategy and the subsequent design of the company's supply chain for the Dallas RDC. This is the essence of management auditing where control issues are addressed for risks that arise from managing an activity in order to help move an organization toward its objectives. The framework guided the development of supply chain risk mitigation strategies that would ensure the flow of goods and services end-to-end across the supply chain, at the promised service level to the customer, at anticipated cost. Figure 16 adapted from Chopra and Meindl (2001) illustrates the framework that guided vulnerability mapping for the Dallas RDC.

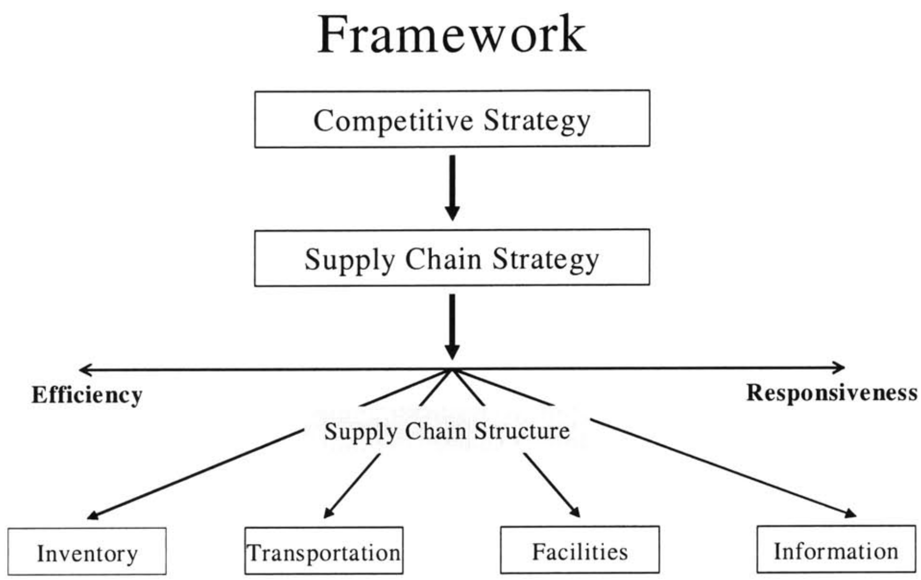

Figure 16. Framework for guiding vulnerability mapping for ABCD's Dallas RDC adapted from Chopra and Meindl (2001).

ABCD operates in a mature industry characterized by low product innovation. In general, the industry competes on price. The price-competitive nature of the industry drives the need for a supply chain strategy at the Dallas RDC that is highly efficient but still retains enough customer responsiveness to be competitive. Using Figure 16, the industry, thus ABCD, operates more toward the efficiency continuum than responsiveness. The implication of this is the need to identify supply chain risks that would prevent ABCD from delivering goods and services at anticipated cost (efficiency). Although identifying supply chain risks that would impede delivering goods and services at the promised service level (responsiveness) was important, vulnerability mapping had to be more heavily weighted toward ensuring ABCD achieves efficiency in the company's supply chain structure.

Figure 16 illustrates the four focus areas of ABCD's supply chain structure for performing vulnerability mapping for the Dallas RDC. These four areas are inventory, transportation, facilities and information, defined as follows:

- Inventory: Policies governing cycle, safety and seasonal inventory levels as well as physical control activities over finished goods.

- Transportation: Policies governing the movement of finished goods into and out of the RDC covering mode selection, route and network design, and carrier selection.

- Facilities: Policies governing the selection of the Dallas RDC in terms of site location and capacity and policies governing inventory storage methodology.

- Information: Policies governing whether the Dallas RDC will be a push or pull point in the supply chain, coordination with upstream manufacturing and downstream customers, forecasting of demand and aggregation of inventory planning and the use of enabling technology (e.g. electronic data interchange).

Due to the limited nature of the pilot, the scope was narrowed to vulnerability mapping of inventory and transportation in understanding the causes of supply chain risk (System Dynamics) and defining supply chain risk (Failure Mode Event and Criticality Analysis). The pilot did not encompass planning for contingencies (business continuity planning) or war gaming (stress testing). The pilot encompassed the four areas of supply chain risk to include process uncertainties, supply uncertainties, demand uncertainties and control uncertainties.

5.2 System Dynamics

The first two steps in System Dynamics modeling are to (step 1) identify a problem and (step 2) develop a dynamic hypothesis explaining the cause of the problem. Figure 17 provides four examples of how these first two steps were applied to the Dallas RDC. Figure 17 identifies types of supply chain uncertainties and explains the cause of the uncertainty in terms of the primary area within the Dallas RDC which is affected, the primary risk mitigation tactic deployed to alleviate the uncertainty and the impact the uncertainty has on the supply chain. The role of the audit team is to ensure that a primary risk mitigation tactic is in place, to subsequently validate whether the primary risk mitigation tactic is robust enough to alleviate the supply chain risk, and to confirm the primary risk mitigation tactic is being implemented as designed. Since the pilot only dealt with vulnerability mapping and not an audit of supply chain risk, validation and confirmation activities were not performed.

Type Of Uncertainty	Name of Uncertainty	Primary Area Affected	Impact	Primary Risk Mitigation Tactic
Supply	Rail Service	Order Rate From Mill	Efficiency	Escalation Process
Process	Labeling	Order Rate From Customer	Responsiveness	Procedure Documentation
Control	Inventory Replenishment	Order Rate From Mill	Efficiency	DRP (Access Database)
Demand	Customer Order Levels	Inventory	Responsiveness	Written Contracts/Special Reports

Figure 17. Examples of System Dynamics problems and hypotheses to problems associated with ABCD's Dallas RDC based upon vulnerability mapping pilot.

A more detailed explanation of Figure 17 is as follows:

- Supply Uncertainty: Inventory replenishment from the primary mills to the Dallas RDC could become erratic due to poor rail service. The uncertainty in transportation lead times could affect the rate in which replenishment orders arrived at the Dallas RDC and lead to higher quantities of pipeline inventory. Hence, the efficiency of the RDC could be reduced in that greater inventory holding costs could be incurred. The primary risk mitigation tactic to deal with the supply uncertainty would be an escalation process between senior managers of ABCD and senior managers of the rail carrier.

- Process Uncertainty: Incorrect product labeling could be performed at the Dallas RDC leading to performance penalties from retail customers per the terms of contractually obligated service levels. The uncertainty in process execution could affect the rate in which customer orders arrived at the Dallas RDC in that replacement orders would have to be expedited. The performance penalties and expediting of orders could lead to decreased customer responsiveness. The primary risk mitigation tactic to deal with the process uncertainty would be the establishment of detailed operating procedures for product labeling along with management audits to ensure the procedures were being followed.

- Control Uncertainty: Inventory replenishments could be planned solely based upon mill operating efficiencies and not actual customer demand for product serviced through the Dallas RDC. The uncertainty in setting production planning could affect the rate in which replenishment orders arrive at the Dallas RDC and lead to higher quantities of on-hand inventory. Hence, the efficiency of the Dallas RDC could be reduced in that greater inventory holding costs could be incurred. The primary risk mitigation tactic to deal with the control uncertainty would be the use of an Access database inventory system to balance inventory needs of the Dallas RDC (inventory pulled from the primary mill) with efficiency needs for the primary mill (inventory pushed to the Dallas RDC). This Access database is the vehicle for executing distribution requirements planning (DRP).

- Demand Uncertainty: Future order levels for a significant customer could be unpredictable due to the customer's tenuous financial condition. The uncertainty in demand levels could affect the rate in which customer orders arrive at the Dallas RDC and expose ABCD to the potential write-off of customer-specific inventory being maintained. In addition, ABCD could begin working down inventory levels for this customer to limit their exposure thus jeopardizing customer responsiveness if a stock-out were to occur. The primary risk mitigation tactic to deal with the demand uncertainty would be written contracts guaranteeing payment for minimal inventory levels and special reports to monitor that inventory levels did not grow in excess of these levels.

The next step in System Dynamics modeling is to build a computer simulation model of the system at the root cause of the problem (step 3). Figure 18 outlines the base model for the Dallas RDC. In this model, material is pushed from the mills based upon an order rate and is placed into inventory at the Dallas RDC. Material is subsequently pulled from inventory based upon an order rate and is placed into the possession of the customer.

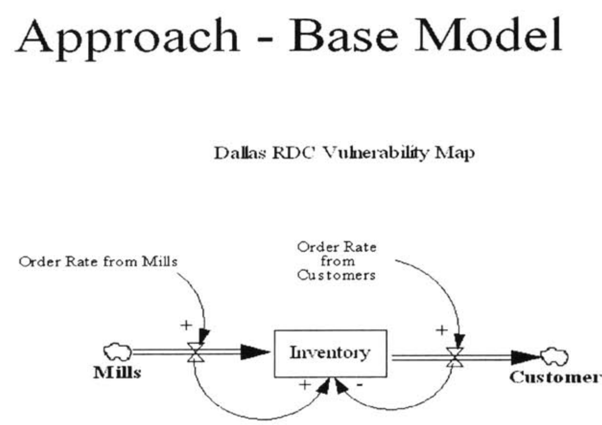

Figure 18. System Dynamics base model for the Dallas RDC.

A more detailed explanation of Figure 18 is as follows with definitions adapted from Sterman (2000):

- Source: The primary mill (source) is represented by a cloud and shows the flow of inventory (stock) originating outside the boundary of the Dallas RDC.

- Flow: The order rate from the DRP system (flow) is represented by an arrow and shows how shipments are pushed to the Dallas RDC and pulled from the primary mill resulting in increasing inventory levels (stock).

- Stock: Inventory (stock) is represented by a rectangle and shows the delay of materials flowing into and out of the Dallas RDC. The stock of inventory decouples manufacturing from order fulfillment.

- Flow: The order rate set from the customer (flow) is represented by an arrow and shows how shipments are pulled from the Dallas RDC resulting in decreasing inventory levels (stock).

- Sink: The customer (source) is represented by a cloud and shows the flow of inventory (stock) leaving the boundary of the Dallas RDC.

The System Dynamics model must be further refined to build a model of the process, supply, demand and control uncertainties identified with operating the Dallas RDC. Figure 19 illustrates the enhanced model for the Dallas RDC showing the control uncertainty associated with inventory replenishments. In this enhanced model, a high order rate from the mill is reinforced by the primary mill's need to gain production efficiency (push inventory to the Dallas RDC). Counterbalancing a high order rate from the mill is the order scheduling process from the DRP system whereby customer responsiveness is sought with the lowest inventory levels possible (pull inventory from the primary mill).

Approach – Enhanced Model

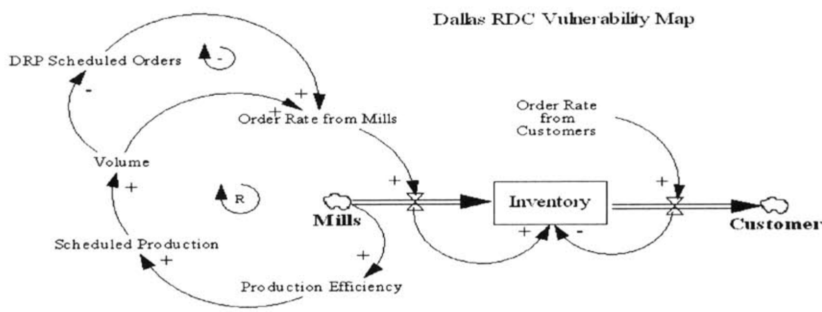

Figure 19. System Dynamics enhanced model for the Dallas RDC.

A more detailed explanation of Figure 19 is as follows:

- Reinforcing Loop: The primary mill (source) pushes for greater production efficiency. As the push for greater production efficiency grows the primary mill ramps up production; as production is ramped up the volume from the primary mill rises; as the volume from the primary mill rises the order rate from the primary mill (flow) increases; and as the order rate from the primary mill increases inventory levels (stock) build. Since each of these causes and effects moves in the same direction, the dynamics of this causal loop is reinforcing.

- Counterbalancing Loop: The DRP system tries to pull production from the primary mill to match supply with customer demand. As the DRP system pulls production from the primary mill, production volume is matched against the DRP system so that as volume levels rise the scheduled order release quantity from the DRP system goes down; as the scheduled order quantity release goes down the order rate from the primary mill (flow) decreases; and as the order rate from the primary mill decreases inventory levels (stock) depletes. Since each of these causes and effects does not move in the same direction the dynamics of this causal loop is counterbalancing to the reinforcing loop described above.

The power of System Dynamics is to design effective policies. In terms of the DRP system identified as a counterbalancing loop to the primary mill's push for greater production, the inventory policy driving the DRP must be assessed and modeled. Since the DRP system is the primary risk mitigation tactic to oversupply, the structure and dynamics of this complex system must be fully understood. Figure 20 diagrams an inventory policy which could drive the scheduling of inventory replacement for the Dallas RDC. This model is for an adaptive base-stock policy for a single-item inventory system where the demand process is non-stationary (Graves, 1999). In this detailed model of a single-item inventory policy with non-stationary demand, the impacts of ordering, receiving and customer demand upon inventory levels are looked at. In addition, the related aspects of forecasting, replenishment lead-time and customer demand and demand disturbance are also outlined.

Approach – Detailed Model

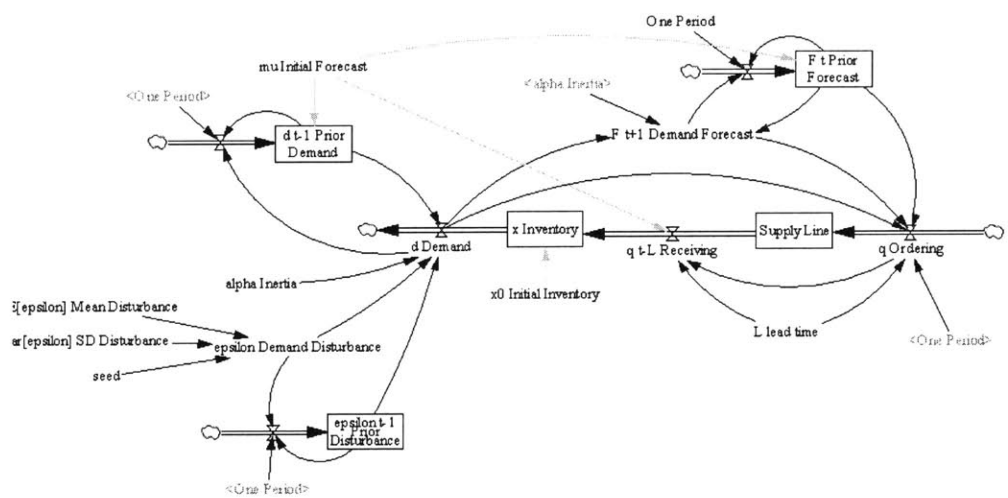

Figure 20. System Dynamics model for a single-item inventory policy with non-stationary demand (Fiddaman, 1999).

A more detailed explanation of Figure 20 is as follows:

- Source: Inventory originates from the primary mill (not titled on the detailed model but represented on the far right).

- Flow: Inventory is pulled from the primary mill to the Dallas RDC based upon the ordering pattern as dictated by the DRP system.

- Stock: Pipeline inventory is created in the supply line as inventory moves from the primary mill to the rail carrier.

- Flow: Inventory is transferred from the supply line to the Dallas RDC based upon the receiving function.

- Stock: Inventory is placed into stock at the Dallas RDC.

- Flow: Inventory is drawn down from the Dallas RDC based upon the demand pattern from customers.

- Sink: Inventory is placed in the possession of the customer (not titled on the detailed model but represented on the far left).

- Causal Loop (epsilon t-1 Prior Disturbance): Demand disturbance for period t-1 represented by mean disturbance and standard deviation of disturbance is modeled to demonstrate the calculation of the demand pattern from customers (flow). Period t-1 represents the prior period and is calculated by taking the current period (t) and subtracting one period (-1).

- Causal Loop (dt-1 Prior Demand): Demand for period dt-1 is modeled to demonstrate the calculation of the demand pattern from customers (flow). Period dt-1 represents the prior period and is calculated by taking the current period (dt) and subtracting one period (-1).

- Causal Loop (Ft Prior Forecast): Forecast for period Ft is modeled to show impact on demand forecast for period Ft+1 derived from the demand pattern from customers (flow) for use to predict the future order ordering pattern for the DRP system (flow). Period Ft+1 represents the next period and is calculated by taking the current period (Ft) and adding one period (+1).

- Causal Loop (L lead time): Replenishment lead time is modeled to show transportation delay from primary mill to receiving function (flow) to calculate impact on pipeline inventory (stock).

The fourth step in System Dynamics is to test the model to be certain that it reproduces the behavior seen in the real world (step 4). A detailed model of single-item inventory policy with non-stationary demand allows a computer simulation to be run to test whether the information being used by the DRP system is accurate and to test whether the inventory policy is being followed within the supply chain. Running the detailed model also tests the validity of the model itself. The last step in System Dynamics is to devise and test in the model the alternative policies that alleviate the problem, and implement a solution (step 5). This allows for calculating the impact on inventory levels of forecasting improvements, lead time reductions, etc. In addition, the failure modes that must be assessed using Failure Mode and Criticality Analysis can be identified. The rationale for steps four and five is as follows:

- Historical Information for Use in Step 4: Past data can be input for initial inventory levels, demand disturbance, prior period actual demand, prior period forecast, current forecast and supply line lead time delay. The expected inventory levels can then be calculated by the model and compared to inventory levels actually experienced at the Dallas RDC. If there is a material discrepancy between the results as calculated by the System Dynamics model and actual experience, the difference can be investigated. These differences could result from inaccurate data used to generate model results (hence inaccurate data being utilized to drive the DRP system) or inventory practices being carried out in conflict with the risk mitigation tactic to control physical activities over finished goods. In addition, the model itself could be faulty. The magnitude of differences can help determine failure modes that must be assessed using Failure Mode Event and Criticality Analysis.

- Predications for Use in Step 5: Future expectations can be input for initial inventory levels, demand disturbance, prior period actual demand, prior period forecast, current forecast and supply line lead time delay. The predicted inventory levels can be calculated by the model to see what the resulting quantities would look like. Each input variable can then be varied to see how the magnitude of change impacts subsequent inventory levels. The magnitude of resulting effects on inventory levels can help determine failure modes that must be assessed using Failure Mode and Criticality Analysis.

During System Dynamics modeling, control uncertainty related to inventory replenishments was identified. This uncertainty dealt with ensuring inventory replenishments were planned based upon customer demand for product serviced through the Dallas RDC (pull system) versus being planned based solely upon primary mill operating efficiencies (push system). The primary risk mitigation tactic for this supply chain risk was the use of an Access database where distribution requirements planning was coordinated. This DRP system was subsequently modeled to show how this system counterbalances the primary mill's desire for greater production volumes. The System Dynamics model was further refined in order to detail the inventory policy which could drive the scheduling of inventory replacement within the DRP system, a single-item inventory policy with non-stationary demand. From there, the inventory policy can be broken down into pieces to define each possible failure mode that could lead to high inventory levels (reduced efficiency) or stock-outs (reduced responsiveness). This is illustrated in the section that follows.

Failure Mode Event and Criticality Analysis

After the causes of supply chain risk have been understood and modeled using System Dynamics, the risks can be further defined using Failure Mode Event and Criticality Analysis (FMECA). This analysis allows for the ranking of risks associated with failure modes in order to prioritize corrective actions. This is the essence of risk-based auditing where the focus is upon the way an organization perceives and manages supply chain risk. In the case of a single-item inventory policy with non-stationary demand, the actions could be geared toward improving the forecasting process in order to lower subsequent inventory levels while still maintaining promised levels of service. Figure 21 demonstrates a possible FMECA analysis for the potential failure mode of not capturing softening market conditions thereby resulting in excess inventory levels. The data is for illustrative purposes only and was not derived as a result of the pilot.

Item: Dallas RDC - DRP
Start Date: 21-Apr-05
Key Date: 28-Apr-05

Failure Mode Effect and Criticality Analysis
Process FMECA

FMEA Team: Team Leader: Joe Smith, FMEA Support:John Hancock

Process Function / Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s) / Mechanism(s) of Failure		Current Process Controls		R. P. N.
DRP (single-item inventory with non-stationary demand)	F t+1 Demand Forecast Shows Unacceptable Bias	Forecast Not Capturing Softening Market Resulting In Excess Inventory of	8		Continuous Forecast Improvement Not Demonstrated	9	Forecast Accuracy is Monitored and Reported Monthly	6	432

Figure 21. FMECA example for forecast bias within a single-item inventory policy with non-stationary demand before corrective actions.

Figure 21 shows a calculation of 432 for the risk priority number (RPN) associated with not capturing softening market conditions within the demand forecast. The RPN is derived from multiplying the impact an effect will have on the inventory levels (severity) by the perceived likelihood of a failure happening during the forecasting process (occurrence) by the perceived likelihood that the current process controls will detect a failure's cause or a failure mode before impacting inventory levels (detection). Each factor for severity, occurrence and detection are rated on a scale of 1-10. Recommended FMECA ranking definitions were used for the pilot but should be customized by the internal audit team in actual practice. The customized definitions should be used consistently across the enterprise. Ratings are arbitrary based upon the judgment of the team but are still beneficial in ranking supply chain risks in order to prioritize where efforts should be focused. The formula is: RPN = (S) Severity x (O) Occurrence x (D) Detection. For the failure mode shown in Figure 21 the formula is: 432 = 8 X 9 X 6. Figure 21 is laid out as follows with definitions adapted from Dailey (2004):

- <u>Step 1 Identify Functions:</u> The process function / requirement is the intended purpose of what is being analyzed. For this FMECA, the review is on the DRP system utilizing a single-item inventory policy with non-stationary demand.

- <u>Step 2 Identify Failure Modes:</u> The potential failure mode is the manner in which process failure manifests itself. The failure mode becomes evident when the F t+1 demand forecast shows unacceptable bias by reaching a tracking signal which goes beyond the tracking signal limit. The tracking signal is a measure of forecast bias calculated by dividing the mean absolute deviation for the forecast into the running sum of forecast error.

- <u>Step 3 Identify Effects of the Failure Mode:</u> The potential effect of failure represents the adverse consequence of the failure mode. In the case of forecast bias, the consequence is the forecast not capturing softening market conditions thus resulting in excess inventory. The System Dynamics model can determine the potential effect mathematically by running a simulation incorporating the amount of forecast bias.

- Step 4 Determine Severity: The severity denotes the impact the failure mode will have on predetermined criteria within a rating of 1 – 10 (10 being most severe). The criteria in this case are optimal inventory levels. The rating of 8 equates to a very high rating representing a major disruption to inventory levels.

- Classification: Categorizations are applied to specific severity-occurrence-detection combinations depending upon the preferred classification system set up by the FMECA team leader. This feature was not utilized during the pilot and therefore is not explored further.

- Steps 5 & 6 Apply Procedures for Potential Consequences and Identify Possible Causes: Cause is the reason the process elements results in a failure mode. The base reason for this FMECA is that continuous forecast improvement has not been practiced.

- Step 7 Determine Occurrence: The occurrence is the perceived likelihood of a failure happening during the intended process within a rating of 1 – 10 (10 being occurring most often). The rating of 9 denotes one failure rate every three forecasts. Hence, the tracking signal limit will be reached within three forecasting periods. This is a standard rating using the recommended FMECA ranking definitions.

- Step 8 Calculate Criticality: The criticality emphasizes the failure mode's effect in terms of only severity and occurrence; excludes detection. The formula is: Criticality = (S) Severity x (O) Occurrence. For the failure mode shown in Figure 21 the formula is: 72 = 8 X 9. This is a standard calculation using the recommended FMECA approach.

- Step 9 Identify Design of Controls: A control is any mechanism that prevents a failure from occurring, or detects the failure cause for failure mode and precludes it from reaching the predetermined criteria. The criteria in this case is optimal inventory levels. The current process control is forecast accuracy being monitored and reported monthly. Since forecast accuracy does not indicate forecast bias this control is deemed to be weak.

- Step 10 Determine Detection: Detection is the identification and remediation of a failure cause or its consequent failure mode prior to its impact on the predetermined criteria within a rating of 1 – 10 (10 being least likely to detect). The criteria in this case is optimal inventory levels. The rating of 6 denotes there is a low likelihood the current design of controls will detect a potential cause of failure or subsequent failure mode. This is a standard rating using the recommended FMECA ranking definitions.

- Step 11 Perform Final Risk Analysis: The risk analysis is the mathematical product of the numerical severity, occurrence and detection resulting in a risk priority number. The RPN in this example is 432. This number represents a high level of risk. A high level of risk is reached with a RPN 90 or above, a medium level of risk is reached with a RPN of 60 through 89 and a low level of risk is obtained with a RPN of 59 or below. This is a standard rating using the recommended FMECA ranking definitions.

FMECA goes beyond providing an analysis of the current situation--it should result in improved controls. The improvement arises from recommending actions that will strengthen process controls in the areas of severity, occurrence and detection rankings. Figure 22 provides an example of this improvement. The data is for illustrative purposes only and was not derived as a result of the pilot.

Failure Mode Effect and Criticality Analysis
Corrective Actions

Recommended Actions	Responsibility & Target Completion Date	Action Results				
		Actions Taken	Sev			R. P. N.
Implement Collaborative Forecasting Wtih Companies X, Y and Z	Bob Jones; 19-May-05	Store Inventory Items with High Variability and Low Order Quantities at Primary Mill Change Forecasting Technique to Time Series with Seasonal and Trended Data	6	5	2	60

Figure 22. FMECA example for forecast bias within a single-item inventory with non-stationary demand after corrective actions.

Step 12 of the FMECA process is to take actions to reduce risk. Figure 22 is discussed as follows to demonstrate this step with definitions adapted from Dailey (2004):

- <u>Recommended Action:</u> The recommended action to strengthen process controls is to implement collaborative forecasting with companies X, Y and Z. The collaborative forecasting process would include provisions for monitoring forecast bias and adjusting the forecasting technique, as necessary, before the tracking signal limit is reached. Recommended actions are initiatives that have not yet been implemented.

- Responsibility & Target Completion Date: Responsibility is assigned to the appropriate team member and sets an expected finish date. For this example, implementing collaborative forecasting with companies X, Y and Z is targeted to be complete by May 19th and is being spearheaded by Bob Jones. Please note that company names, completion date and person responsible are fictitious and used for illustrative purposes only.

- Actions Taken: The actions represent steps that have already been implemented to strengthen process controls. These include storing inventory items with high variability and low order quantities at the primary mill in order to take advantage of risk pooling and thus lowering inventory levels. The forecasting technique has been changed to a time series method with seasonal and trended data to lower forecast bias.

- Ratings: Numerical assignments are given to the severity, occurrence and detection levels taking into account the recommended actions and actions already taken. For this example the new ratings are 6, 5 and 2 respectively. These new ratings result in an RPN of 60. The new RPN moves the level of risk from high to medium thus lowering the overall supply chain risk associated with the DRP system utilizing a single-item inventory policy with non-stationary demand.

The FMECA process defined the risk associated with a DRP system that was identified during the System Dynamics modeling. However, the FMECA process broke the risk down into specific failure modes, risk ratings and actions. Clearly the most important aspect of FMECA was the ability to strengthen controls by recommending actions that could reduce the overall risk levels. As a result, a high risk area was transformed into a medium risk area. This significantly improved the likelihood that optimal inventory levels would be maintained.

Summary

System Dynamics and Failure Mode Event and Criticality Analysis allows for the prioritized ranking of potential failure modes. Ordering possible failure points from highest to lowest focuses attention on those items most likely to cause disruption in the supply chain. By facilitating action on high risk items, the internal audit team can coordinate the improvement of process controls not only to achieve detection of supply chain disruption but to substantially improve the prevention of disruption. Preventing problems before they occur is the heart of vulnerability mapping to help ensure the end-to-end flow of goods and services in the supply chain at the promised service level to the customer at known cost.

6 Thesis Summary

Internal auditors are well placed to help companies manage supply chain risks. No longer focused merely on providing a check over accounting transactions, the internal auditor now applies risk-based auditing techniques to management activities that span the enterprise. Indeed, auditors now actively set measures that mitigate risk across the entire company. This enterprise-wide view primes internal auditing to help focus resources on those supply chain activities most critical to driving corporate strategy forward. The need for better risk analysis is driven by the increasingly sophisticated advanced planning and scheduling applications companies are using to optimize their supply chain network, and by the streamlining of operations whereby inefficiencies are eliminated such as excess inventory and redundant manufacturing capacity. There is now less room for error throughout the supply chain.

A company needs a mechanism for maintaining a balance between the financial benefits of centralizing supply chain activities and the accompanying increased risk of both the frequency and magnitude of disruptions. The suggested mechanism is to adapt the internal audit department to the task. How the internal audit team is organized and positioned within the company is the lynchpin to their ability to provide value. A model with four distinct process-focused, audit teams, one each to cover planning, sourcing, manufacturing, and delivery may be the answer. Each of the process teams audits a single process wherever it resides within the enterprise and reviews how work flows through the entire supply chain. For example, the strategic sourcing team would look at the activities from selecting vendors and placing orders all the way through paying the vendor's invoice. This contrasts to the traditional approach of assigning internal audit teams to individual business units. The recommended approach limits the chance for error throughout the supply chain whereas the traditional approach does not.

Organizing internal audit teams around end-to-end supply chain processes as opposed to either business units or specific functions promises to bring a high degree of consistency to the supply chain network without adding additional costs. First, it avoids the problem of multiple teams auditing the same process in different parts of the organization using different approaches. Second, managers are much better positioned to help the organization avoid and respond to supply chain disruptions. But how can the internal auditing department be brought into the supply chain fold? Clearly, the team has to have a deep understanding of supply chain design, planning and operations. Since conventional audit teams tend to be staffed by finance and IT personnel, specialists have to be recruited either through new hiring or redeployment and retraining of existing employees. The latter option provides individuals who are knowledgeable about the business and have established working relationships. On the downside, retrained people may not be experienced supply chain professionals, and since they are already embedded in the organization may be less likely to challenge the status quo. Thus, companies would be wise to consider a combination of both approaches, building teams that possess a balance of company and supply chain experience.

There are five critical tasks that companies need to perform when developing a supply chain auditing capability. These tasks include coordination to ensure that touch points within the supply chain are accounted for within the internal audit department's risk mitigation strategy and organizational design to build teams with backgrounds in finance, operations, information technology and data analysis. These tasks also include the use of metrics to establish appropriate supply chain indices for use in vulnerability mapping and for determining supply chain risk levels. Finally, they encompass audit processes necessary to implement a strategy to mitigate supply chain risk effectively and efficiently and reviews to facilitate supply chain peer evaluations within the organization's business units.

Any corporate initiative that requires resources but does not demonstrate a clear return-on-investment is difficult to justify and supply chain risk mitigation falls into this category. Managers win plaudits for cutting costs and increasing revenues, but are not usually applauded for mitigating risk and preventing a failure before it happens. But the large-scale day-to-day risks within a company are often seated in the way the supply chain is executed. This strategic issue must be confronted to ensure the economic well-being of the organization. There are numerous examples of the high price companies pay for not anticipating supply chain dislocations, or not having the ability to recover quickly from operational interruptions. Instituting a risk management program encompassing the five critical tasks greatly reduces the chance of supply chain disruptions occurring.

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