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A Framework for Reducing the Impact of Disruptions to the Supply Chain: Observations from Multiple Executives

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Introduction

Recently, the topics of enterprise risk management (ERM) and business continuity planning (BCP) are often at the top of many corporate agendas. In the past, many of the discussions on risk management focused on financial reporting and Sarbanes-Oxley, but the recent spate of disasters in 2005 such as Hurricane Katrina and rampant commodity prices have increased executive focus on supply chain risk. The *supply chain* encompasses all organizations and activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as the associated information flows (Handfield and Nichols, 2002). *Supply chain risk management* (SCRM) is the integration and management of organizations within a supply chain to minimize risk and reduce the likelihood of disruptions through cooperative organizational relationships, effective business processes, and high levels of information sharing.

The impact of supply chain disruptions, while difficult to quantify, can be costly. A recent study by Hendricks and Singhal (2003) investigated stock market reactions when firms publicly announced that they were experiencing supply chain glitches or disruptions that were causing production or shipping delays. Results of the study of 519 supply chain problem announcements showed that stock market reactions decrease shareholder value by 10.28 percent. In a follow-up to their previous study, Hendricks and Singhal (2005) studied the effect of 827 publicly announced disruptions on the long run stock price (one year before the disruption and two years after) and found a mean abnormal return of nearly −40 percent, along with significant increases in equity risk. Their results also showed that the majority of supply chain disruptions involved parts shortages, lack of response to customer-requested changes, production problems, ramp-up problems, and quality problems.

Many recent events illustrate this phenomenon. For example, Boeing experienced supplier delivery failure of two critical parts, with an estimated loss to the company of $2.6 billion (Radjou, 2002). In 2002, less than 100 workers in the longshoreman union strike disrupted West Coast port operations. As a result, it took six month for some containers to be delivered and schedules to return to normal (Cavinato, 2004). Finally, the impact of Hurricane Katrina resulted in billions of dollars of lost revenue to major retailers such as British Petroleum, Shell, Conoco Phillips, and Lyondell, as well as causing gasoline shortages in many parts of the United States and resulting in lost economic activity. Given this and other events, it is not surprising that supply chain disruptions have caught the attention of executives.

In a recent survey at Global 1000 companies, supply chain disruptions were perceived as the single biggest threat to their companies' revenue streams (Green, 2004). Although senior executives now recognize that supply chain disruptions can be devastating to an enterprise's bottom line, strategies to mitigate supply chain disruptions are typically not well-developed or even initiated. A concerning statistic is that only between 5 percent and 25 percent

of Fortune 500 companies are estimated to be prepared to handle a major supply chain crisis or disruption (Mitroff and Alpaslan, 2003).

One factor that is increasing the risk exposure of a supply chain disruption is the increasing propensity of companies to outsource processes to global suppliers. The complexity associated with multiple hand-offs in global supply chains increases the probability of disruptions. As the number of "hand-offs" required to ship products through multiple carriers, multiple ports, and multiple government checks points increases, so does the probability of poor communication, human error, and missed shipments. One executive we interviewed from a major electronics company noted: "We have successfully outsourced production of our products to China. Unfortunately, we now recognize that we do not have the processes in place to manage risk associated with this supply chain effectively!" In this environment, questions arise such as: What steps can an organization take to design their supply chains to ensure uninterrupted material availability? Is it possible to respond in an agile manner to customer requirements in a global sourcing environment?

This chapter addresses the dichotomous challenge faced by executives who are challenged with seeking to boost their profit margins through outsourcing to global suppliers, all the while minimizing the risk associated with these newly formed supply networks. This problem can be summarized as a research question:

> What actions can managers take to reduce the impact and frequency of supply chain disruptions while also reducing product cost through a global sourcing strategy?

We addressed this research question through a series of focused interviews with senior executives involved in managing supply chain risk. We describe this methodology and then develop a framework for managing risk. This framework is summarized as a high-level process that executives can employ to identify and reduce supply chain risk. We conclude with some key managerial principles for designing supply chains that have inherently lower probabilities of disruption within the global outsourcing environment.

Methodology

To benchmark risk planning and mitigation practices, we conducted a series of focused interviews and captured various insights in the area of global supply chain disruptions. We interviewed executives from a pharmaceutical company, two medical device manufacturers, a semiconductor manufacturer, two international logistics providers, three global retailers, a computer manufacturer, a semiconductor manufacturer, and a military contractor. We also interviewed a number of Chinese executives working in supply chain positions for Fortune 500 companies during four visits to Shanghai in 2005. Executives interviewed had various job titles such as Chief Operating Officer,

Chief Logistics Officer, Vice President of International Supply Chain, and Senior Manager of Import Operations, as well as managerial positions such as Director of Global Supply Chain, Category Manager, and Import/Export Director. We also performed an in-depth study of an automotive supply chain, which included interactions with various executives at the OEM, first-tier suppliers, and a key point of distribution. The common theme among these executives' responsibilities was they managed product flow either originating from or destined to overseas locations. We primarily sought insights into disruptions that impact material availability (quantity, quality, timeliness) in global sourcing networks. The resulting risk management process is contained in the following section. During the entire study, we adhered to the guidelines and protocols described in Yin (1994) and Eisenhardt (1989), and followed qualitative data analysis procedures (Miles and Huberman, 1994).

Supply Chain Risk Management Process

In interviewing the executives, we identified several common themes based on the manner in which these executives established risk measurement systems and managed ongoing sources of supply chain risk. As we proceeded through the interviews, we compared similarities, differences, and common themes. A pattern of emerging behavior was observed, which is captured in the risk management model shown in Figure 2.1. The high-level set of processes associated with management of risk begins by mapping the supply chain measuring the risk of critical nodes, identifying appropriate risk-reduction mechanisms for the critical high-risk nodes, and deploying specific actions to mitigate the risk at these nodes. The latter set of actions

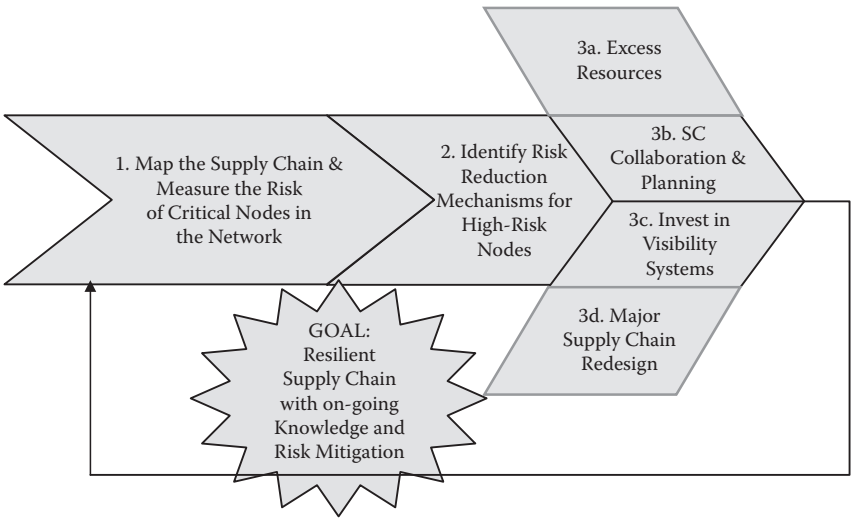

Figure 2.1 Supply chain risk management framework.

may include applying excess resources, deploying collaborative processes with key supply chain partners, initiating inventory visibility systems, or redesigning the supply chain.

Mapping the Supply Chain Measuring the Risk of Critical Nodes in the Network

Supply chains are complex and dynamic networks comprised of supply chain components or nodes. To identify the vulnerabilities in a supply chain network, some form of filter must be applied to "screen" the different potential points that are most likely to experience a critical risk incident. Typically, risk is characterized by both the probability of an event and its severity given that an event occurs. Risks or disruptions in the supply chain are not only increasing in frequency, but also the severity of their impact can be costly and potentially bring portions of the supply chain to a complete halt. First, the supply chain nodes must be mapped at a high level to understand the supply chain design and material flow. Next, measuring supply chain risk is a function of measuring the probability of a disruption at nodes where there is significant risk, as well as estimating the severity of the impact on the entire network based on a disruption at a single node. A summary set of equations defining the drivers of supply chain risk is shown in Figure 2.2.

To begin with, we propose that supply chain risk is a function of sum or probabilities of disruptions at critical nodes in the network, multiplied by the revenue impact of a disruption in revenue dollars on the end customer. These elements can be broken down further into a set of functions that define these distributions.

As shown in Figure 2.2, we measure supply chain risk as a function of the probability of disruption multiplied by its revenue impact. The probability

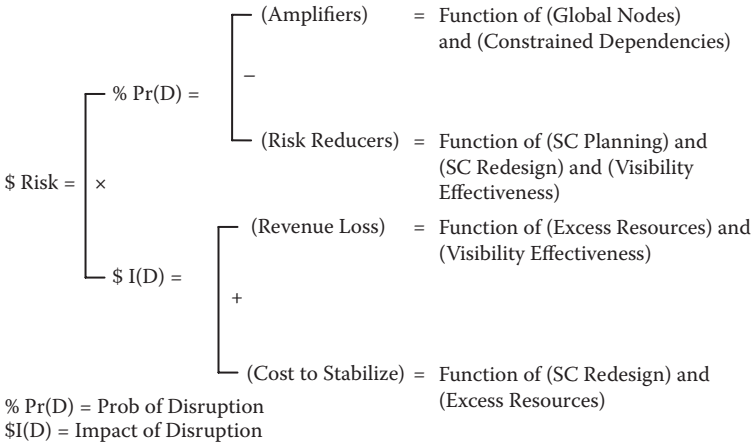

Figure 2.2 Quantifying supply chain risk.

of an event is a function of the breadth of the supply chain, in terms of the number of global nodes involved as well as the number of constrained dependencies. As the number of leverage points and the lead-time associated with ordering and receiving products from multiple global sources increases, the difficulty of detection and early recovery amplifies the probability of a disruptive event. As the number of constraints (e.g., bottlenecks) in the supply chain from supplier to end customer increases, the difficulty of disruption detection and recovery increases. However, the probability of an event occurring may be reduced by effective supply chain planning and collaboration, quick response for supply chain redesign, and information visibility effectiveness. The relative impact of a disruption at a single node is a function of the extent to which the organization has taken preventive measures to reduce the risk through applying excess resources, or the investment in visibility or event management systems that alert the company to a disruption. One of the key principles that we emphasize in this perspective is the fact that quick response to a disruption can significantly reduce the impact of the disruption. Finally, we propose that in situations where a risk is unknown or the impact so great that it cannot be reduced, that the organization consider a significant redesign of its supply chain to start afresh and create a new and robust method of delivering value to the end customer.

A disruption is defined as a major breakdown in production or distribution nodes that impacts other nodes in the supply chain. Disruptions typically create a bottleneck at one of these nodes that can, in effect, shut down the entire supply chain network. Even small events such as a fire, a machine breakdown, a production quality problem, or a customs delay can cause a major disruption, as well as natural disasters or catastrophic events such as Hurricane Katrina or 9/11. While disruptions are difficult to predict, they can be planned for and they can be estimated. For example, a major automotive company was able to develop a Poisson distribution of the probability of a fire occurring at any major plant. Once established, the plants that had a significantly higher number of fires than the distribution average became candidates for further investigation. To manage the set of disruptions and the entire risk of the network, it is therefore important to begin by not only understanding the probability and impact of supply chain disruptions, but also to map all the nodes of the supply chain, identifying high-risk nodes, measuring the risk at these nodes to better understand disruption impact and nodal relationships (how the supply chain nodes are interconnected).

Creating a supply chain risk map with estimates of disruption probabilities and associated revenue impact estimates is difficult, but not impossible, to develop. Moreover, we found that when a group of executives presented with a nodal structure and an associated set of risk estimates based on solid market intelligence relayed by subject matter experts, a realistic set of estimated probabilities and "war-gaming" scenarios can be derived. By multiplying the probability and revenue impacted at the major nodes in a supply chain, a baseline risk metric can highlight the potential disruptive

nodes in the network. Even if conducted on an annual basis, such an exercise can serve as an initial screening mechanism to identify nodes that require the greatest managerial attention to avoid a major disruption.

One outcome of these exercises is that executives quickly realize the scope and scale of the problem. In a global sourcing network, the number of nodes increases, which by definition increases the risk of the network as a whole. Thus, a good first step to "limit" the scope of the search for risky supply chain nodes is to begin by identifying global supply chain nodes that are at the highest risk for disruptions. In our interviews we discovered that certain attributes of a company's global supply chain are often good candidates for early warning detection. We asked executives to describe the types of disruptions experienced in the past five years perceived as the most serious. After recording their responses, we coded and classified the interview notes and found that all of their responses fell into one of two categories shown in Tables 2.1 and 2.2. We describe such elements as "amplifiers", defined as a characteristic of a supply chain that increases the *probability of a disruptive event*. All the disruption amplifiers fell into one of two categories: (1) the

Table 2.1 Global Sourcing Amplifiers of Disruption

The probability of supply chain disruptions is increased when any of the following parameters increases in a given supply chain:
Instability of supplier's environment
Number of brokers
Length of lead-time
Concentration or clustering of suppliers
Scarcity of qualified labor
Instability of workforce
Degree of customs regulations
Level of specialization of storage requirements
Level of security requirements
Level of demand for product (volume and variability)
Level of legislative actions related to importing/exporting
Poor communication
Level of regional/country political instability
Number of transfer points
Lack of vessel capacity and channel overload
Strain on port infrastructure
Potential for terrorism
Level of natural disasters
Lack of visibility of entire system/supply chain

Table 2.2 Constrained Dependencies

The probability of supply chain disruptions is increased when any of the following parameters increases in a given supply chain:
Use of proprietary technology
Limitations on the number of sources
Level of stringent quality requirements
Lack of supplier manufacturing capacity and flexibility
Level of uniqueness of sourced parts

extent to which a firm relies on global sources of supply, or (2) the number of constrained dependencies.

Global Sourcing

The growth in low-cost-country sourcing from places such as China, India, Eastern Europe, and Malaysia is skyrocketing. Companies such as General Motors, General Electric, Goldman Sachs, Home Depot, and even Avon have Chinese expansion plans and global sourcing plans at the top of their to-do lists. Although the decision to source globally is often based on the anticipation of lower costs, these decisions often overlook the potential amplification of risk that occurs when these global sourcing channels are developed. Major risk nodes include supplier plants, inbound transportation, customs regulation, port operations, or numerous other handoffs that are potential catalysts for a "domino" effect to occur. As the number of such nodes increases, generally so does the probability of a disruptive event. Some of the other amplifiers associated with global sourcing are shown in Table 2.1. Language and time zone differences, for example, delay responses, as opposed to working with a supplier who is local and speaks the same language. Another problem is that as the length of the lead-time required to obtain shipments from these locations for domestic imports increases, the ability to be flexible and change shipments en route is limited. (One will have a difficult time persuading a supplier to cancel an order that is on a container on a ship bound from Asia and due to arrive at the dock in a month.) Consider the following examples that highlight this element:

- A major retailer that imports the majority of its products from China was devastated by the West Coast port strike, which caused many of its products to be out-of-stock during the critical Christmas season. Although the exact number of lost sales is unknown, estimates are that millions of dollars were lost due to "out of stocks" when customers could not find the items they wanted and went elsewhere to purchase them. Further, the cost of recovering containers and shipments that were "lost" in the melee ran into millions of dollars. Los Angeles port operations, in this case, was the major risk node, and the port became

the primary focus of managerial attention for reducing the probability of future disruptions.

- A retailer stated that the most severe types of supply chain disruptions occurred in overseas locations due to poor communication and customs procedures at major shipping ports. He also noted, however, that planning around these disruptions was possible, as some of them were predictable. For example, European labor strikes in shipping and transportation seem to occur almost every year in the summer between Wednesday and Friday — so that workers get an extended holiday weekend. These transportation hubs were deemed "seasonal" risk nodes for this reason and became the focal node for managerial attention.

Constrained Dependencies:

The constrained dependencies element (shown in Figure 2.2) is similar to the number of global sourcing nodes, but also is often related to other elements. As shown in Table 2.2, several factors drive the number of constrained dependencies. When a proprietary product is sourced from a single supplier, and that supplier experiences problems, the disruption is likely amplified. Other elements associated with constraints include stringent mandated or regulated quality requirements and unique parts that are difficult to manufacture and re-source. Such factors tend to increase the number of sourcing alternatives that exist in complex supply chains, which limits the degree of freedom around the possibilities of recovery. As constrained dependencies increase, so does the magnitude of the "domino effect" as the disruption ripples through multiple nodes of the supply chain. On the other hand, as companies create alternative sources for their parts and components, a problem at one node can facilitate recovery as a "back-up plan" has already been designed into the network. Consider the following examples.

- A major logistics provider noted that a product's complexity, quality requirements, number of unique parts, product perishability and storage requirements (for example, does heat affect the product), and part size (small gets lost) increases the difficulty of managing problems when and if they occur. In this case, a filter for determining risk nodes involved all operations associated with a small number of products with limited sourcing alternatives.
- A large manufacturer of appliances had developed a new convection oven that caught customers' fancy and began selling quickly. Distributors were unable to order more in time, although they knew a competitor would soon enter the market with a similar product. The reason for this shortage was a supplier in China that was plating the *oven grill*! The supplier had been outsourced from their first-tier supplier, and it had taken the manufacturer several weeks to discover the source of the capacity shortage. When the manufacturer finally discovered the

source of the parts shortage, managers were told that the supplier was working three shifts, and was unable to produce enough grills, causing a major bottleneck. By the time a second supplier was located and qualified, the competition had established a toe-hold in the market and was already taking market share. The constrained dependency in this case was the Chinese supplier.

- A large pharmaceutical company noted that most of its disruptions were related to the complexity of design in artwork for package inserts. The company ships drugs to every country in the world, and must stay abreast of regulations in every locale. As government regulatory requirements for packaging and paper pamphlets in each country change, entire shipments must be stopped and scrapped if the artwork is not current. The artwork department in this case was the constrained dependency, as the team did not have the resources to keep up with the number of pack change demands placed on the team. All products entering the supply chain were required approval by this team.

Recent events associated with Hurricane Katrina illustrate the consequences of not filtering potential risks, as unprepared government agencies struggled to deal with an event that was not only highly probable, but which also lacked contingency plans. The vulnerabilities of the city of New Orleans were never properly estimated and measured by government officials; the exposure of refining plans in the Gulf of Mexico were also not well-identified by energy executives. If they had taken the time to investigate, government representatives and executives would have recognized that there was a 1 in 200 probability that New Orleans would be hit by a hurricane and have the levees fail.

Identify Risk Reduction Mechanisms for High Risk Nodes

Once the company has narrowed down its list of potential risk incident nodes to a manageable set, the next task is to prioritize actions to mitigate and manage these risks. The probability of disruptive events can be controlled for in some cases by remedies, but in other cases, when significant amplifiers are present, this may not be possible. Therefore, executives must seek to reduce the impact through various approaches. A variety of different risk reduction mechanisms were identified by the companies we interviewed in the research, and the full list is shown in Table 2.3. These mechanisms can be classified into several categories. To first understand these categories, consider the impact of a disruption and the approach to deal with it, as shown in Figure 2.3. Figure 2.3 illustrates the critical components of a risk planning strategy: (1) the ability to discover that a disruption has occurred, and (2) the ability to establish plans to effectively recover from the disruption. From the moment a major supply chain disruption occurs, the speed at which an organization recognizes and responds to the disruption effectively determines

Table 2.3 Risk Reduction Mechanisms

Strategically Positioned Excess Resources:

- Expediting
- Safety Stock

Supply Chain Planning and Collaboration:

- Supplier qualification/assessment tools
- C-TPAT and other customs programs
- Risk enumeration, severity analysis, and contingency planning
- Relationship management and joint planning
- Supply chain education and risk management training
- Process control (to facilitate management by exception)
- Cross-functional risk planning at partner locations
- Demand/supply forecast reviews across entire supply chain
- Weekly teleconferences or meetings on potential new risks
- Optimization of supply chain system
- Risk management command center
- Defined communication network protocols and mechanisms
- Daily status meetings
- Defined hierarchical meetings to share key performance indicators
- Defined contingency plan responsibilities with decision-making authority for critical events at all nodes
- Defined or self-executing contingency plans
- Post event analysis and lessons learned meetings
- Diversification planning to reduce constrained node options

Disruption Discovery Visibility Systems:

- Risk monitoring systems
- Inventory visibility systems
- Event management systems (managing by exception)
- Deploy RFID at strategic nodes in supply chain
- Predictive analysis modeling tools – early awareness of impending disruptions
- Command group to analyze end-to-end supply chain operations

Supply Chain Redesign:

- Network redesign
- Product or process re-design

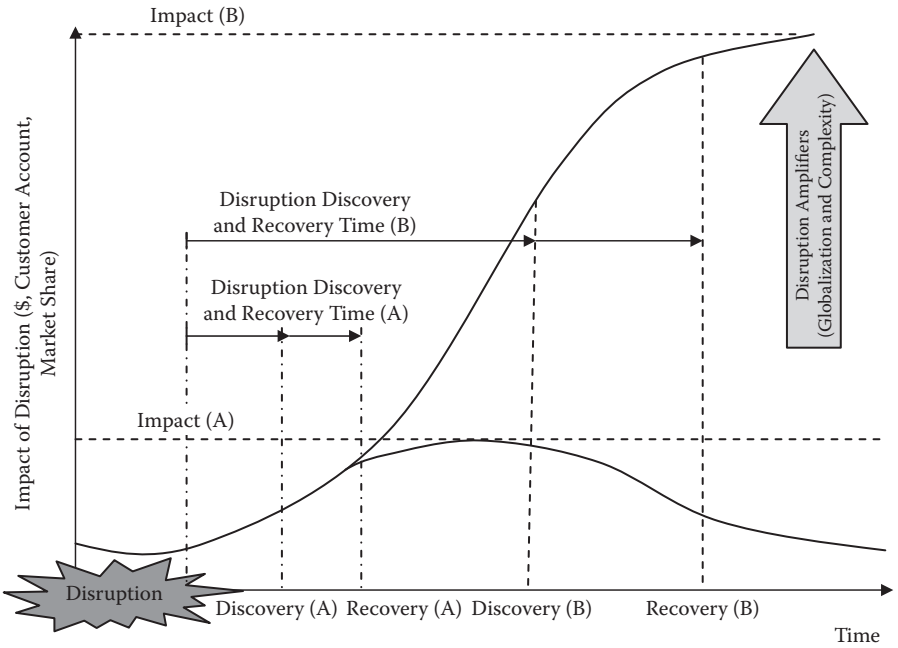

Figure 2.3 Supply chain disruption discovery and recovery.

how well the problem is contained and the resulting cost to the organization. Once the disruption occurs, the first critical action is to recognize that it has occurred and deploy a mitigation effort. Although it may sound absurd, many companies fail to recognize that a disruption has even occurred. The difference between example A and B in Figure 2.3 suggests that early recognition of a problem in the supply chain will allow the company to deploy a mitigation strategy quicker. The second critical action is the effectiveness and speed of the mitigation strategy. Organizations that have well-thought-out action plans know how to react and have put in resources to guard against the problem. The third component is the ability of an organization to create a more robust supply chain, through complexity reduction and process improvements.

Management Responses to High-Risk Nodes

Once they have identified "high-risk" nodes, executives have several risk reduction strategies they can use to eliminate the impact of disruptions on the end customer. The elements of risk reduction are as follows:

1. *Excess resources* reduce the time between disruption discovery and recovery.
2. *Supply chain planning and collaboration* ensures that the design of the supply chain is made more robust to reduce the probability of these events occurring again.

3. Improved information visibility reduces the time between the disruption and its discovery, and reduces the impact of the disruption.
4. *Supply chain redesign* involves a significant investment in product or process redesign to reduce risk.

Each of these risk reducers is next described.

Excess Resources

One of the easiest strategies to reduce risk for companies managing global supply chains is the application of excess resources to buffer the firm against any potential disruptions. This approach is most common when the magnitude of a potential disruption is high, or when the probability of a disruption is also known. This might include the following:

- Increase the bank (or buffer) of inventory held at warehouses, manufacturing locations, and distribution centers, and assess inventory buffers in domestic distribution channels at a part level, to assess contingency and scenario planning.
- Increase planned lead-times beyond actual lead-times to allow a greater buffer for response.
- Add additional personnel or shifts that will under-utilize resources but provide greater flexibility to react when a disruption occurs.
- Use two or more suppliers for a critical input into a product or service.

It is interesting to note that although inventory levels have been reducing overall in the supply chain, the correlation between higher premium freight shipments and inventory reduction is significant. Thus, companies seem to be substituting inventory (one form of excess resources) for greater use of premium freight, thus merely shifting financial resources to a different area of the supply chain. An understanding of the relative levels of premium transportation costs and other excess resources required to sustain supply chain agility and inventory levels in the face of disruptions is an important element of any risk management strategy. Interviewees also stated that current models of total landed cost do not capture the holistic cost of global sourcing due to the hidden costs of visibility, premium freight (response), buffers, port shutdowns, etc. One international logistics provider executive framed the issue by stating that "every time you do a handoff in a global supply chain, it costs money and there is a potential for a disruption."

Supply Chain Planning and Collaboration Risk Reducers

Applying excess resources and deploying visibility systems are both *reactive* strategies to risk. That is, they reduce the impact of the disruption but do not address the probability of the disruption occurring in the first place. A second approach is to attempt to *prevent* disruptions from occurring through ongoing supply chain planning and risk reduction, which reduces the probability of a

disruptive event. Prevention involves first understanding the key players in one's global sourcing channel, and establishing the need to work together to minimize the potential for disruptions. Once these relationships are established, the partners can meet in an open environment to identify the leverage points that represent risk, and work collaboratively to plan in advance for potential problems, or better yet, eliminate these risks altogether. Global procurement and logistics personnel play a key role in establishing and laying the foundation for a more robust supply chain by getting the *right players* involved early on in designing the global sourcing channel.

In the earliest stages of sourcing strategy development (involving the solicitation, negotiation with and contracting of sources of material supply), a global sourcing team should:

- Perform on-site supplier evaluations and screen suppliers that may have poor logistics planning, poor second-tier supplier management, and low process reliability, to identify high potential disruptors.
- Require each potential supplier to produce a detailed plan of disruption awareness, and identify contingency plans that can be executed if disruptions occur within the supplier's own facility or supply base.
- Establish supplier's capability to establish information sharing with customers, to provide updated information on the visibility of material flows. Ideally, this information should be shared throughout the network electronically; however, with the limitations on bandwidth in certain areas of China, manual updates may be required on a daily basis. In one case, a company discovered that its information sharing mechanism involved a worker who traveled 35 miles daily to a location where a fax machine could be used to share production updates.
- Factor in the expected costs of disruptions and problem resolution into the total cost of sourcing from a particular supplier, to elevate this parameter in the eyes of the team making the final decision.

A senior executive we interviewed at a large global computer manufacturer noted the following:

> "It takes a team of IE's, of product engineers, or supplier quality engineers, procurement and logistics people that will wrap around a supplier relationship from our company — and an equivalent number of specialists and planning people from the supplier's management team, to dive into the process. … People from the supplier (field application engineers) live in our facilities, and they are the feedback mechanisms that go back to their company to deal with supplier quality processes and failure analysis. We utilize lots of real-time Internet data systems between us and the

> supplier — collaborative and reciprocal information databases" — that share what is going on, when material gets here, quality, and yield of material that we are using. We also rely on daily, weekly, and quarterly performance reviews with the supplier."

Once a given supplier has been selected by the sourcing team, an ongoing dialogue with the supplier, as well as the transportation and warehouse providers in the channel, should be established to include:

- Employ weekly teleconferences with critical partners to identify current issues that may disrupt daily operations, and tactics to reduce them.
- Foster security enhancements that comply with new initiatives in Customs-Trade Partnership against Terrorism, Container Security Initiative, and others.
- Enable disruption incident reporting following a major disruption event to identify root cause and failure mode and effects analysis to learn from and prevent recurrence of similar events.
- Perform training and education to improve decision-making capabilities, and equip managers and associates in the channel with plans and processes for managing disruptions when and if they occur.

Again, these types of interactions require that the organization invest in the human assets required to manage these critical relationships. They will also have to train these people, and put in supplier reporting systems, new processes, and in some cases new systems, to facilitate the ongoing dialogue and communication that can identify and prevent disruptions from occurring.

Deploy Visibility Systems to Ensure Quicker Response to Disruptions

A second approach that involves a higher level of investment is deploying a visibility system to quickly identify the disruption, which reduces the time required to quickly react and take action to prevent the disruption from impacting customers. When a disruption occurs, key executives need a quick way to be alerted that a problem occurred. These types of event and alerting systems often fall into the category of visibility and enterprise risk planning models. Such models span system-wide nodes in the supply chain, and can be found in many different forms.

- Launch "exception" event planning systems that are able to discover critical logistics events that exceed normal planning parameters on an exception basis. When discovered, an alert can be sent to executives via pager, phone call, e-mail, or other communication form. The alert can trigger managerial action to mitigate the impact of the disruption as quickly as possible. This area includes gathering supply chain intelligence and monitoring the supply base to allow proactive maneuvers

against material flow disruptions. For example, a major pharmaceutical company has deployed a transportation event management system that tracks the departure and arrival times of shipments going through high-risk distribution channels. In the event that the average "planned" lead-time through the channel is exceeded by a certain parameter (i.e., the shipment is delayed and does not arrive when the system expects it to), a "trigger" notice is sent to users.

- Pilot test RFID technologies to track containers in distribution channels at critical nodes. For example, one company is testing RFID in its containers to detect when containers are held up or lost in major ports, where loss of containers is a common occurrence.
- Implement inventory visibility systems to track demand, inventory, and capacity levels at key nodes in the supply chain, including ports and shipping locations.
- Employ predictive analysis systems, incorporating intelligent search agents and dynamic risk indexes at major nodes in the supply chain to identify potential problems
- Facilitate real-time supply chain reconfiguration to enable real-time rescheduling of shipments or contingency plans in response to disruption discovery.

Supply Chain Redesign

As companies recognize that many of the risks present in their supply chains represent a significant threat to their financial performance, they are investing significant amounts of funds to resolve these risks through supply chain redesign. For example, many retail organizations we interviewed were in the process of redesigning their supply chain, were considering port diversification, and were partnering with service providers transportation, carriers, and customers to identify potential solutions. These focused working groups were mapping supply chain ports of entry, identifying pressure points, and prioritizing top risk areas — then identifying how to reconfigure channels to minimize the amount of freight going through these channels. Efforts may also occur to redesign components and products to minimize the need for global sourcing and convert to industry standard components that are easier to source through conventional channels. Some examples of these strategies include:

- Create damage control plans across the supply chain through modeling of supply chain events and scenario planning. A major retailer, anticipating the West Coast port strike, took steps to identify the potential impacts of shipments from China being stopped. A simulation was run that predicted that the bottlenecks would extend back to Chinese ports in Shanghai, and indeed even up through the Yangtze River. (This prediction turned out to be true.) To mitigate these effects, the company

built up inventory in Shanghai and investigated alternative routes through Hong Kong and East Coast ports, to avert the strike.

- Redesign for disruption avoidance. A major electronics manufacturer elected to redesign its product chip set to minimize the need for "green field" sources in China, and began keeping some of the highly complex manufacturing of components in the United States to avoid potential disruptions.

Application of the Four Risk Reduction Elements

The companies we interviewed that were experiencing a high degree of product or process complexity, but whose operations were primarily domestic, tended to apply a greater use of excess resources to guard against disruptions and reduce the time required for recovery. This is a typical approach to prevent the impact of disruption in complex systems. A possible tool for creating an effective system for managing disruptions is to implement a disruption incident reporting system that identifies where excess resources should be located at critical, high-risk nodes in the supply chain to mitigate the effect of possible disruptions. For example, a major automotive company today holds 40 or more days of parts inventory sourced from China in North America, to prevent its assembly plants from shutting down in the event of a disruption. Conversely, companies that were highly involved in global sourcing, but with less complex products or processes, were beginning to deploy a greater use of visibility systems to identify potential disruptors and track inventory across the supply chain. In another case, a major pharmaceutical company recognized too late on September 11, 2001, that its supply chain had been severely compromised. Seven flights in the air en route to the United States from Europe with high-value pharmaceutical products were diverted: two to Canada and five returned to the United Kingdom. It took a full 24 hours simply to discover this information, and there was no knowledge of the exact products on the flights. They did not know what airports the planes were diverted to. Meanwhile, the overseas factories had not yet been notified of the delay, and continued to produce and ship products to the freight forwarder. The freight forwarder location was filling up rapidly. The team engaged immediately and initiated a prioritization process upon discovery of this disaster. This involved daily teleconference calls with U.S. demand management, the freight forwarder, and the U.K. distribution group. The transfer of product destined to travel by air was moved onto ocean carriers, to at least ensure that it was moving in the right direction. In addition, rerouting of goods in Canada being shipped by truck to the United States through ports was required.

After the event, the pharmaceutical logistics team recognized that they did not have a robust process for disaster management. They also recognized that once all the parties in the supply chain were communicating with one another, had visibility to the same information, and were making decisions

jointly instead of in a silo, that management decisions were dramatically more effective and easier. As one executive noted: "Physical flow and product movement doesn't just happen by magic — previously the shipping area was successful be being invisible — it was also its major problem. In effect, 9/11 brought about a high-level recognition of the importance of effective supply chain planning. We realized that we had no process to move air shipments to sea in the event of a disaster — so that we needed to work with government officials to do this and use our creativity to solve problems." This event also allowed the pharmaceutical company to establish a solid business case outlining the need for an investment in a global transportation event management system that provided greater visibility into disruptions and allowed all parties to view the same information and communicate regularly on status and updates. However, in some cases, electronic visibility systems may not be available, particularly in remote global locations. One major logistics provider developed an intricate system for exchanging information. First, information was transmitted via walkie-talkie and then typed up in a local office. The information was faxed to a broker, who would then initiate the paperwork and enter the information into the company's primary logistics management system.

The most extensive approach used by firms with complex supply chains that expand globally is to rely on increased planning, collaboration, and education of partners in the supply chain. The importance of collaboration was most clearly identified by a major retailer. Prior to the West Coast port strike, there were impending signals that the Los Angeles port union strike was imminent. To manage this risk, a dedicated logistics team at the retailer took an active role with industry trade groups to educate themselves on the issues. They conducted regular phone calls with key people to identify what was happening, and educated themselves on the labor contract and work rules that were under discussion — what were the demands of the ILWU and why are they asking for it? They also established strong communication links with senior management at six major ocean carriers. The team did not weight any single opinion but did *look for patterns in responses*, asking questions such as "What are your contingency plans?" and "What information do you have on the status of the strike?" These weekly phone calls helped the company understand the issues and the potential risk involved.

Becoming educated was just the first step. The management team then planned for worst-case scenarios and established contingency plans that included:

- Renting chassis and putting them aside, knowing that if there was a strike, their containers would be buried in stacks. Having the chassis allowed them to set them aside for easy retrieval.
- Securing extra drivers due to predictions that those drivers would be a bottleneck. The team also recognized the need to pay a premium per load to truck drivers to move their product as a result of the high demand for drivers.

- Increased diversification of ports. Through discussions with ocean freight carriers, the team identified alternative ports that could be used. In this case, the Tacoma Port Authority was contacted and a meeting with the leadership team occurred. The team realized that they needed to have a presence at this port ahead of time — BEFORE the strike occurred — and began to move small volumes through Tacoma as a contingency.
- The team also expanded its business model to adopt a broader view of the supply chain, to encompass impacted vessel availability. A team of people flew to Shanghai to assess the situation, where they realized that they could move some of their manufactured product by barge to Hong Kong and thereby take alternative routes out of the Shanghai port, which was becoming bottlenecked from the strike.
- Finally, the team also collaborated with other retailers to jointly schedule charters to expedite freight — there was not enough ocean capacity — and, in fact, ocean capacity is at a major premium today, with rates skyrocketing.

Our interviews also indicated that companies are more willing to invest in a major supply chain redesign effort after a "near-miss" major disruption event. Executives, once they recover from the disruption, learn from the event and take steps to redesign their supply chains to minimize the probability that the problem will occur again, or better yet, eliminate the possibility of it ever occurring again. This involves the development of tools for *dynamic* management of supply chain systems and redesigning or re-optimization of the supply chain. In systems such as supply chains, optimization cannot be a single static model. Rather, tools that adjust with the dynamic nature of supply chain events are needed. These tools should have global enterprise scope for enterprise redesign considerations, and need to provide solutions in real-time or near-real-time. It should be noted that, for the most part, current network optimization models in use are optimized for a "snapshot" in time and provide the optimal solution for the current operating and economic environment. What is needed is a set of tools that can track changes in the supply chain and work under a variety of operating and economic environments.

Managerial Issues in Supply Chain Disruptions

There are three interrelated important attributes that arise from this research that companies should consider in managing supply chain disruptions. Firms in the early stages of risk management should begin to assess and develop systems for managing supply chain risk.

1. Develop a high-level nodal supply chain map for a critical branch of global sourcing operations, highlighting not only material flow, but information flow, inventory levels, decision points, mechanisms, and triggers.

2. Develop a risk incident node list that identifies the probability of an event at each of the major nodes in the network, and the possible revenue stream impacted if the event were to occur. Do not engage in "happy talk" during this period, but strive to deal with the real possibility of a complete network shutdown if the event were to occur.
3. Establish a greater understanding of the external factors affecting the supply chain, through development of a node-by-node risk enumeration and identification plan, utilizing in-depth supplier or logistics partner interviews. Build a knowledge base of supply chain risk and identify key subject matter experts in the network who should be consulted on a timely basis.
4. Establish additional insights into where and how much inventory is located throughout the supply chain, and how to rapidly access and reposition the inventory during a supply chain disruption.
5. Develop a detailed report documenting the factors that cause or amplify disruptions. A preliminary list has been identified in this research. In addition, conducting "post mortems" of major past disruptions to identify contributing factors can help identify weaknesses in current supply chain design, or product sourcing decisions that exacerbate supply chain risk exposure.
6. Evaluate contingency plans on this pilot product for risk reduction effectiveness, and identify key thresholds when mitigation decisions would be executed. Develop a long-term probability of incidence reduction based on the deployment schedule of initiatives such as visibility systems or supply chain collaboration.
7. Evaluate the risk and return on each investment. What is the potential cost of launching such an initiative, versus using a "quick fix" such as excess inventory? Bear in mind that a quick fix may solve the immediate problem but will not reduce the overall risk present in the network. Consult internal product design and marketing resources to ensure that the initiative is aligned with the future technology roadmap for the enterprise.

As discussed in this research, the foundation for a solid supply chain risk management program includes improved knowledge of where the disruptions can occur, and the training to know when and how to respond. The level of awareness of the potential for disruptions, and the capability to respond, is the single greatest preventive action that organizations can take to prevent the effects of a major disruption from disrupting global operations. By better understanding the nature of supply chain risk, one can engage one's management team in a candid discussion of how the organization should prepare for the inevitable.

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