Chapter 2
Risk Identification

Abstract As a first step to managing supply chain risks, this chapter focuses on ways to *identify* and categorize risks. First, as a way to distinguish causes from effects, drivers from consequences, risks whose consequences are apparent soon after an incident from those whose consequences are spread over months, and risks that have already materialized from incidents that might happen in the future, we present a "butterfly" model that conceptually separates underlying causes, actual events and consequences. Second, keeping in mind who should manage supply chain risk, we categorize risks in a way that follows the supply chain organization. Most companies have different groups facing the supply side (purchasing), those working in internal processes (manufacturing, storage and internal distribution), and those facing the demand side (distribution and sales). Therefore, we categorize risk motivated by the supply chain management organization: supply risks, process risks, and demand risks.

2.1 Introduction

There are many ways to identify and categorize risks, and each organization has its own way for developing its ***risk register***: a list of identified risks with their importance rating. But why should we categorize risks (or supply chain risks) at all? Possible reasons include helping us to understand the distinctions among these risks and to prioritize different risk mitigation investment decisions. In this chapter, we provide two different ways for categorizing supply chain risks by suggesting answers to (1) *how* we should manage any particular category of risks and (2) *who* should manage this category of risks.

Many *risk categorization* methods for identifying risks do not suggest *how* to address risks. There are many methods for charting different types of risk using taxonomy-based risk identification (c.f., Carr et al., 1993). Juttner et al. (2003) provide a classification based on the sources of risk: environmental risk sources, network risk sources, and organizational risk sources. Chopra and Sodhi (2004) dis-

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cuss delays and disruptions, Sodhi and Lee (2007) present supply-related, demand-related and contextual risks and Tang and Tomlin (2008) discuss supply risk, process risks, and demand risks.

There are also different ways of *risk identification* including identifying critical uncertainties in scenario planning (c.f., Garvin and Levesque, 2006). In identifying risks, supply chain researchers have used the terms *uncertainty* and *risk* interchangeably although economics researchers have attempted to narrow *risk* to only those situations where possible outcomes can be assumed to follow a known probability distribution. In fact, there are *upside risks* that can help an organization to achieve desired objectives, *downside risks* that can inhibit achieving these objectives, and *other risks* that create uncertainty about outcomes—Hopkin (2010) calls these opportunity risks, hazard risks, and control risks; respectively.

The diversity in risk identification and categorization is not simply because each organization has its unique circumstances or that different risk researchers come from different backgrounds. We believe that the real problem is that the vocabulary of risk, including that of supply chain risk, still needs to be fine tuned in practice. As such, we need to develop a conceptual view of risk in general and supply chain risk in particular so that everyone, not only in the organization but also in supplier and customer organizations in the supply chain, uses the vocabulary consistently. Such a shared vocabulary should also help us in answering *how* to manage different categories of supply chain risks.

We also need to categorize risks in a way that allows us to match any category to a specific entity within the organization for risk management, i.e., to enable us to answer the question of *who* should manage a particular risk category. For supply chain risk, this is not easy because any risk incident could start anywhere in the supply chain and end up causing huge impact somewhere else. In this chapter, we provide a categorization based on the perspective of a supply chain organization within the company, giving examples of mitigation efforts. This risk categorization maps each category to that part of the organization that is in the best position to prevent the risk incidents or at least contain the impact of risk incidents in this category. We also categorize risks whose prevention requires a centralized approach under a category that maps to the corporate entity.

As such, we take a twofold view of categorizing and identifying risks. First, we present a conceptual view of risk in general and supply chain risk in particular. The intent is to develop a shared vocabulary for risk within the organization (or supply chain) and to give an indication of *how* each risk category can be managed. Second, we present a tangible categorization of supply chain risks that suggests *who*, i.e., which part of the supply chain organization or the corporate entity itself, should seek to prevent the risk incidents or at least contain the impact of these incidents in each risk category. We also give examples of how companies manage the different categories of supply chain risks, although we discuss various risk mitigation strategies in Chapter 4.

2.2 A Conceptual View of Risk for Identification and Categorization

To develop a shared vocabulary for risk or supply chain risk, we need to sharpen the existing vocabulary first. We should be able to distinguish causes from effects, drivers from consequences, risks whose consequences are apparent in seconds and minutes from those whose consequences are spread over months, and risks that have already materialized from incidents that could happen in the future—in common parlance, all are confusingly termed "risks". We first present a "butterfly" depiction of risk that conceptually separates underlying causes, actual events and consequences.[1] Next, we present two categories of risks based on their impact: disruptions and delays (Chopra and Sodhi, 2004). Finally, we present a view of risk that is typical of supply-chain risk in contrast to enterprise risk: network risk associated with local-and-global causes and local-and-global effects.

2.2.1 A Butterfly Depiction of Supply Chain Risk

It is helpful to think of the commonly used term "risk" as issues ranging from underlying *causes* to actual *risk events* to *impacts*. A useful point of delineation is the occurrence of a risk event or incident. Causes are *before* the risk event while the impact is felt *after* the occurrence of such an event. Likewise, prevention efforts are *before* the event and the response efforts are made *afterward*. The location of the causes, the event and the consequences can be quite different especially in a supply chain: causes for a risk event may lie far from where the incident actually occurs as we shall discuss in Section 2.3 and the impact of any incident may be felt far beyond the location of this event.

We find it helpful to use a "butterfly" depiction of supply chain risk (Figure 2.1) atop an *x*-axis representing time as well as the relative location in the supply chain. The risk event is the body (thorax and abdomen) of the butterfly. The left-hand wing represents underlying causes and prevention efforts that could lead to this event, while the right wing depicts the post-event impact and response efforts. The left wing can be extended to represent causes upstream in the supply chain and the right wing extended to depict impacts further downstream in the supply chain relative to the time and location of the risk incident. Any preparation for quick response to risk events has to be done before the response but such preparation could be before or after the event (Figure 2.1).

There are several benefits of the butterfly depiction as regards how to manage any risk category. The observable risk event separates causes and effects, adding clarity to what is *the* risk. The timeline reflects prevention, response, and preparation-to-response efforts in time so we can plan these for any particular risk category.

[1] This idea was given to us by Paul Hopkin. The butterfly has been used to depict risks in many ways other than the way we present here as well.

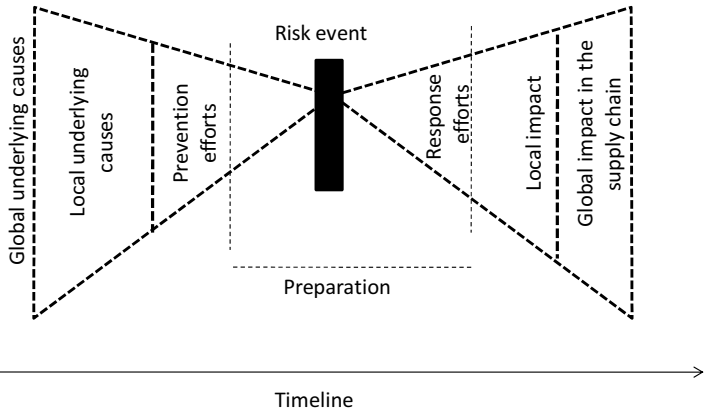

Fig. 2.1 A butterfly depiction of supply chain risk

Although the butterfly depiction is quite clear in representing risk as a spectrum around a single event, we know from practice that one risk event can trigger another risk event, building up negative consequences even when each event in itself may have contained consequences. For example, consider the Union Carbide gas leak in Bhopal (India) in 1984 that caused the deaths and blindness of tens of thousands of people.[2] This disaster was a result of a combination of missteps with one risk event

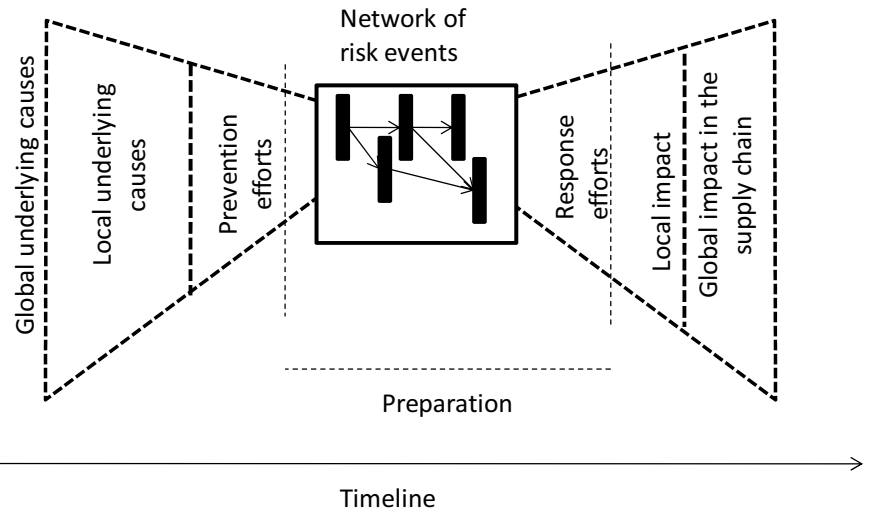

Fig. 2.2 A butterfly depiction of risk with a network of risk events

[2] There is an interesting organizational follow-up. Dow Chemical agreed to buy Union Carbide in 1999, completing the deal in 2001. Dow's stated policy is that "the company has neither a connection to nor legal liability for the tragic events of the 1984 gas release." As a subsidiary of

triggering another, eventually resulting in enormous negative impact. As with any perfect storm, it is not clear where or how to respond in such a network of events when this network has already triggered but the depiction should at least help to highlight the need to prevent the triggering of such a "network" of events. We can modify the butterfly depiction by replacing the single event, i.e., the body of the butterfly, by a network of events (Figure 2.2).

The butterfly depiction is quite clear when the event has large consequences; however, we do have events in the supply chain whose consequences are small individually but may still be large in the aggregate. For instant, a stockout for an individual order at a warehouse may have only a small consequence, but over time, repeated stockouts can lead to large accumulated losses hitting the company's bottom line. And, customers experiencing such repeated stockouts may choose to take their business elsewhere. We need to use the history of past events to prevent future events, or at least make them much less likely to occur. The timeline in the butterfly diagram can then be depicted as circular to show that the event is repeated over time, slowly accumulating the negative losses (Figure 2.3).

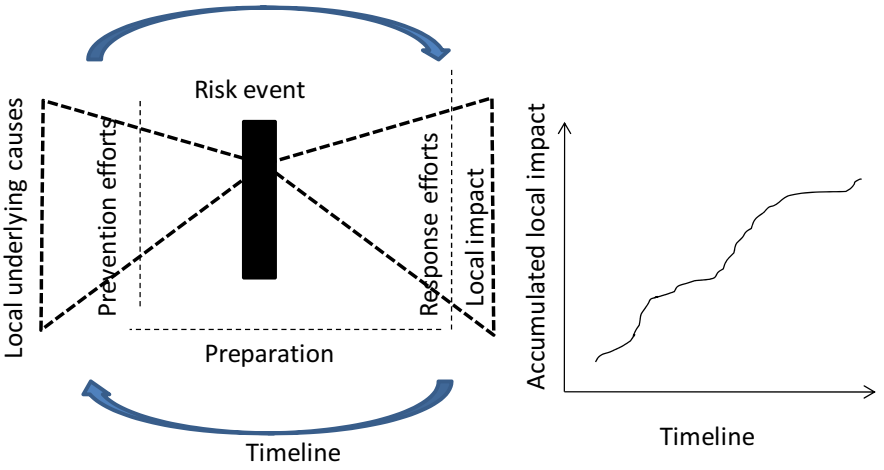

Fig. 2.3 A butterfly depiction of repeated risk events—note the circular timeline, both causes and effects being primarily local, and the gradually accumulating losses

Dow Chemical after the takeover, Union Carbide maintains there are no outstanding legal claims on it. Dow Chemical also says its subsidiary, Dow India, has no influence over Union Carbide to provide any help to victims. See http://news.bbc.co.uk/1/hi/programmes/bhopal/4023447.stm.

2.2.2 Delays and Disruptions: "Normal" and "Abnormal" Risks

There are two fundamentally different types of supply chain risks—delays and disruptions. These correspond to the "normal" risks experienced in supply chain management with the small and somewhat expected fluctuations of matching supply to demand, and to the "abnormal" risks of huge and unexpected mismatch of supply to demand due to a big failure with either the supply or the demand collapsing.

Delays in material flows often occur when a supplier, through overly high utilization or other causes of inflexibility, cannot respond to changes in demand. Other culprits include poor-quality output at supplier plants or at *their* suppliers' plants, high levels of handling or inspections during border crossings, or changing transportation modes during shipping.

Disruptions to material flows anywhere in the supply-chain are unpredictable and rare, but often quite damaging. Natural disasters, labor strikes, fires and terrorism can all halt the flow of materials. Consider the following examples. Following a fire in February 1997 at an parts factory owned by Aisin Seiki, a key supplier, Toyota was forced to temporarily shut down production at most of its Japanese plants.[3] The 1994 Kobe earthquake in Japan left many small companies like Kelly Micro Systems of Irvine, California without any supply of parts.[4] The California dockworkers strike in 2002 produced shortages of high-demand retail items.[5] The bankruptcy in 2001 of UPF-Thompson, sole chassis supplier to Land Rover, caused major problems for the auto maker.[6] Immediately after the attacks of September 11, 2001, U.S. auto manufacturers ran short of parts; transport trucks had been delayed at the Canadian border.[7] Supply disruptions can also increase prices, as the Midwest discovered painfully in August, 2001, regional gasoline process skyrocketed following a refinery fire at the height of summer demand.[8]

Many executives and researchers started paying more attention to handling major disruptions after the September 11 event (c.f., Chopra and Sodhi, 2004; Kleindorfer and Saad, 2005; Rice et al., 2003; Sheffi, 2001; 2005 a and b). However, it remains critical for firms to develop ways to manage supply chain risks arising from delays, the problems of coordinating supply and demand, because these risks are ever-present everywhere in the supply chain and can have an enormous accumulated impact.

Classification of risks as delays or disruptions suggests different answers to the question of *how* to deal with such risks. Companies can avoid or be prepared for delays by appropriately placing and sizing their capacity and inventory reserves at the lowest cost. If material-flow delays are frequent, companies can plan mitigation

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[3] "Fire hits parts supply network at Toyota," *Financial Times*, February 4, 1997

[4] "Damage to chip makers puts sourcing in spotlight," *Journal of Commerce*, January 30, 1995

[5] "Retailers scramble to keep stores stocked," *Wall Street Journal,* October 21, 2002

[6] "Making it safe to rely on a single partner," *Financial Times*, April 1, 2002

[7] "Inventory controls reexamined: Attacks reveal vulnerability of Just-in-time," *Plain Dealer*, October 29, 2001

[8] "Prices jump at gasoline pumps in the area," *St. Louis Post-Dispatch*, August 29, 2001

strategies based on historical information. One simple solution is to have excess flexible capacity in existing plants. Toyota, for example, carries excess capacity at its plants at the shop floor by way of team leaders who can work on any station in the assembly line, thus reducing the need for spare station-specific workers to cover absences. This ensures that daily production goals are met even if minor problems occur along the assembly line.

Another solution is positioning capacity and inventory depending on the cost of the products. Telecom equipment maker Cisco has *capacity* to assemble higher-value items in the United States so it can respond quickly to orders from up-market American customers. In contrast, the company holds an *inventory* of lower-value, high-demand items produced in low-cost (but not very responsive) locations overseas. So by matching its approach to product value, Cisco keeps supplier-delay risks low with low inventory costs.

Yet another solution is to combine inventory with different transport modes. PC manufacturer Dell holds very little inventory of components in North America or Europe for computer sales in the west, instead, it keeps most of the component inventory in Asia as part of its "postponement" strategy. By doing so, Dell "pools" its inventory and ships high-value components by air from the Far East to U.S. and Europe as needed, and ships less expensive components regularly by sea at low cost. In this way, Dell minimizes delay-related risk as well as inventory-related costs.

Disruptions require different approaches. Companies can counter disruptions in material flow by building inventory or by having redundant suppliers; after all, it is unlikely that all suppliers would be disrupted at the same time. However, holding inventory in this context can get very costly because holding and obsolescence costs incur continually, while the inventory would be used only in the rare event of a disruption. In essence, the company pays (and pays) for reserves that probably will never get tapped. Still, building inventory *does* make sense if the company can predict the disruption with reasonable confidence. In 2002, many retailers selectively built up inventories after learning of the impending California dockworker strike. When the strike disrupted supplies, damage to retailers was minimal. Stockpiling inventory as a hedge against disruption also makes sense for commodity products with low holding costs and no danger of obsolescence. The large petroleum reserve kept by the United States is an example of this strategy.

However, if the products have *high* holding costs and/or a *high rate of obsolescence*, it may be better to use redundant suppliers rather than to hold inventory against the threat of disruption. Motorola, for example, buys many of its handset components from multiple vendors, depending on the components' volume. Doing so prepares the company against disruptions without building up fast-depreciating inventory. It lowers the cost of redundancy by using multiple suppliers for high-volume products and single-sourcing for low-volume products. By doing so, the company maintains economies of scale at its suppliers to get good prices.

2.2.3 Local-and-Global Drivers and Local-and-Global Consequences

We need to distinguish the occurrence of uncertain events from their consequences: the uncertain event is the risk, while the eventual consequences (and to whom) depend on the actions taken by different parties after the event occurs. For example, from the viewpoint of many manufacturers, the September 11 event was unforeseen and hence it was an uncertain event. However, it was the subsequent suspension of air transportation that was directly responsible for causing supply delays that disrupted the manufacturing operations of many U.S. manufacturers.

Consequences may be local or global depending on whether the impact of the risk incident is limited to a particular location within the supply chain or whether the entire supply chain is affected. *Global consequences* impact the entire supply chain. For example, due to a recent surge in gasoline prices, Ford's supply chain for SUV manufacturing came to a halt in 2008 as consumers switched to compact cars; and Mattel suspended its production after recalling over 20 millions of toys in 2007. *Local consequences* impact a particular market or a particular site. For example, Ford closed five plants in the United States for several days after all air traffic was suspended after the September 11 event.

However, where an incident occurs may or may not be connected to where the consequences are felt. Thus, assessing supply chain risk entails understanding where a risk incident can occur as distinct from where the consequences might be. We can categorize supply-chain risks as being related to incidents that occur globally, spanning the entire supply chain, or those that occur locally at a particular supply chain entity only.

Global risks are defined in the context of the global environment within which the supply chain operates. The corresponding uncertainties pertain to social or political instabilities, credit crunch crises, and commodity price increases.

Local risks are defined in the context of specific supply chain entities. Risk events could be natural disasters, labour union strikes, supplier bankruptcies, contaminated production processes, or loss of intellectual property rights at a specific supply chain entity. Local risks could also stem from the damaging behaviour of particular supply chain partners.

We can thus categorize supply chain risks by the "location of occurrence" and by "location of consequence" (Table 2.1) to set the stage for developing mitigation strategies. Identifying the point of occurrence of each type of risk and its consequences would create shared awareness of different types of risks and their potential impact on different supply chain parties. This process can enable supply chain partners to better define their roles and responsibilities and to generate support for collaborative efforts for mitigating risks for all parties. For example, after suffering from a *global* $2 billion loss in sales caused by a *local* fire that disrupted the production of microchips at a supplier's plant, Ericsson worked with its supply chain partners to develop proactive plans should an incident of such time recur (c.f., Norrman and Jansson 2004).

Table 2.1 Supply chain risk drivers and consequences (also see Chapter 6)

		Consequences *(Region of possible eventual impact)*	
		Local *(impact to a particular supply chain entity or market)*	***Global*** *(impact to the entire supply chain or multiple markets)*
Supply Chain Risk Driver *(Point of possible occurrence)*	***Local*** *(originating at a supply-chain entity or in a particular market)*	Local risks stemming from supply, demand, or failure match supply and demand.	Risks originating in a plant or region whose consequences eventually impact the entire supply chain or markets.
	Global *(originating supply-chain-wide or globally).*	Global risks that affect a particular supply chain entity.	Global risks that can affect the entire supply chain as a whole.

Clearly, the affected supply chain entity is responsible for reducing the local risk when the consequences are also local. Some of this is very much part of supply chain management, e.g., maintaining inventory to reduce the impact of unexpected delays in supplies.

At the other extreme, for global risk drivers that have global consequences, collaborative efforts from the entire supply chain are needed at the corporate levels of companies. For example, to improve supply chain security, U.S. Customs established the Customs-Trade Partnership against Terrorism (C-TPAT) certification program in 2002. This certification program requires all supply chain partners to comply with a standard operating procedure to ensure security. To entice companies to comply with the best security practices, C-TPAT certified companies are allowed to clear customs faster with less inspection (c.f., Tang 2006a).

To handle local risk with global consequences—some would argue this should be the focus of managing supply chain risk—we need to understand the risk management efforts both at the point of occurrence and at the affected locations. For example, after recognizing the global consequence of a world-wide recall of lead-tainted toys associated with the local risk of a particular sub-supplier using lead-tainted paints in the production of these toys, Mattel announced a safety check system to prevent the manufacture of toys with noncompliant levels of lead in paint (c.f., Pyke and Tang, 2008).

Finally, situations entailing global risks with local consequences are usually the result of corporate policy applied inappropriately or incorrectly to a local situation. For instance, there may be local negative consequences of a corporate procurement policy. This can be mitigated by communication between the local facilities with the corporate entity.

2.3 Risk Categorization Motivated by the Supply Chain Organization

We now present a categorization that suggests *who* should prevent risk events or at least contain the impact of risk events for a particular risk category. Given the importance of supply chain management, companies already have their respective organizations in place to carry out the supply-chain activities that entailed. Therefore, it makes sense to categorize risks in a way that follows the supply chain organization. This way, different entities within the supply chain organization can determine who are best positioned to prevent or contain the consequences of certain types of risks events and who should be responsible for managing the corresponding risk categories. Most companies have different groups facing the supply side (i.e., purchasing), those working in internal processes (manufacturing, storage and internal distribution), and those facing the demand side (distribution and sales). Therefore, we can consider three types of risk motivated by the supply chain management organization:

- **Supply risks**
- **Process risks**
- **Demand risks**

There are also

- **Corporate-level risks**

for which the entity charged with risk management is the corporate entity with a remit over the entire company (Table 2.2).

Table 2.2 Supply chain risk categorization motivated by the supply chain organization

Supply risks	Process risks	Demand risks	Corporate-level risks
• Supplier failure • Supply commitment • Supply cost	• Design • Yield • Inventory • Capacity	• Forecasting • Change in technology or in consumer preference • Receivable	• Financial • Supply chain visibility • Political/Social • IT systems • Intellectual property • Exchange rate

Prevention in risk management (and hence motivating this categorization) is important, because one risk event can trigger another of the same or of a different type. As indicated above, Toyota's accelerator-related problem resulted in loss of reputation and decrease in demand along with political risks in the US.

2.3.1 Supply Risks

Supply risks pertain to risk events on the supply side that include supplier defaults or other unexpected changes in supply cost, delivery, quality or reliability. Outsourcing risks fall in this category and their importance is growing as more manufacturers reduce the number of direct suppliers and source globally. Indeed, many U.S. manufacturers reduced the number of direct suppliers throughout the 1980's and 1990's to reduce the cost of managing multiple suppliers and to foster better supplier relationships. Some companies even pushed for sole sourcing. While managing a smaller number of suppliers is more efficient, a smaller supplier base can expose the company to greater risk. Consider the following types of risks on the supply side:

Supplier failure. This is a well-documented risk with many examples such as the bankruptcy in 2001 of UPF-Thompson, sole chassis supplier to Land Rover, which caused major problems for the auto maker. During the 2008-09 economic crisis including the credit squeeze, automakers BMW and Daimler along with UK defence company VT Group told their top suppliers to come to the company for financial help as a way to reduce their supply risks.

Supply Commitment. If the buying organization has to commit to long-term purchases from its supplier without the option of revising the quantities, it can have the risk of having unmet demand or excess inventory over time. For instance, Canon is the sole supplier of the engines for the HP LaserJet printers. Hewlett-Packard has to place its order six months in advance and is not allowed to change the order quantity once the order is placed. This arrangement limits the company's ability to react to changes in demand (Lee, 2004).

Supply Cost. This refers to unanticipated increases in acquisition costs resulting from supplier price hikes or from fluctuating exchange rates. Price increases are more likely when a company uses only one supply source. When Intercon Japan's connector manufacturer sourced a special type of bronze from a single metal supplier (Asahi Metal), it had little bargaining power. Consequently, Intercon Japan experienced significant price increases from Asahi Metal (Tang, 1999). We consider exchange-rate risk in a separate category at the corporate level as managing it centralized risk mitigation, for instance, sourcing from a country with a different currency can be hedged on the demand side by selling to the same country (see Chapter 8). Still, as an example consider the fact that in the mid-2000s, the weakening of the dollar drove up not only oil prices in dollars for U.S. companies but also the costs of imports from Europe.

Price increases by suppliers can be blunted by signing long-term contracts, by having redundant suppliers, or, in rare instances, by holding inventory. But long-term purchasing can badly damage profits if prices for the contracted goods fall. For example, obligations signed by California during the peak of its electricity crisis in 2001 forced the state to pay 800% more than the 2002 market price.[9] Also, long-term contracts with little quantity flexibility, as already indicated above as supply

[9] "California may have new energy deals," *New York Times*, August 8, 2002

commitment risk, can lead to a company not being able to match its supply to a changing demand.

Contracting with redundant suppliers can work if companies can maintain economies of scale. Global giants like Toyota seek out local economies of scale by single-sourcing at the plant level, but use different suppliers globally. That way, even though a company might be the sole-supplier to a particular Toyota plant(s), it must keep prices down to compete for business across the entire Toyota network. Alternatively, some firms use multiple, redundant suppliers, even if it means sacrificing some economies of scale. Cisco, for one, claims to have four or five more suppliers than it needs. The company keeps the resulting higher costs in check by monitoring and benchmarking suppliers against each other.[10] A good example of using inventory to counter the threat of price increases is the U.S. strategic oil reserve policy. Meant primarily meant to prevent oil supply disruption, the reserve also has been used on occasion to keep down prices. Another instance comes from U.S. based International Paper Company. To keep prices of raw material down, the company sources raw materials from independent forest owners, as well as from its own forests with trees as raw-material inventory.

2.3.2 Process Risks

These risks pertain to risks within the organization's internal supply chain, typically pertaining to design, manufacturing and distribution. Consider the following categories of supply-chain risks:

Design. Despite significant efforts in implementing Total Quality Management (TQM), Lean Manufacturing and Six Sigma, many companies are still facing risks from products produced as a result of faulty design or manufacturing. Toyota's recall of cars in late 2009 and early 2010 owing to "sticky" accelerators has hurt the company's reputation, demand and stock price. In 2007, Mattel recalled over 17 million toys designed internally that were unsafe for small children owing to small loose magnets. (This risk incident was different from the one where toys Mattel had to recall because of a supplier using lead paint.)

Yield. If the manufacturing yield at a plant is uncertain, it can result in the company not being able to match its supply to its demand. Yield problems in 2004 at IBM's plant in East Fishkill, New York contributed to the $150 million first-quarter loss by its microelectronics division (c.f., Krazit 2004). The lower-than-expected yields reduced the plant's effective capacity and limited IBM's ability to meet customer demand.

Inventory. Excess inventory hurts financial performance. That was the case in late 2000, when the PC industry carried roughly 12 weeks of inventory. The combination

[10] Randy Pond, Senior VP, Cisco, November 2002.

of excess inventory and falling prices hurt many companies such as Compaq.[11] The extent of the risk stemming from inventory depends on (1) the value of the product, (2) its rate of obsolescence, and (3) uncertainty of demand or of supply. Holding excess inventory for products with high value or short life cycles can get too expensive but it can work well for low-value commodity products with low obsolescence rates. Naturally, the larger the product variety, the greater a company's exposure to inventory risk.

Three proven approaches can help managers can mitigate inventory risk: (1) pooling inventory, (2) creating common components across products, and (3) postponing or delaying till the receipt of orders the last stage of production from which emerges product variety. Online bookseller Amazon.com serves all its customers in the United States with inventory housed in a handful of warehouses, while book retailer Borders supplies its customers with inventory in several hundred stores. Besides pooling inventory, each Amazon warehouse pools demand over a large geographical area, leading to more stable forecasts and lower total inventory. The strategy helps Amazon achieve 14 inventory turns per year, versus two at Borders.[12]

The paint industry illustrates well how to leverage component commonality and postponement to manage product variety. Traditionally, manufacturers held paint inventory in a rainbow of different colors. Today, paint inventory is held as a common base, which is then is mixed to exact color specifications after the customer orders. This simple but powerful change has significantly lowered paint inventory at retail stores. Apparel maker Benetton also practices pooling and postponement. An inventory of un-dyed sweaters gets stockpiled in one location. The garments are dyed after orders have been received. This pooling of demand across geographical areas and across colors helps Benetton reduce inventory risk while meeting customer demand more effectively.[13]

Companies can also minimize inventory risk by working with a highly responsive supplier, especially for high-value, short life-cycle products. Excess capacity can also lower the amount of inventory required. By running plants at 80 percent utilization, Toyota can handle demand variation without having to hold inventory.

Capacity. Inadequate capacity means a company may be unable to meet its demand and thus suffer from unmet demand. To avoid this, companies can err on the side of having excess capacity. However, building excess capacity is usually a strategic choice as it may take much longer to ramp capacity up or down compared to changing inventory levels and may cost a lot more. Moreover, excess capacity hurts financial performance in terms of providing lower returns on investment and on investment. That was the case in 2002–03, when many semiconductor firms had to run at 50 percent capacity because of soft demand.

Managers can lower excess capacity risk by making existing capacity more *flexible*. Flexibility is a form of pooling that allows use of the same capacity for a variety

[11] "PC prices fall with demand," *USA Today*, December 13, 2000

[12] Borders filed for bankruptcy in the US in February 2011.

[13] Benetton (A), *Harvard Business School* case 9-685-014.

of products. For example, Hino Trucks plants employ multiple assembly lines, the number of workers on each line determining the line speed. This flexibility not only lets Hino change production on any line by moving its capacity of workers in response to fluctuating demand, but it also keeps the excess capacity of workers that Hino would have to carry much lower than a situation where workers would be line-specific.

Toyota decreases risks from idle capacity by ensuring that each plant is flexible enough to supply more than one market. Demand fluctuations can be satisfied from a variety of plants, which decreases total capacity required. The company carries the idea of flexibility down to the shop floor, where team leaders can work on any station in the assembly line, reducing the need for spare station-specific workers to cover absences.[14]

Lastly, a company can minimize excess capacity by serving geographically scattered customers from the same location. Italian automaker Ferrari, for example, minimizes total production capacity by centralizing production of all cars in a single plant. The arrangement also provides Ferrari with economies of scale, even though Ferrari produces much fewer cars than the big auto companies.

2.3.3 Demand Risks

The uncertain nature of product demand is one of the supply chain risks that all companies need to face with uncertainty surrounding volume and product mix. To increase revenue, many firms sell their products in multiple countries. To satisfy country-specific requirements such as power supply and language driver, Hewlett-Packard (HP) has to develop multiple versions for each model of their DeskJet printers. Each version serves a particular geographical region (Asia-Pacific, Europe, or Americas). Due to uncertain demand in each region, HP faced the problem of overstocking certain printers in one region and under-stocking certain printers in other regions (Kopczak and Lee, 1993). For companies that sell multiple products, not only is the total demand volume unpredictable but also the demand mix, i.e., the individual demand for each of the product variants. Demand risk therefore encompasses uncertainties in both volume and mix.

Forecasting. Forecast risk stems from the mismatch between a company's forecast and actual demand. If the forecast turns out to have been too low, then there may not be enough products available to sell. If forecast turns out to have been too high, the weak demand will result in excess inventories and price-markdowns. Long lead times for production (hence a farther forecast horizon), seasonality of demand, high product variety, and short product life cycles all increase forecast error. Also, errors tend to be larger when a few customers make larger purchases as opposed to many customers making smaller purchases.

[14] "Toyota Motor Manufacturing USA Inc.," Harvard Business School Case 9-693-019.

Forecast errors also result from *information distortion* within the supply-chain. In late 2003, for example, product shortages in western Europe led Nokia customers to order more than they needed, so they would be able to meet demand in case Nokia began rationing or allocations. These exaggerated figures distorted Nokia's reading of the market, causing the company to inaccurately forecast sales.[15] Other causes of information distortion include: promotions and incentives that lead to forward buying; batching of purchases, which leads to higher volatility in orders; and lack of knowledge of end-customer demand at upstream locations.

Distortion increases in the supply-chain as you get further away from the end consumer, a phenomenon known as the *bullwhip effect* (Lee et al., 1997). Companies can reduce the sting of the bullwhip effect, though, by adjusting pricing and incentives to decrease variation in orders. Increasing the visibility of demand information across the supply-chain also helps. Continuous Replenishment Programs (CRP), and Collaborative Planning, Forecasting, and Replenishment (CPFR) and other supply-chain initiatives also can soften the bullwhip effect.

The impact of the resulting forecast errors can be lessened by selectively holding inventory or by building responsive production and delivery capacity. Holding inventory is appropriate for commodity products with relatively low holding costs; responsive delivery is better for expensive products with short lifecycles (and corresponding large forecast errors). Motorola practices responsive delivery each day when it flies in phones from China in response to demand by customer Nextel. Instead of stocking parts for uncertain demand, Dell also flies in high-value items from Asian suppliers on an as-needed basis as mentioned before.

Change in technology or in consumer preference. Closely tied to forecast risk is the longer-term trends of changes in technology introduced by competitors and change in consumer preference whether tied to the change in technology or to something else. Such changes not only undermine a company's demand but also render capacity investment highly optimistic, thus hitting goals on return on investment. The electronics industry is constantly buffeted by new technology or designs and Apple's 2010 introduction of the iPad left competitors such as Amazon's Kindle scrambling for comparable offerings or having to offer price reduction. Large investment in new technologies may require collaboration with competitors to reduce the risk of another technology or a different set of standards leaving a company high-and-dry. The question is not just about the availability of technology but which technologies consumers will adopt. This means constant research and development not only of products but also of consumers in different market segments. One approach is to research and monitor existing and potential customers not only through sales but also through online forums and social networking sites.

[15] "Nokia feels the squeeze from shortage," *Off the Record Research*, November 13, 2003

2.3.4 Corporate-Level Risks

There are also risks to the entire supply chain—supply side, within the organization and demand side—and hence to the enterprise itself. As such, companies need centralized action coordinated with internal and external entities in the supply chain.

Financial risk. When a company is expanding markets, it is rare that the focus will be on profitability or other financial measures. Instead, the goal is typically market share, "presence", name recognition, and other objective and subjective measures. Another issue related to conglomerates is shareholder interest translating to cash injections to keep some companies within the conglomerate afloat in difficult times. Add to this a currency crisis and credit markets drying up, we have a situation where the company may suddenly face bankruptcy. Moreover, in a conglomerate or in a supply chain, one company going bankrupt could have a domino effect on other members of the conglomerate or on suppliers and other supply chain partners.

Maintaining liquidity in an industry with short product life-cycles and high obsolescence rate can be a challenge. Over-investing in inventory can lead to big losses or even bankruptcy. This was the case for Hayes, the company that developed the standard for modems at the start of the Internet revolution.

There is also risk from receivables as inability to collect on receivables can torpedo the performance of any company. In 2002, Sears Roebuck's credit division reported unexpected losses caused by delinquent cardholders.[16] As a result, Sears stock plummeted more than 30% in one day. The company learned the hard way that filtering customers for creditworthiness is a very prudent and powerful way to reduce receivables risk. Filtering customers for creditworthiness is necessary to reduce receivables risk, but as with Sears, aggressive sales growth goals can result in sloppy credit checks.

Another approach is to spread the risk across more customers. McMaster Carr, a maintenance-materials supplier with hundreds of thousands of customers, enjoys a much lower receivables risk than a competitor selling to a single, large customer. The Achilles' Heel here is a widespread economic shock that harms the creditworthiness of all customers, a fate that befell Cisco during the dotcom bust in 2001 and, many suppliers in the 2008-09 economic downturn in western countries.

For companies selling globally, exchange rate fluctuations and movements can create receivables risk tied to not only the ability to collect against invoices in the future but also the exchange rate. As such, many companies sell to distributors or large retailers in many parts of the world using only cash (rather than 30-day terms) and that too in standard currencies: US dollar, euro, or pound sterling.

Finally, receivables risk can stem from errors in processing invoices and in invoicing and payment delays. Samsung Electronics uses proof-of-delivery technology to reduce receivables risk by reducing errors and by cutting down on the amount of time between delivery and invoicing. This time could be as much as 15 days if it were paper-based. Instead, a driver scans packages upon delivery as proof of re-

[16] "Sears earnings will be hurt by credit unit," *The New York Times*, October 18, 2002

ceipt. The information is uploaded to the SAP system, thereby triggering the invoice (Sodhi and Lee, 2007).

Supply chain visibility. As the number of partners increases in a global supply chain, the level of visibility and control can be reduced significantly. For instance, according to a study conducted by AMR Research in 2006, supply chain visibility is relatively low: few companies have either future demand or current inventory information from downstream partners and more than half the companies take more than two weeks to sense changes in actual demand. The low visibility level and the low control level reduce the "confidence" of each supply chain partner regarding the replenishment lead time/order status quoted by upstream partners and demand forecasts provided by downstream partners. Such a low confidence level can cause the entire supply chain enters a "risk spiral" so that each supply chain partner either "inflates" their order or "disguises" their on-hand inventory (Christopher and Lee, 2004). The confidence level deteriorates further as every partner starts gaming the system, and hence, the "risk spiral" continues. To break this vicious cycle, supply chain visibility both within the organization and with suppliers as well as customers by way of timely communication, and coordinated corrective actions are needed to improve the confidence level of each internal or external supply chain partner.

Political/social risks. A global supply chain is subjected to social/political risks when multiple countries are involved. For example, Airbus, a four-nation consortium, incurred an opportunity loss of 4.8 billion euros due to a two-year delay in launching the super-jumbo A380. In addition to technical problems associated with the wiring system, political issues among the four countries with manufacturing plants to make these planes are thought to be a contributing reason. Airbus' parent, EADS, struggled in the mid-2000s to develop a restructuring plan to replace political haggling with industrial logic (Gumbel, 2006).

IT systems risk. The more a company connects its systems into an efficient network, the greater the threat that a failure anywhere can cause failure everywhere. A breakdown of information infrastructure can devastate today's highly networked environments. In 2002, the fast-spreading "Love Bug" computer-virus infection shut down email systems at the Pentagon, at NASA and at the Ford Motor Company among others causing billions of dollars in estimated damages.[17] In 2010, the Stuxnet virus (actually "worm") that takes control over equipment caused worldwide industrial alarm as a foreign government succeeded in infecting the Iranian nuclear plant in Bushehr.[18] The same year Google also discovered it was under "cyber-attack".

The banking industry has long recognized systems risk as a major threat to its business systems. In 1988, the Basel Committee on Banking Supervision warned about the growing reliance on globally integrated systems. "The greater use of more

[17] "FBI hunts love bug source: Damage from e-mail source cuts across USA and worldwide," *USA Today*, May 5, 2000

[18] Stuxnet worm causes worldwide alarm, *Financial Times*, Sep. 23, 2010

highly automated technology has the potential to transform risks from manual processing errors to system failure risks," the committee wrote.[19]

A defense against systems failure is use of robust backup systems and well-designed, well-communicated recovery processes that duplicate all data and transactions. Such approaches helped securities firms recover quickly and convincingly following the World Trade Center attacks in 2001.[20] Still, these are relatively simple ways that may not help with the kind of attack made on the Iranian facilities on industrial equipment. As such, companies (and governments) are struggling with cyber-security even as many of the same governments are investing in developing technology for cyber-attacks.

Intellectual property. This risk of loss of intellectual property has grown rapidly, as supply chains become less vertically integrated and more global, and companies outsource to contract manufacturers who are used by their competitors or who can turn into competitors. Intellectual property risk has long-term implications on a company's profitability. While outsourcing or offshoring to low-cost countries does lower the cost of goods sold, the company can become more vulnerable to loss of its intellectual property.

For example, even though the reform of the Intellectual Property protection law made progress after China's WTO entry in 2001,[21] infringements can still occur in China. For instance, multinational firms are not necessarily protected legally when their Chinese suppliers start producing unauthorized products using virtually identical design and materials. When the relationship between New Balance shoes and Qiuzhi Footwear, one of its Chinese suppliers, went sour, the supplier started producing "New Barlun" shoes using a logo that resembled the New Balance's "N". New Balance filed a lawsuit in China in 2002 (Chandler and Fung, 2006) eventually winning it in 2006.[22] However, it can still be difficult to protect intellectual property and to eliminate the risk of near-counterfeits under certain licensing or contractual agreements.

Companies can mitigate intellectual property risk by bringing, or keeping, some production in-house or, at least, under direct company control. This is one reason why Motorola owns some of the testing equipment at its supplier locations. Another way managers can decrease risk is by limiting the flow of new intellectual property into countries with weak legal controls protecting it. Companies like Cisco, which outsources all manufacturing, also lower risk by creating business processes that no single manufacturer can replicate the entire product (or the process that goes into making it). Electronics manufacturer Sharp even repairs equipment itself, thus preventing any possibility, accidental or otherwise, that its vendors will share propri-

[19] See the BIS website for the Basel Committee's communications, in particular, "Sound practices for the management and supervision of operational risk".

[20] "Backup systems pass trying test," *Washington Post*, September 27, 2001

[21] See Judicial Protection of IPR in China, http://www.chinaiprlaw.com/english/news/news5.htm, accessed 4th Nov. 2010.

[22] See New Balance's press release http://www.newbalance.com/public-relations/library/2006/new-balance-wins-landmark-lawsuit-in-china-against-counterfeit-brand/ accessed 4th Nov. 2010.

etary information with Sharp competitors. The company goes so far as to reprogram various computer-aided machines used by its vendors without sharing the information.

Exchange-rate. This type of risk, mentioned earlier with supply costs, can be countered by creating financial hedges, balancing cost and revenue flows by region, and building flexible global capacity. Toyota's manufacturing strategy, to cite one good example, allows each plant to serve the local market and at least one other market across the world. This flexibility lets Toyota shift production if exchange rates change appreciably. Another way to reduce exchange-rate risk is to source, to the extent possible, from the same currency region where sales are being made. Limiting global sales to a few currencies—the US dollar and the euro, for instance—reduces the exchange-rate risk to only these currencies and the company's home currency if different. In general, the nature of global supply chains is such that sourcing and selling may be in very different currencies. As such, Samsung Electronics uses futures at the country or region level to help stabilize the operational effect of currency fluctuations (Sodhi and Lee, 2007).

However, things can get more complicated than simply hedging the rates between two countries. For a country-based subsidiary of a global company, one issue is the exchange rate at which profits can be sent back to (or at least reported in) the parent company's country. This subsidiary may source parts from other countries and may distribute and sell products in yet other countries. As such, exchange rates and even the question of what base currency to use become complex issues for companies with global supply chains.

While daily exchange rate movements are of operational interest, long-term trends like the decline of the US dollar in the mid 2000's relative to other major currencies or the decline of the pound against the euro from 1.5 to 1.1 euros/pound over the two-year starting January 1, 2007 period have strategic implications for the supply chain. Britain's decision to not join the eurozone impacts companies who are contemplating investment in the UK or in the rest of Europe. The various currencies of the emerging economies of Central and Eastern Europe also provide a challenge as regards exchange rate given their importance as "near-shore" locations for manufacturing for western consumption.

Environmental risk and compliance cost. Environmental standards in the UK and the rest of the EU are quite high compared to other European countries and to the US. But these higher standards also mean higher costs. Industries producing waste through manufacturing or through the end-consumers disposing the products at the end of the life face the question of who should pay the cost of doing so: local or central government, the company, end-consumers, or eventually of course, future generations if we do not do anything at all. Many companies have taken proactive steps in anticipation of requirements to be placed by the EU. Companies can also conduct R&D to reduce waste, energy consumption in manufacturing and/or consumer use, or otherwise reduce environment impact. Toyota in Europe has used its famed Toyota Production System to cut down water and energy consumption per car

in manufacturing and to eliminate waste going to landfill.[23] Samsung Europe set up a new environment team in 2003 comprising specialists to work with government regulators and other electronics manufacturers (Sodhi and Lee 2007).

Regulation compliance. While compliance on accounting and in particular on transfer pricing is not a supply chain issue per se, it does have implications on reputation risk as consumers may not want to buy products from a company with a reputation of not having transparent transactions.

2.4 Summary

We described two fundamental ways of identifying and categorizing supply chain risks motivated by the questions of how to manage these risks and who should manage these risks. The first way required an abstract view of risk, the intent being to help a company to distinguish between causes and effects and to suggest prevention and response efforts respectively. To this end, we provided three different ways to view risk: (1) a butterfly depiction of supply chain risk to distinguish between causes, events and consequences, (2) delays and disruptions to distinguish risk with small losses that accumulate to significant losses from risks that cause large losses right away, and (3) a network view to distinguish risks on a 2-by-2 framework of the origin of the risk drivers (local or global) from the region of impact (local or global).

The second way required categorizing risks in a way that follows the typical organization structure of supply chain management functions in any company. Doing so, we can help a company to figure out where risk events could best be prevented or at least responded to in a timely fashion. Specifically, we identified and categorized risks along the company's supply chain: supplier-related, process-related and demand-related risks. We also provided another category of risks that apply to the enterprise as a whole, which we called corporate-level risks.

[23] See http://www.toyota-europe.com/corporate/environment/360-approach/making-the-car.aspx