

Operational Strategies for Managing Supply Chain Disruption Risk¹

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1. Introduction

On June 16 2009, Genzyme Corporation announced that it had discovered the virus Vesivirus 2117 in one of the bioreactors at its plant in Allston, Massachusetts.² While the virus strain is not thought to be harmful to humans, it does interfere with production efficiency. Genzyme made the decision to shut down production of the three drugs - Cerezyme, Fabrazyme and Myozyme - produced in the plant. In FY2008, Cerezyme and Fabrazyme (used for the treatment of Gaucher and Fabry diseases) accounted for \$1.7 billion of the company's \$4.6 billion in revenue. Genzyme anticipated that the Allston plant would be back up and running by the end of July. However, because of the long processing lead time associated with biopharmaceuticals, production launched in August would not yield product until later in the year. At the time of the disruption, Genzyme was in the late stages of constructing a second facility in Framingham, Massachusetts for the production of Cerezyme and Fabrazyme. While the Framingham plant would provide an added layer of protection against any future interruptions in the production of Cerezyme and Fabrazyme, Genzyme's only protection in June 2009 was its existing inventories of these two drugs. Unfortunately, the company's stockpile was not large enough to fully absorb the production loss. Genzyme's July 22 press release stated that:

“Cerezyme and Fabrazyme inventories are not sufficient to avoid shortages during the period of suspended production and recovery. Genzyme is working closely with treating physicians, other health care providers, patient communities and regulatory officials worldwide to support patients with Gaucher and Fabry disease during the temporary period of supply constraint.”

The press release estimated that the revenue loss associated with the disruption would be in the range of \$250-\$600 million depending on whether the pre-disruption work-in-process inventory would be usable. Presumably the revenue loss would have been much greater if Genzyme did not have an inventory stockpile but would have been less if the Framingham plant had already come online. Fortunately for Genzyme (though not for the patients), there were no other existing Food and Drug Administration (FDA) approved drugs for the treatment of the Gaucher and Fabry diseases, and so the strategic risk of sustained market-share loss was not a preeminent concern in this instance. Genzyme did not anticipate shortages of Myozyme, the other drug produced in the Allston plant, in part because it

¹ This work is intended as a chapter for the “Handbook of Integrated Risk Management in Global Supply Chains” co-edited by Panos Kouvelis, Onur Boyabatli, Lingxiu Dong, and Rong Li, to be published by John Wiley & Sons, Inc.

² All references to Genzyme in this chapter are based on information contained in press releases, communications and financial statements issued by the company.

had recently received approval from the European Commission for production of Myozyme at its facility in Geel Belgium.

We can learn two important lessons from Genzyme's experience. The first lesson is that supply chain disruptions can and do have very large financial and strategic consequences. The second lesson is that operational strategies, if correctly designed and implemented, can effectively mitigate the financial and strategic risk associated with supply chain disruptions. It is the second lesson that is the focus of this chapter. Our primary purpose is to introduce supply chain practitioners and scholars to the operational strategies that firms can implement to manage supply chain disruption risk. Table 1 identifies and briefly describes the five key operational strategies. In this chapter we explore each of these five strategies, with the goal of highlighting key factors that managers need to consider when designing and implementing their disruption mitigation strategy. In writing this chapter we made four important scope-related decisions that we wish to bring to the attention of the reader:

- While the lessons covered in this chapter are grounded in academic research, this chapter is not meant to serve as a review of the existing academic literature. It draws primarily, but not exclusively, on the research conducted by the authors. Where appropriate we will refer the reader to publications that underpin some of the recommendations offered in this chapter.
- While an effective risk management program comprises risk identification, assessment, response planning and ongoing monitoring and control, we do not attempt to address all four categories in this chapter. Our focus is on the operational strategies that firms can put in place to manage disruption risks and, as such, this chapter falls mostly in the response planning category. However, we will at times touch upon the other categories when they are relevant to understanding the advantage or disadvantage of a particular operational strategy.
- While supply chain management cuts across multiple firms, this chapter does not explore the incentives and informational issues that complicate multi-firm disruption management. This topic is explored in Chapter X.³
- While some people might take a more expansive definition of supply chain disruption risk, this chapter will limit its definition to the risk of significant deviations between the delivered/produced quantity and the required quantity. As such, cost and quality risk will not be considered.

The rest of the chapter is organized as follows. In Sections 2-6 we discuss each of the five strategies described in Table 1. We then conclude in Section 7 by discussing the value of deploying multiple strategies and by identifying some directions for future research to advance the knowledge and practice of supply chain disruption management.

³ Note to Editors – you will need to put in reference to Vlad Babich chapter here when chapter numbers and titles are finalized.

Table 1: Five Operational Strategies for Managing Disruption Risk

Operational Strategy	Description	Example(s)
Stockpile Inventory	Hold inventory that can be used to fill customer demand even if supply is interrupted.	In 2004, United Technologies Corporation temporarily increased its inventory buffer to protect against a potential supply disruption due to financial difficulties at a key supplier.
Diversify Supply	Source product from multiple vendors/facilities so that a problem at one vendor/facility does not affect the entire supply.	Nokia's multiple-supplier strategy reduced the impact of the 2000 Philips Semiconductor disruption. Chiquita's multiple grower-location strategy reduced the impact of the 1998 Hurricane Mitch disruption.
Backup Supply	Have an emergency supplier (or logistics provider) that is not normally used but that can be activated in the event of a supply problem.	Nokia responded to the Philips Semiconductor disruption by temporarily increasing production at alternative suppliers. New Balance responded to the 2002 west-coast dock disruption by rerouting ships to the east coast and by air freighting supplies.
Manage Demand	Influence demand to better match the actual supply by, for example, adjusting prices or offering incentives to encourage customers to purchase products that are less supply-constrained.	Dell responded to the disruption in memory supply caused by the 1999 Taiwanese earthquake by shifting customer demand to lower-memory computers.
Strengthen supply chain	Work with suppliers to reduce the frequency and/or severity of supply problems.	Unlike its competitor Xilinx, Altera does not source from multiple semiconductor foundries but works closely with its foundry partner (UMC) to minimize yield-related supply disruptions.

2. Stockpile Inventory

The concept of using inventory to protect against supply/production disruptions is a simple one. A company builds up a stockpile of inventory that can be used to fill demand during a disruption. As compared to the other strategies listed in Table 1, it is a relatively easy strategy to implement, in part because it does not require coordination with suppliers or customers. While Genzyme may well have been correct in choosing inventory as its disruption mitigation strategy, its experience during the Allston plant disruption offers a cautionary lesson. Genzyme could not immediately use its stockpile of Cerezyme inventory to meet patient demand during the virus-induced production disruption as the virus

might also have contaminated the inventory. Before releasing this inventory, Genzyme had to prove to the FDA and the European Medicines Evaluation Agency that the inventory was not contaminated. Even after obtaining this approval, the inventory stockpile was not large enough to prevent shortages. The company had less inventory stockpiled than originally thought (because some of Allston capacity was being used for production of Myozyme) and the production disruption was longer than originally anticipated because Genzyme decided to conduct a more extensive sanitization of the Allston facility. While the inventory stockpile undoubtedly helped Genzyme navigate a difficult time, their experience suggests that inventory has its weaknesses as a disruption strategy. Indeed, the simple concept of stockpiling inventory is complicated by four important factors that need to be considered when evaluating inventory as a possible strategy. The factors are risk profile, detection, isolation, and recovery.

Risk profile: In standard risk-management processes, risks are sometimes categorized along two dimensions: likelihood and severity. This categorization is also helpful in disruption management. Some disruptive events may occur relatively often (i.e., high likelihood) but the associated interruption may be short (i.e., low severity). Other disruptive events may occur rarely (i.e., low likelihood) but the associated interruption may be very long (i.e., high severity). This distinction is particularly important when evaluating inventory as a strategy for mitigating disruptions. The severity (length) of a disruption determines how much inventory a company would need to fully protect itself against any supply interruptions. For disruptive events that are frequent but short, a company does not need to stockpile much inventory to protect itself. However, for events that are rare but long, a company would need to stockpile a very large quantity of inventory. This presents two problems – opportunity and temptation. While the direct cost of storing the inventory (warehousing, labor, insurance, etc.) might be tolerable, there is a large opportunity cost associated with a large stockpile. The company has invested money in creating the inventory and it is not turning this money into revenue. This expense may not show up on an income statement but it is a substantial hidden cost of doing business and one that reduces a company's inventory turns and hence its return on assets.⁴ The second problem is one of temptation. For frequent-but-short disruptions, managers observe the inventory serving its intended purpose of buffering against production interruptions. For rare-but-long disruptions, managers feel the pain of lower inventory turns but might not observe the protection benefit because the disruptive event has not occurred. It is naturally tempting to drain the stockpile to boost inventory turns based on the assumption that a disruption won't occur soon because one has not occurred for a long time. For rare-but-long disruptions, the opportunity cost of inventory makes it an economically unattractive strategy and the temptation issue can render inventory an unsustainable strategy unless there are disciplined processes for maintaining the stockpile. In contrast, inventory can be a very effective strategy for protecting against frequent-but-short disruptions. Of course, a company might opt for an inventory stockpile to protect against rare-but-long disruptions if its particular set of circumstances renders the other strategies listed in Table 1 even less attractive.

⁴ For short lifecycle products, this problem is exacerbated because unsold inventory is obsolete at the end of the product lifecycle.

Detection: The fundamental problem with using inventory to protect against rare-but-long disruptions is that a large stockpile has to be carried for a long time. What if a company could adapt the size of its stockpile, increasing it when the threat of disruption was high and reducing it when the threat of disruption was low? By tailoring the stockpile size to the current level of risk, a company can alleviate the opportunity and temptation issues, thereby making inventory a much more attractive strategy. Adaptive strategies are becoming a reality, as evidenced by this description of United Technology Corporation's (UTC) use of supplier monitoring software:

The software toolset uses pattern recognition technology to constantly monitor supplier data to determine if any of UTC's 18,000 suppliers are heading for trouble. In August 2004 the system generated a financial alert based on a recognized pattern of events for a key castings supplier. That partner was immediately identified as being important to a number of product lines, and a system-generated e-mail was sent to the OTL staff warning of a potential bankruptcy ... [and] UTC increased its inventory buffer as an added layer of protection.

- From Global Logistic & Supply Chain Strategies, December 2005.

Implementing an adaptive inventory strategy requires certain capabilities on the part of the company. First, the company needs some form of ongoing threat-detection process that monitors potential disruptive events and effectively detects and distinguishes between levels of risk. Therefore, an adaptive strategy is best suited to disruptive events in which (i) the risk evolves over time and (ii) the firm can assess changes in the risk. Internal disruptions (such as labor stoppages) might fall within this category. Second, the company must have the ability to rapidly respond to an increase in the risk level. That is, it must have sufficient capacity to rapidly build up the stockpile when necessary. Otherwise, the protection level lags far behind the risk level and the adaptive strategy fails. In short, inventory becomes more attractive as the firm is better able to sense and respond to disruption risks.

Isolation: Inventory can help protect against the consequence of a disruption only if the inventory is usable and can be delivered to the demand location(s). If the underlying disruptive event damages the inventory or prevents its release, then the stockpile offers no protection. Fortunately for Genzyme and its patients, the virus did not contaminate the inventory stockpile. Phillips Semiconductor was less fortunate in 2000 when lightning caused a ten-minute fire in its Albuquerque, New Mexico plant. "Smoke particles had spread into the sterile room in the heart of the factory, contaminating the entire stock of millions of chips stored there" (Latour 2001). If inventory is to be a company's chosen strategy, then it must strive to isolate the inventory from the disruptive events it is to protect against. If it is meant to protect against a hazard-induced plant failure, then the stockpile should not be stored in or near the plant. If it is meant to protect against a transportation-link failure, then it had better be stored on the customer side of the link. Assuming the stockpile is not ring fenced but is continuously replenished in a first in – first out manner, then the company must be able to rapidly detect any contamination-induced disruption or else the stockpile will also be contaminated. In short, inventory is an effective safeguard only if it can be isolated from the disruptive event.

Recovery: The effect of a disruption does not end when the interrupted facility comes back online. Due to production lead times, there may be a further delay before the facility actually produces finished product. Even after the point when demand is being met, the firm's inventory stockpile (assuming it has chosen that strategy) will need to be replenished. Until such time as the stockpile is rebuilt, the company is operating at a reduced level of protection. A disruption that occurs during this recovery time is especially problematic as it coincides with a temporarily diminished resiliency. The longer it takes to rebuild the inventory stockpile the longer the period of heightened exposure. The primary drivers of the post-disruption recovery time are the production lead time and capacity. The lead time determines how long until finished product starts to flow and the capacity determines how rapidly the stockpile can be rebuilt. Inventory is rebuilt only if production exceeds demand. Therefore, the closer the capacity is to demand, the longer the time to rebuild the stockpile. To compensate for this extended recovery time, a company needs to increase its initial stockpile quantity because, in effect, the stockpile has to protect against the possibility of disruptions during recovery. In short, the longer the recovery time, the more inventory is needed and the less attractive a strategy it becomes.

Inventory is a simple strategy but has substantial hidden costs and dangers if the above factors are not carefully considered. That being said, inventory has its place in disruption management and should not be arbitrarily ignored. Even if inventory is not the primary strategy for managing disruptions, a company might want to consider holding a small stockpile as a secondary strategy. This buys the company some valuable time at the onset of a disruption if the primary strategy cannot be instantaneously activated. For those readers wanting to delve more deeply into the quantitative analysis of the inventory strategy, please see, for example, Song and Zipkin (1996), Tomlin (2006), Tomlin and Snyder (2007), Tomlin (2009a), and references therein.

3. Diversify Supply

Genzyme has manufacturing facilities in Belgium, Ireland, England, and the United States. Some facilities produce active ingredients, others engage in bulk production of final product, while others carry out filling and finishing operations. (Some facilities perform more than one of these steps.) The Allston plant carries out bulk production of key genetic-disease targeted products, e.g. Cerezyme, Fabrazyme and Myozyme. Synvisc, a biosurgery product, is produced in Ridgefield, NJ. The recently expanded facility in Geel, Belgium can produce protein-based product and so complements the Allston plant's capability and capacity. In February 2009, the European Commission granted Genzyme approval for larger-scale production of Myozyme at the Geel facility. The value and limitations of Genzyme's partially-diversified manufacturing network was in evidence during the virus-induced interruption to its Allston production. Because Genzyme had the ability and approval to produce Myozyme in two locations, the Allston interruption only partially disrupted Myozyme production. However, Cerezyme and Fabrazyme were fully disrupted by the Allston problem. Additionally, because only a subset of Genzyme's product portfolio was produced in Allston, an interruption to that plant did not affect all of its products.

The Genzyme experience captures the essence of the diversified supply strategy. By splitting production (or sourcing) across multiple facilities (or suppliers), a company partially protects itself against disruptions because a problem at one site only interrupts a portion of the company's product flow. If the non-disrupted site can ramp up production, i.e., provide emergency capacity, then it offers additional disruption protection but we will cover that disruption strategy in the next section on backup supply. Creating a diversified supply network is not without its challenges, and the following factors need to be carefully weighed when evaluating/implementing a diversified supply strategy for disruption management.⁵

Cost: At a very basic level, there is a cost associated with diversifying a supply network. There can be significant investment costs incurred each time a new facility is built or a new supplier is qualified. Operating several sites or suppliers multiplies the fixed costs associated with facility and supplier management. Variable costs associated with coordination increase. In an effort to protect itself against geographically-located disruptions, a company might source from multiple countries. This increases the average cost of goods sold assuming different locations have different operating costs. The economies of scale gained by concentrating an activity in one location are diluted by diversification. While it is true that diversification can promote competition which can drive down unit costs, the cost implications of a diversification strategy need to be carefully weighed against the benefits.

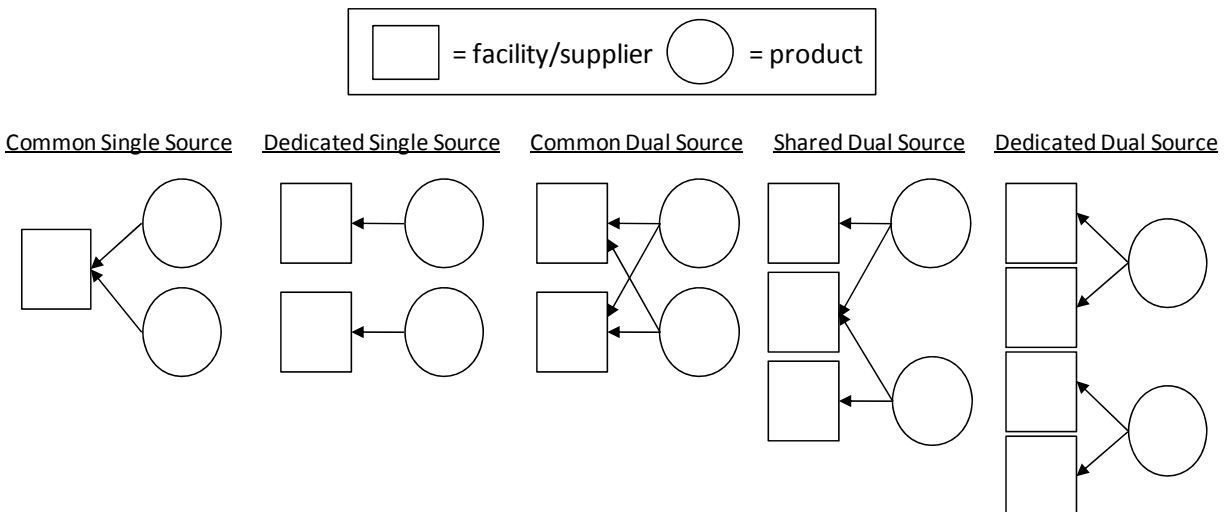


Figure 1: Levels of Supply Diversification

Configuration: Diversification is not an all-or-nothing choice. Rather, the choice is the level of diversification the company desires to build into its product supply network. Using two products for ease of illustration, Figure 1 depicts network configurations that exhibit increasing levels of diversification (and cost) as one moves from left to right. At one extreme end of the spectrum, a

⁵ There are other reasons beyond disruption protection for creating a diversified network. The discussion in this chapter is not intended to cover the wider range of benefits and concerns. Instead, it focuses on disruption related considerations.

company can concentrate production of all of its products in one facility, i.e., have no diversification protection. At the other end, a company can use multiple facilities for each product with no facility producing more than one of its products. This extreme form of diversification maximizes protection because a disruption to one facility only partially interrupts at most one product's supply. (Figure 1 limits itself to dual sourcing but increased protection can be achieved by using more than two supply sites for a product.) Because of the cost and protection benefits associated with diversification, most companies will not want to position themselves at either end of the spectrum but instead will want to find an appropriate middle ground. The level of diversification and particular configuration chosen will depend not only on the company's assessment of the costs and protection benefits but also on technical, organizational, and regulatory constraints that the company operates within.

Correlation: The protection offered by diversification rests upon the assumption that one facility continues to operate during a disruption to another facility. This assumption breaks down if a disruption interrupts both facilities. As the probability of both facilities simultaneously failing increases the value of diversification decreases. That is, the higher the correlation in failure across sites, the less protection diversification provides. Disruptive events arise from a number of underlying causes, some of which are specific to one site while others are (or at least can be) common across sites. The failure correlation increases with the number of common-cause events that pose a disruption risk. Put another way, a company can increase its diversification protection by reducing the likelihood of common-cause events. Sourcing from multiple sites in the same geographical region introduces the possibility of a natural disaster disrupting all sites, and so sourcing from sites in different regions eliminates this common-cause disruption and increases diversification protection. Shared geography is not the only source of common-cause disruptions: any common factor shared across sites introduces the possibility of common-cause disruptions. Genzyme believe that the Vesivirus 2117 contamination in its Allston plant originated in a raw material. Once Genzyme had developed an appropriate inspection technique, they were able to verify that the virus had contaminated production once already in the Geel plant. Fortunately that incident had already been resolved and so the virus did not induce a simultaneous interruption, but it could have. Along with geography and raw materials, managers need to investigate processes, systems, and policies when evaluating the potential for failure correlation across sites.

Consistency: By sourcing a product from multiple sites, a company introduces the potential for site-induced variations in their product supply. Depending on the company's tolerance for inconsistencies and the product's testability, consistency considerations can play an important role in the implementation of diversification. While one company might accept small deviations in product features, another company might require near-identical features such that products from two sites are fully interchangeable. For products, such as semiconductors, where the production process is a key driver of product variation, companies may need to replicate processes and equipments across sites if interchangeability of product is desired. Intel's well known "copy-exactly" production strategy is one such example. For products where identical functionality can be achieved using a variety of equipment or processes, there are more options available when diversifying supply. The fitness-for-purpose of some products can be fully evaluated with a nondestructive test on the finished product. However, for other products, biopharmaceuticals for example, fitness-for-purpose can only be established by

examination and verification of the production process. The FDA has stringent process validation standards for qualifying a new production process, as do equivalent agencies in other countries. A goal of this regulatory hurdle is to ensure consistent product quality. Before Genzyme could release production of Myozyme from its Geel facility, it had to gain approval from the European Commission because the Geel facility produced the product in larger bioreactors than used in the Allston plant. Those companies that require higher consistency and who are prone to process-induced variation, pharmaceutical companies being a prime example, face the most difficulty when implementing a diversification strategy.

Diversification can be a powerful antidote to disruption risk but it is not without side effects. Diversification can increase costs and complexity. Also, network configuration decisions can be time consuming to implement and even more difficult to undo. Managers need to carefully weigh many factors when deciding how much diversification they need and how best to configure that diversification. A number of supply chain design software companies offer tools that address some of the tradeoffs (e.g., fixed and variable transportation costs) inherent in network design, but no one tool captures all relevant factors. Managers therefore need to invest significant time and effort when crafting their diversification strategy. For those readers wanting to delve more deeply into the research underpinning some of the points discussed in this section, please see, for example, Tomlin and Wang (2005), Dada et al (2007), Tomlin (2009b), and references therein.

4. Backup Supply

The inventory and supply diversification strategies require a company to make significant investments in advance of any potential disruption. The company must absorb the direct and indirect costs associated with the protection strategy whether a disruption occurs or not. A more appealing strategy might be one in which the cost is incurred only in the event of an actual disruption. One way to align the expenditure of resources with the occurrence of a disruption is to rely on a backup supply strategy. In this strategy, a source or site that does not routinely produce the disrupted product temporarily steps in to meet the supply requirement during the disruption to the primary source. Analogously, a company might avail of an emergency transportation mode if their standard mode is disrupted. For example, in response to the air-traffic disruption resulting from the September 11th terrorist attack, Chrysler temporarily shipped components by ground from the U.S. to their Dodge Ram assembly plant in Mexico. If a company has a diversified supply strategy, then one of the sources that currently manufactures the product might be able to temporarily increase production. This would be a combined diversified/backup supply strategy. For example, when Genzyme's Framingham production facility comes online⁶, it will have two approved sites capable of producing Cerezyme and Fabrazyme. In addition to diversifying supply as a protection against future disruptions, Genzyme will have the option of temporarily increasing production at one facility during a disruption to the other facility. This will provide an added

⁶ Mechanical construction of the Framingham plant is scheduled for late 2009 but due to the lead time associated with qualification runs and regulatory approval, Genzyme does not anticipate commercial production until 2011 for Fabrazyme and 2012 for Cerezyme.

layer of protection. Incurring cost only when necessary is an attractive proposition but there are complicating factors that need to be considered when evaluating the backup strategy.

Availability and Cost: Just as the diversified strategy breaks down if all sources fail simultaneously, the backup strategy breaks down if the backup source is not available when called upon. If a company has excess capacity (capable of performing the disrupted activity) within its own network of facilities, then availability is not an issue.⁷ However, if a company has to look outside its own network for emergency capacity, then availability may become a significant issue. First, there must be a third-party provider capable of performing the disrupted activity and this party must have (or be able to obtain) additional capacity. The more specialized the activity the fewer competent providers there are likely to be. Second, the company must be able to access the backup source's capacity. Accessing backup capacity can be especially problematic if a disruption affects a supplier shared by two competitors. In the aftermath of the Phillips Semiconductor disruption, a key-customer, Nokia, obtained emergency capacity from other Phillips Semiconductor facilities. Ericsson, a competitor of Nokia and also a customer of the disrupted plant, was not able to obtain additional capacity from Phillips as it had already been allocated to Nokia (Latour 2001). Also, Ericsson had been rationalizing its supply base and so had limited options for finding qualified sources in an emergency. Smaller companies may find that their ability to access scarce capacity is limited as suppliers allocate their capacity to more important customers. Disruptions can temporarily create competition between companies that don't even operate in the same industry. The fight is not over customers but over access to a scarce resource. When multiple companies are interrupted by a common disruption, such as the 2002 west coast port disruption in the United States, they compete over access to whatever spare capacity exists. There was intense competition for airfreight capacity from Asia during the port disruption as firms attempted to circumvent the disruption by flying goods to the United States. As demand outstripped supply, airfreight costs increased by 30% within a week and not all companies were able to access airfreight capacity even if they were willing to pay the price. Companies that had long-established relationships with the third-party transportation providers were (understandably) given preferential allocation. To guarantee availability, a company may enter into a contract with a vendor to provide capacity in the event of an emergency.⁸ Such a contract will normally stipulate how much capacity the vendor will provide and associated payments. The vendor needs to be compensated for providing emergency capacity, and this compensation might take the form of an upfront (or ongoing) payment for reserved capacity and/or an agreement to pay a premium when the capacity is accessed. Either way there is often a higher variable cost associated with emergency processing. Even if backup production occurs within a company's network, there may be costs associated with overtime or expediting supplies to the emergency facility. A careful accounting of the associated costs needs to be undertaken when evaluating the backup strategy.

⁷ Of course, just as with the diversified supply strategy, if a common cause event interrupts both the regular and the emergency source, then the backup strategy offers no protection. See the earlier discussion on correlation in the diversified strategy.

⁸ Care must be taken when validating the provider's ability. If the provider is making commitments to multiple customers, does it have the capacity to simultaneously meet all of its commitments? If not, then at least one customer is going to be severely disappointed if a disruption simultaneously affects all the vendor's customers.

Response Time and Magnitude: Assuming that the company can access backup capacity, the next question is how long does it take and how much back capacity can it obtain? The shorter the response time (how long) and the higher the response magnitude (how much) then the more protection is provided by the backup strategy. Response time can be broken into three parts: detection time, coordination time, and ramp time. Detection time refers to the time between the onset of the disruption and the acknowledgment by the company that it has a problem. In the Phillips Semiconductor disruption, Nokia detected the problem almost instantly while Ericsson did not react for several weeks. To minimize detection time, companies must be vigilant in monitoring all supply and production activities for any hint of problems to come. Coordination time refers to the time between detection and agreement by a backup source to provide capacity. Here, prior planning and relationships are vital. Companies that engage in effective business continuity planning will have plans and assigned responsibilities for reacting to a disruption. If backup supply is the company's strategy, then continuity planning should have laid out the necessary steps involved in coordinating backup suppliers. Coordination will be faster if the company has an existing arrangement with the supplier for the provision of backup capacity. Prior qualification of the supplier (if possible) eliminates the time-consuming step of validating the backup source at the start of a disruption. Even after coordinating with the backup provider, there will be a delay in bringing the additional capacity online unless the provider has all the necessary supplies and idle labor and equipment of the required type. This ramp time, i.e., the time between agreeing to provide capacity and producing the extra units at the agreed volume, is the third element of the response time.⁹ Response magnitude refers to the amount of additional capacity that can be made available. This will be a function of the spare capacity (or readily accessible capacity) of backup sources and the number of sources. Those companies requiring highly specialized labor or equipment may find it difficult to find much additional capacity unless they have taken the (possibly prohibitively) expensive step of paying to ensure specialized assets are available when called upon. Companies can reduce response time and increase response magnitude through advanced planning, by investing in additional internal capacity, and by paying for preferential access to third party capacity. Assuming a limited budget, should a company expend more resources on improving response time or magnitude? It depends. In particular, it depends on the nature of the disruptions the company faces. For frequent-but-short disruptions, a backup strategy is essentially useless unless the response time is very short. As such, the firm should focus on reducing response time. It can store inventory to make up for the capacity shortfall caused by the response magnitude being insufficient to cover lost production.¹⁰ For rare-but-long disruptions, response magnitude is crucial assuming that the response time is not egregious. The firm can store inventory to cover the lost production during the response time whereas using inventory to make up for a large ongoing capacity shortfall during an extended disruption would be very expensive.

The backup supply strategy is a very attractive strategy for protecting against rare-but-long disruptions because it aligns the protection expense with the reality of a disruption. The company is not paying to

⁹ The ramp time will be lower if the backup source is already producing the product, and so a company that implements a diversified supply strategy has an advantage in implementing a backup strategy because diversification complements the backup strategy.

¹⁰ A company might want to rely solely on the inventory strategy for short-frequent disruptions.

protect against a hypothetical event but reacting to an actual event. However, companies can be overly optimistic about the effectiveness of their backup strategy. When evaluating and/or implementing the backup supply strategy, managers need to engage in a realistic appraisal of availability, cost, response time and magnitude. By engaging in scenario planning around these four dimensions, companies can better assess and implement a robust backup strategy. For those readers wanting to delve more deeply into the research underpinning some of the points discussed in this section, please see, for example, Tomlin (2006), Chopra et al. (2007), Tomlin (2009b), and references therein.

5. Manage Demand

In the three strategies discussed so far, company efforts are directed at managing the supply side of the disruption-related supply-demand imbalance. An alternative, or complementary, strategy is to manage the demand side of the imbalance. Genzyme devoted lots of energy to working with patients, physicians, health organizations and regulatory authorities to mitigate the disruption effects. Because the inventories of Cerezyme and Fabrazyme were insufficient to cover demand, Genzyme had to determine how to ration the drugs to minimize adverse health reactions. In collaboration with physicians and regulatory authorities, the company developed treatment protocols that altered the consumption rate for patients in an effort to match demand with available supply, with a goal of protecting the most at-risk patients. In addition, Genzyme made attempts to enable patients to switch to alternative treatments. Although there were no approved commercially available alternative to Cerezyme, Genzyme was in the clinical-trials stage for an investigational drug – GENZ-112638. Certain patients would be eligible to enroll in these trials. Also, Genzyme petitioned the FDA to allow the temporary prescription of GENZ-112638 even though it had yet to be approved. (The FDA can grant approval for the use of investigational drugs if circumstances dictate it is in the best interest of the patient population. The FDA also worked with Shire and Protalix, companies that were developing drugs to compete with Cerezyme, to consider applications for special approval of their investigational drugs as a means of generating additional supply.) As part of their broader disruption-recovery strategy, Genzyme actively communicated with patients, physicians and other stakeholders as they crafted their rationing and switching plans. A dedicated website – <http://supplyupdate.genzyme.com/> - was created to keep patients informed of the ongoing status of the drug supply. Genzyme's experiences highlight crucial foundations of an effective demand management strategy - switching, rationing, and communication.

Switching:

If a company sells more than one product and customers exhibit some willingness to switch between products, then the company might be able to mitigate a supply disruption by inducing customers to switch from the supply-constrained product to a non-constrained product. In September 1999, an earthquake in Taiwan disrupted production of crucial supplies, including memory, used in personal computers. Dell Inc. reacted to the disruption by shifting customer demand to lower-memory computers. Switching is an option only if the company has a supply of an alternative, acceptable product

that it can make available to customers affected by the disruption. If the company's supply/production network is configured so that all cross-substitutable products flow through the same facilities, then all these products may be constrained by a disruption and demand switching would not be feasible. Our earlier discussion of supply diversification highlighted network configuration as key lever. In Figure 1, certain configurations have complete overlap in the sources used for each product whereas other configurations exhibit some degree of product-source diversification, that is, production resources are not shared by all products. Companies wanting to use demand switching to manage supply disruptions need to configure their network so that it exhibits some level of product-source diversification. Demand switching is not limited to managing supply-demand imbalances induced by disruptions. Dell Inc. has excellent demand switching capabilities that helps it manage uncertainties in demand. By judicious use of special offers and the radio-button recommendations on its website, Dell is able to shape short-term demand to better match its incoming supply. Dell can do this because (i) it has developed excellent supply-visibility capabilities, that is, it continuously monitors the status of incoming supplies and inventory levels, (ii) it has developed insight into how customer purchasing behavior responds to pricing and recommendations, and (iii) it has an effective direct-to-customer website channel and so can directly influence its customers rather than relying on channel partners who might be just as happy to switch customers to a competitor's product. It was precisely because Dell had already developed these capabilities, that is was able to effectively respond to the Taiwanese earthquake disruption.

Rationing:

Assuming a company cannot switch (enough) customers to balance supply and demand during the disruption-induced supply constraint, then it must decide how to allocate its limited supply amongst its customers. The appropriate rationing mechanism will depend on the goals of the company and the options its customers have to take their business elsewhere. Is there a key customer that the company must retain at all costs? If so, then filling this customer's demand first might be appropriate even at the cost of shorting all other customers. Is it important to treat, and to be seen to treat, all customers equally? If so, then a rationing rule that allocates customers a common percentage of their request might be appropriate, or, to avoid customer gaming, the allocation might be based on recent volumes purchased. If certain customers can easily take their future business elsewhere then the company might want to give a preferential allocation to these customers. None of these choices are easy as some customers will be unhappy. The company has to decide who to make unhappy and how unhappy. In some cases, the Genzyme case being a prime example, the customer cost should not be measured in monetary terms as rationing supply has the potential to harm a person's health. Supply rationing in these instances is a much more complex challenge. In the words of Geoff McDonough, a Genzyme senior vice president, the philosophy underpinning Genzyme's rationing program was to "preserve inventory for the most vulnerable patients and to ensure global equity in this extremely challenging time for patients and physicians". Genzyme's rationing program is best described by quoting from their August 10 2009 press release:

In the United States, Genzyme last week implemented a dose conservation program to try to ensure that the most vulnerable patients continue to receive Cerezyme. The company is now shipping Cerezyme only to two patient populations: patients with Gaucher disease type 1 who

are 18 years of age or younger, and patients with Gaucher disease types 2 and 3. As part of U.S. dose conservation, Genzyme has also created an emergency access program, through which physicians may apply to receive Cerezyme for patients who are in life-threatening situations. Applications will be reviewed using criteria formulated in consultation with stakeholders from the physician and patient communities, and decisions will be made by a Genzyme medical committee with guidance from an independent group of physicians and patient representatives. Patient access via this program will be determined by available inventories going forward. Genzyme expects the U.S. dose conservation measures to remain in place until supply begins to normalize at the end of this year. This dose conservation program depends on the release of the two remaining finished Cerezyme lots but no work in process material. Outside of the United States, Genzyme is currently in discussions with regulatory authorities, physicians, and patient organizations to determine how to manage the supply of Cerezyme, and the company will begin shipping according to the revised inventory levels this week.

Genzyme's actions highlight the immense challenges that can arise in rationing. In theory, pricing offers an alternative to rationing. If supply is constrained, prices can be temporarily increased to reduce demand. This can be a dangerous strategy, however, if customers (or the general public) believe that the company is profiting unfairly from a problem of their own making. In industries where goods are bought and sold on a spot market, pricing may be a feasible lever for balancing supply and demand.

Communication:

Genzyme was very proactive in communicating its supply problem and rationing/recovery plans with those affected. This helped alleviate, if not eliminate, the concerns of patients. During the Taiwanese earthquake disruption, Dell induced customers to switch their purchases to lower-memory computers. Apple, on the other hand, did not possess Dell's demand switching capabilities but attempted to meet customer requests by shipping different product from what they ordered (Griffy-Brown 2003). Customers were understandably unhappy and Apple fared worse than Dell during the disruption (Sheffi 2005). Proactive communication is crucial when implementing rationing or switching, as otherwise the company runs the substantial risk of damaging customer relationships and its wider brand equity as a result of unflattering news reports. An effective strategy needs to consider the audience (who), the message (what), the timing (when), and the medium (how) when developing its plans to manage customer and stakeholder communications. Executives would be well advised to immediately enlist the help of communication specialists in developing their communication plans, and employees should be informed about how to handle customer and press inquiries.

Demand management can be an effective strategy for mitigating supply disruptions if the company has the necessary capabilities already in place. The supply-chain and customer-management processes and systems required for the switching element of the strategy can be difficult to develop and implement. It is more likely that a company would develop the switching capability to manage ongoing demand volatility than to develop it with the primary purpose of managing the risk of supply disruptions.

However, if a company has the capability it should certainly avail of it during a disruption.¹¹ Rationing may be forced upon the company whether it has planned for this eventuality or not. Advanced planning is highly advisable to enable smoother implementation during the disruption. When evaluating the demand management strategy, managers need to be realistic about their own capabilities and the response of customers to switching incentives and rationing plans. For those readers wanting to delve more deeply into the research underpinning some of the points discussed in this section, please see, for example, Alizamir et al. (2007), Tomlin (2009b), and references therein.

6. Strengthen supply chain

Risk is sometimes measured along two dimensions: likelihood and impact. The four strategies covered so far all tackle the impact of a disruption, that is, they seek to minimize the negative consequences of a supply interruption. Companies can, and should, also consider addressing the likelihood of a disruption. By stress testing their operations and conducting effective scenario planning, companies can identify and rectify weakness in their current operations that leave themselves vulnerable to internal disruptions. Building strong internal processes does not go far enough. According to Genzyme's June 25 press release:

The virus [that caused the Allston plant disruption] was likely introduced through a raw material used in the manufacturing process, and the company is collaborating with its suppliers to address this issue and implement steps to protect against recurrence. Genzyme is also evaluating adding steps to its raw-materials screening and virus-removal processes to make them more robust, including testing all of its raw materials for the presence of Vesivirus 2117 using the highly specific assay it developed. In addition, Genzyme is collaborating with other biologics manufacturers to learn from their experience and apply this knowledge to resolve the current situation and implement enhanced safeguards. Genzyme intends to share its own experience with this virus through appropriate mechanisms so that others within the industry may benefit. This includes working to ensure that an assay for Vesivirus 2117 becomes widely available to the industry.

As is common, Genzyme relied on suppliers to produce important ingredients. This meant that Genzyme was at risk of a supplier-induced disruption, either through incoming materials causing problems at a Genzyme facility or through a supplier disruption interrupting material flow to a Genzyme facility. Most companies find themselves in a similar position. Therefore, they must determine how best to protect themselves from supplier-induced disruptions. Companies can avail of the four strategies discussed so far but they can also develop their supply base to reduce the likelihood of supplier-related interruptions. When contemplating this strategy, companies need to consider their approach to supplier development; the timing of supplier commitment, and the risks of spillover.

¹¹ Companies operating in industries with high demand volatility and high inventory-related costs are more likely to make the necessary demand-switching investments as they continually battle supply-demand imbalances.

Approaches: Framing supplier development in the wider context of increasing supplier “performance and/or capabilities to meet the firm’s short- and/or long-term supply needs,” Krause (1997) offers the following categorization of supplier development approaches: (i) enforced competition through sourcing from multiple suppliers; (ii) incentives, i.e., the promise to a supplier of benefits such as increased volume, and (iii) direct involvement, whereby the company exerts effort to improve its suppliers capabilities. Direct involvement can range from relatively low-effort activities such as informal evaluation and feedback, through medium-effort activities such as certification programs, to more effort-intensive activities such as supplier training programs and equipment investments. According to their studies, Krause et al (2007) found that delivery-reliability related improvement outcomes depended more on direct involvement, then did cost improvement outcomes. This suggests that enforced competition and incentives, while effective at reducing costs, may be less effective than the direct involvement approach at strengthening supplier reliability. Companies would therefore be well advised to work directly with suppliers on improving their reliability. In fact, a 2008 survey (Global Supply Chain Trends 2008-2010) by the consulting company PRTM finds that many companies are indeed taking this path: “companies have developed numerous ways to minimize disruption related to quality and delivery issues. Increasing the frequency of on-site audits is the most commonly cited approach, followed by physical deployment of their company’s resources within the supplier’s location, increased inspection, and increased supplier training. Other risk mitigation strategies mentioned frequently include consistent dual sourcing strategies.” Well-known companies in a wide range of industries, including Intel in the electronics industry, Honda and Toyota in the automotive industry, and Kimberly Clark in the consumer goods industry, are engaged in direct-involvement supplier development.

Commitment: Supplier improvement efforts can and do fail to achieve their desired outcome. A company attempting to improve a supplier’s reliability might find that the supplier’s processes are no more resilient despite the effort invested by the company. This poses something of a quandary for the company: should it commit to the supplier, i.e., enter a binding agreement to use the supplier, before it observes the outcome of its improvement efforts or should it postpone commitment until improvement outcomes are known? Early commitment assures the supplier that it will receive orders from the company and so provides an incentive for the supplier to engage in meaningful collaboration. This can be very beneficial if improvement outcomes depend on good-faith efforts on the part of both companies. Late commitment enables the company to hedge against improvement failure because it gives the company the option of allocating its orders amongst suppliers after observing improvement outcomes. Both tactics have merit and some companies choose early commitment while others choose late commitment. Late commitment is less valuable if a company has a very heterogeneous supply base, that is, when potential suppliers (of the same component) differ significantly in cost or some other relevant dimension. Postponing supplier selection through late commitment offers little value as it is already obvious which supplier will be preferred regardless of improvement efforts. Late commitment is of particular value when improvement efforts at different suppliers exhibit different outcomes. If the improvement success probability is very high or very low, then it is likely that all improvement efforts with either succeed or fail, and so outcomes will be similar. Late commitment is therefore more valuable when improvement success probabilities are not too high or too low. If improvement costs are low, then

the company can afford to engage in improvement efforts with multiple companies before allocating its orders. Low improvement costs therefore favor late commitment. Companies undertaking supplier development efforts need to carefully weigh the advantages and disadvantages of the commitment timing options.

Spillover: Companies often source from the same supplier as their competitors. By working with the supplier to improve its operations, the company runs the risk of unwittingly benefiting its competitor. The supplier may take the knowledge or assets gained during the improvement effort and improve its service offering to the competitor. In essence, one company can be a free-rider that gains from another company's supplier development efforts. A greater risk is that the supplier will unwittingly (or knowingly) pass along confidential information learned during the collaboration to the competitor. Companies need to weigh these risks and determine if safeguards can be put in place. On a more positive note, competitors might benefit from collaborating to address a common threat. Collaboration can spread the costs amongst more companies and might lead to a better solution.

By strengthening their supply chains through supplier development efforts, companies can reduce the likelihood of supplier-induced disruptions. Oftentimes, supplier development programs grow out of one-time projects instigated in reaction to a particular supplier failure. Effective supplier development program requires careful planning and implementation. In addition to the issues discussed above, managers need to determine which suppliers to target, how to allocate effort across their supply base, and how to measure outcomes. For those readers wanting to delve more deeply into the research underpinning some of the points discussed in this section, please see, for example, Krause (1997), Krause et al. (2007), Wang et al (2008), and references therein.

7. Conclusions

Companies should carefully consider all five strategies – inventory, supply diversification, backup supply, demand management, and supply-chain strengthening – when developing their risk management plans. Each strategy has its strengths and limitations and managers need to align the strategy with the environment they operate in. A one-size fits all approach of employing the same strategy for all product lines may not be appropriate if different products exhibit different supply chain and market characteristics. The disruption management strategy should be tailored to the needs of each product. Managers may also want to deploy multiple strategies, e.g., combine inventory with backup supply, to add an extra layer of protection if they are especially concerned about minimizing interruptions. Because some of these five strategies – inventory, backup supply, and demand management – help mitigate demand uncertainty, managers should not segregate supply-risk and demand-risk planning. Instead, these five strategies should be viewed through the broader lens of supply-chain risk management which encompasses availability, cost, demand and quality risks.

The field of disruption risk management is still in its relative infancy, and many questions remain unanswered. Research and development that addresses the following needs would help advance the knowledge and practice of supply chain disruption management.

From insight to decision support: As one might expect in a nascent field, much of the scholarship to date on disruption risk management has focused on improving our understanding of the underlying phenomena. That is, research has helped shed light on the factors that need to be weighed when developing a disruption management strategy. Much of the quantitative work has been done in a “controlled setting” using simplified models that are amenable to analysis. Moving forward, there is a need to develop decision-support tools that can help managers quantitatively evaluate various strategies in a realistic supply chain setting. Such a development would echo the evolution of network design and inventory-target setting from small-scale models with limiting assumptions to commercial-strength software applications. This will require models that are scalable to allow for hundreds, if not thousands, of stock keeping units (products) and hundreds of supply chain processing locations and links. A first step would be the development of large-scale models that enable performance-evaluation of a chosen strategy. Going further, companies would benefit from large-scale models that also recommend appropriate strategies based on the manager’s objective and budget.

Risk evaluation: Much of the existing work on disruption risk management assumes that managers have some estimates of the likelihood and severity of disruptions. This may be reasonable in some circumstances but not in all. For disruptions caused by natural disasters or supplier bankruptcies, there may be publically available hazard or financial information that is helpful in estimating the underlying likelihoods. For recurring disruptive events, firms can refine their estimates based on past history. Companies would benefit from the development of robust methodologies and systems that enable firms to update their risk estimates based on past experience and public sources of information. However, even with such systems, it is difficult to estimate the probability of events that occur very rarely. If an event has not occurred in the past, that does not mean it cannot occur in the future, and so basing estimates on the past frequency of occurrence can be misleading. As with any quantitative modeling approach, managers should engage in sensitivity testing to ensure that their plans are robust to misestimation of the disruption parameters. However, the disruption-management field would benefit from the development of appropriate methodologies that explicitly account for the difficulties in estimating and evaluating low-probability events.

Interruption Insurance: Companies can purchase special insurance policies that provide some coverage for costs or lost income associated with a business interruption. Typically the insurance policy is aimed at insurable events, e.g., fire-related damage, covered by a standard insurance policy. The standard policy helps to defray the cost of repairing/replacing the damaged facility, whereas interruption insurance targets the losses (including income) incurred as a result of the damaged facility interrupting normal business activity. Companies can even purchase coverage for interruptions caused by disruptions at a supplier’s facility, assuming the disruption is caused by an insurable event. Insurance, therefore, offers another tool for managing disruption risk. Under what circumstances is interruption insurance a better solution than an operational strategy? Is interruption insurance a substitute for an operational strategy or does it complement the operational strategies? There is a need for research to answer these and other questions to help bridge the disciplines of insurance and operations.

Thanks to the work of many scholars and practitioners, a solid foundation is being built for the field of disruption risk management. A good start has been made but much remains to be done to deepen our understanding and to develop solutions. Collaboration between scholars and practitioners is crucial to help steer the development of the field so that it addresses the needs and realities of business in a manner that is grounded in rigorous and scientific methodologies.

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