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A Strategic Framework for Managing Failure in JIT Supply Chains

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ABSTRACT

Supply chains can be disrupted at both local and global levels. Just-In-Time (JIT) companies should be particularly interested in managing supply chain failure risk as they often have very little inventory to buffer themselves when their upstream supply chain fails. We develop previous research further and present a strategic framework to manage supply chain failure in JIT supply chains. We identify two dimensions along which the risks of failure can be categorized: location and unpredictability. We go on to identify strategies which companies can use either before (proactive) or after (reactive) the failure to manage supply chain failure. We support our framework with examples of actual responses to supply chain failures in JIT companies. It is also hoped that our strategic framework will be validated empirically in the future leading to specific guidance for managers.

Keywords: *just-in-time; manufacturing industry; organizational risk; partner firms; strategy and policy; supply chain management*

INTRODUCTION

Just-in-time (JIT) manufacturing, with its focus on continuous improvement through waste reduction and problem solving, has been widely hailed as a philosophy that improves organizational performance. JIT principles include only having required inventory; improving quality; trimming lead time by reducing setup time, queue length, and lot sizes; and reducing costs in the process (Cox & Blackstone, 2002). The philosophy offers organizations some significant cost and quality benefits (e.g., Funk, 1995; Duguay, Landry, & Pasin, 1997; Claycomb, Germain, & Droge, 1999), so it is not surprising that large numbers of organizations around the world have implemented or are in the process of implementing JIT manufacturing.

However, there are several disadvantages and implementation difficulties associated with JIT (Im, Hartman, & Bondi, 1994; Inman & Mehra, 1989), including supply chain failure (Altenburg, Griscom, Hart, Smith, & Wohler, 1999; Zsidisin, Ragatz, & Melnyk, 2005; Kleindorfer & Saad, 2005; Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007). The risk of supply chain failure refers to the combination of the probability that an element of the supply chain will fail, and the magnitude of the disruption caused by the failure throughout the remainder of the chain. A recent McKinsey survey found that managers face increasing supply chain risk (Krishnan & Shulman, 2007). Understanding supply chain failure is particularly important for JIT organizations because companies using JIT are especially susceptible to failures in their upstream supply chain as they have limited inventory to protect them if the parts do not arrive on time.

Tang (2006) categorizes supply chain risk as operational or disruptional. Operational risk refers to inherent uncertainties such as uncertain customer demand, uncertain supply, and uncertain cost. Disruption risks relate to natural and man-made disasters or economic crises. This article focuses on the disruptional risk aspect of JIT supply chains since, as Tang points out, the impact of disruptional risk is far greater than that of operational risk.

We begin by briefly outlining research on risk within supply chains, and on the particular challenges facing managers within JIT supply chains. We then go on to develop two dimensions of supply chain failure based on our inference from industry practice reported in the literature: (1) the location, and (2) the unpredictability of the supply chain failure (or unpredictability in recovering from failure). While others have focused on dimensions of supply chain failure such as controllability of the risk or severity of impact, we extend these treatments by emphasizing the location of the supply chain failure: whether the risk of supply chain failure is internal to the firm, external to the firm but internal to the supply chain, or whether it is systemic within an industry/region external to the supply chain. We illustrate the framework by categorizing some of the proactive and reactive processes used by companies to mitigate JIT supply chain failure. We conclude with a discussion of the implications of our framework for research on supply chain failure and JIT, and for practitioners. Our location-based view provides managers with an additional lens with which to view JIT supply chain risk, and an organizing framework to generate potential strategic risk management options.

It is hoped that this exploratory framework will lead to future studies using empirical approaches such as case-based research to validate the proposed framework. Case-based research (Miles & Huberman, 1994; Yin, 1994) can be used to explore in depth the use of different risk management approaches, among others. This type of in-depth research will allow the development of specific guidelines that managers can use to address supply chain risk within the enterprise.

SUPPLY CHAIN FAILURE AND JIT SYSTEMS

Sudden or catastrophic supply chain failure in JIT environments can have serious organizational impacts. The most common response has been to reduce or stop production until systems were operational again. The September 11, 2001 (9/11) terrorist attacks which delayed goods flowing between the United States and Canada, (Keenan, 2001), the 1995 stoppage of commercial traffic on the Rhine River in Germany due to flooding, the August 2003 power outage in the Northeastern and Midwest United States and Ontario, Canada, and the aftermath of the Kobe earthquake are examples.

Mitchell (1995) would categorize these examples as "performance loss" or "time loss" due to supply chain failure. However, the impact of supply chain failure does not end with merely immediate performance and time losses; they can extend to "financial loss" due to lost orders or the operational cost of remedying the failure, "physical loss" of facilities or supplies in cases of fire or flood, and even to "social loss" of the firm's reputation for reliability or "psychological loss" due to the stress of coping with the failure or damage to the organization's self-perception. It is therefore crucial that we better understand supply chain failure, and develop robust supply chain mechanisms and structures to cope with actual or potential failure.

Research on the supply chain design implications of following a JIT manufacturing strategy has tended to focus on "single sourcing, close supplier location, long-term relationships, schedule coordination and sharing, frequent deliveries of small lot sizes and stable supply-chain pipelines" (Das & Handfield, 1997, p. 246). Technical modeling on, for example, lead time uncertainty (e.g., Schwartz & Weng, 2000) has been complemented by survey-based research on the perceived cost reductions from implementing JIT purchasing and logistics (e.g., Dong, Carter, & Dresner, 2001). While some of these studies make passing reference to the risk of supply chain failure, research on JIT supply chains has contradictory messages on managing such risk. On the one hand, some JIT supply chain characteristics such as schedule coordination and long-term relationships encourage repeated interactions, trust, and increased information sharing, hence decreasing the likelihood of supply chain failure over time. On the other, increased strategic risk, or over-reliance on a single or limited number of suppliers (Sadgrove, 1996), can magnify the impact or outcome of any potential upstream supply chain failure since the JIT firm may have fewer alternative sourcing options.

Thus managerial recommendations for designing supply chains to handle failures are often complex or even contradictory. Mechanisms and structures to manage supply chain failure differ in their scope and timing. To take some examples from a recent list by Elkins, Handfield, Blackhurst, and Craighead (2005), some design strategies are implemented within a focal organization (e.g., training employees, including expected costs of failures in the total cost equation), some are implemented across the entire supply chain (e.g., enhancing system-wide visibility and supply chain intelligence by using near-real-time databases), and others require the involvement of supply chain members within particular industries or regions (e.g., gathering intelligence and monitoring critical supply-base locations). Similarly, some strategies are implemented before a failure (e.g., creating early warning systems to discover critical events outside normal planning parameters), and others are designed in response to a failure (e.g., conducting a detailed incident report and analysis following a major disruption). Further complicating the intervention suggestions is that some risks are much more unpredictable than others, and so need relatively more or less intensive monitoring and management.

Given the complexity of supply chain risk, many authors have developed two-dimensional frameworks for risk management. For example Meitz and Castleman (1975), Kraljic (1983), and Sheffi and Rice (2005) incorporate the probability that an element of the supply chain will fail and the magnitude of the disruption caused by the failure throughout the remainder of the chain as dimensions. Chopra and Sodhi (2004) examine 'level of risk' and 'cost of mitigating reserve' as dimensions in order to suggest risk mitigation strategies. Cavinato (2004) examines risk on the 'risk/uniqueness' and 'value/profit potential' dimensions. Kleindorfer and Saad (2005) examine supply chain risk management from a 'cost of disruption' vs. 'cost of risk mitigation' perspective. Thus the various two-dimensional frameworks have proved useful lenses for managers attempting to manage supply chain risk.

Recent treatments of supply risk also recognize the importance of both the source and outcome of the risk of failure (Zsidisin, 2003), and explicitly recognize that the source of supply chain failure can occur further away than the immediate buyer-supplier dyad (Zsidisin, 2003b; Spekman & Davis, 2004). Natural disasters, strikes, or fires can affect not only the first tier, but also second- or third-tier suppliers that are integrated within the JIT manufacturing system. Supply chain failures arising from apparently remote disruptions can have significant impact on an integrated supply chain, particularly within an increasingly uncertain, post-9/11 global environment (Spekman & Davis, 2004; Barry, 2004). Our framework will assist decision makers to develop appropriate responses to apparently distant supply failure risks by focusing on the location of the risk.

An important aspect of managing supply chain failure is to understand how and why supply chain disruptions occur. Chopra and Sodhi (2004) emphasize the importance of understanding the drivers of risk (labor disputes, inadequate capacity, and weather are some examples) and categorize them to help develop effective risk mitigation strategies. Kleindorfer and Saad (2005) suggest 10 principles to help understand and mitigate supply chain failure. Craighead et al. (2007) identify network density, network complexity, and node criticality as drivers of supply chain failure risk, and recovery and warning as drivers of supply chain failure mitigation.

While these are useful starting points for understanding the risk of failure in JIT systems, a framework is needed which helps managers deal with the complexity of risks arising in distant supply locations both before (proactive) and after (reactive) the failure. The research in *proactive* planning in supply chain disruption risk has paid insufficient attention to risk mitigation strategies based on location of the risk (i.e., whether the disruption risk is internal to the firm, external to the firm but internal to the supply chain, or external to the supply chain). This is an important oversight in our current understanding of the proactive management of supply chain failure since risks internal to the firm may be most controllable while disruption risk external to the supply chain may be least controllable. While focusing on the location of supply chain failure, our framework echoes previous research, which includes the unpredictability of the risk. We suggest that the proactive approach to JIT supply chain risk mitigation can be understood better if analyzed on the 'location of failure' and 'unpredictability of failure' dimensions.

In addition, while many articles discuss avoidance of disruption by upfront planning, only a few (Lee, 2004; Sinha et al., 2004; Zsidisin, Melnyk, & Ragatz, 2005a; Zsidisin, Ragatz, & Melnyk 2005b; Tang, 2006; Craighead et al., 2007) discuss *reactive* recovery in the case of supply chain failure. Since supply chain failures will take place occasionally even with the best of proactive planning, we should also address the reactive management of supply chain failure. We suggest that the recovery from JIT supply chain failure (reactive approach) can be usefully analyzed along the same two dimensions of location and unpredictability.

LOCATION AND UNPREDICTABILITY AS DIMENSIONS OF SUPPLY CHAIN FAILURE

While the risk of supply chain failure is influenced by many factors, we focus on two primary dimensions: location and unpredictability. To consider location first, supply chain failures may be classified as: internal to the organization, external to the firm but internal to the supply chain, or external to the supply chain. Internal organizational failures include strikes or chaos arising from internal reorganization. It is important to note that a focal firm's internal failures could affect other supply chain members (for the other members the risk is external to the firm but internal to supply chain situation). Conversely, suppliers might suffer performance loss due to their own internal reorganization or financial difficulties, but this could affect the focal firm and so is categorized as external to the firm but internal to the supply chain. External to supply chain failures are generally due to acts of God such as weather or natural disasters, or acts of human aggression such as terrorism, sabotage, or arson (though these could apply to the other two categories also).

Location as a dimension of supply chain failure is related with controllability to the extent that failures arising further from the firm are less controllable than the focal firm. The advantage of location over controllability is that if managers can understand the location of a given risk, then they are better equipped to find a proactive plan or reactive response based on the location. Highly uncontrollable risks have the implication of managerial impotence. However, as we argue below, risks in distant locations encourage managers to think of mitigation actions matched with the location.

Our second dimension, unpredictability, captures the extent to which the probabilities of a failure and its impacts are ambiguous. This extends from traditional notions of risk (where probabilities and variables are known) and uncertainty (where variables are known, but probabilities are not), to an extreme form of unpredictability where neither the variables nor probabilities associated with supply chain failures are known (Hall & Vredenburg, 2005). Thus highly predictable failures can be understood with traditional risk measurement and management techniques, whereas highly unpredictable failures can usually only be identified after the fact.

The location of supply chain failure is often correlated with unpredictability of occurrence (or the unpredictability of recovering from a failure), since in general, the nearer the failure is to the focal organization, the more information the focal firm may have of the variables or probabilities of failure. Usually, an organization has little visibility of external failures even though it still has to deal with the failure. Sometimes, there may be an indication that the failure will occur such as in the case of an impending hurricane, but at other times there may be no warning. However, even some potential failures internal to the firm are unpredictable, and other external failures may be predictable. Therefore our framework maps location against unpredictability in an orthogonal two-dimensional space, including the entire conceptual set of failures from internal to external and from high predictability to low.

Examples of external failures which have high unpredictability include natural disasters, which can have very far-ranging effects, like floods and earthquakes. In these instances, an entire geographic locale is affected, usually including transportation arteries and local suppliers. Major parts of the global supply chain can be affected for all companies, whether JIT or not, such as with the 1995 earthquake in Kobe, Japan (Forman, Williams, & Sapsford, 1995), the ice storm and resulting power outage of 1998 that produced chaotic conditions in eastern Canada (Chipello, 1998), the 9/11 terrorist attack (Ip, 2001), and the SARS epidemic in Asia (Young, 2003).

Supply chain failure internal to the chain can arise due to actions taken or occurring within the supply chain. Consequently, for the most part they have at least some predictability and can be prevented by better supply chain practices. However, when the supply chain fails due to a strike at the logistics provider, for example, the effect can often be widespread. In the United States, the United Parcel Service (UPS) strike greatly affected its customers, especially those who used UPS as their sole "rush goods" transporter. During the strike, because UPS handled such a large portion of the U.S. market (63% of all rapid deliveries and 80% of all ground deliveries), other companies like Federal Express and the U.S. Postal Service were not able to pick up all the slack. The competition also placed a number of restrictions on customers due to increased volume (Coleman & Jennings, 1998). Nonetheless, since everyone in the U.S. was dealing with the impact of the strike, customers had to be more understanding. Another example of a high-impact strike is when the major trade unions strike, such as the 2002 longshoremen strike on the U.S. West Coast (Cavinato, 2004).

Examples of predictable failures within the firm would be reorganization, including mergers and acquisitions, plant expansions, major supply chain software installations, and the like. When Union Pacific acquired Southern Pacific Rail Corporation, poor integration of the scheduling systems resulted in more than 10,000 rail cars a day stalled due to a shortage of locomotives, crew members, and track space. Union Pacific's customers, whether JIT or not, had to work around the supply chain failure (WSJ, 1997). Problems with an Enterprise Resource System (ERP) software installation resulted in shipment delays and incomplete order shipments at the Hershey Company (Stedman, 1999). While the company kept producing, the software implementation glitches resulted in chocolate piling up in warehouses instead of being shipped.

A less predictable failure within the supply chain would be if a supplier goes bankrupt or encounters financial difficulties, which can result in the work being stopped quickly. This can be a particularly serious failure, since there is a focus on single sourcing and small lot deliveries in JIT. Land Rover in the UK faced this difficulty when its only chassis supplier UPF-Thomson faced financial difficulties in 2001 (Meczes, 2004).

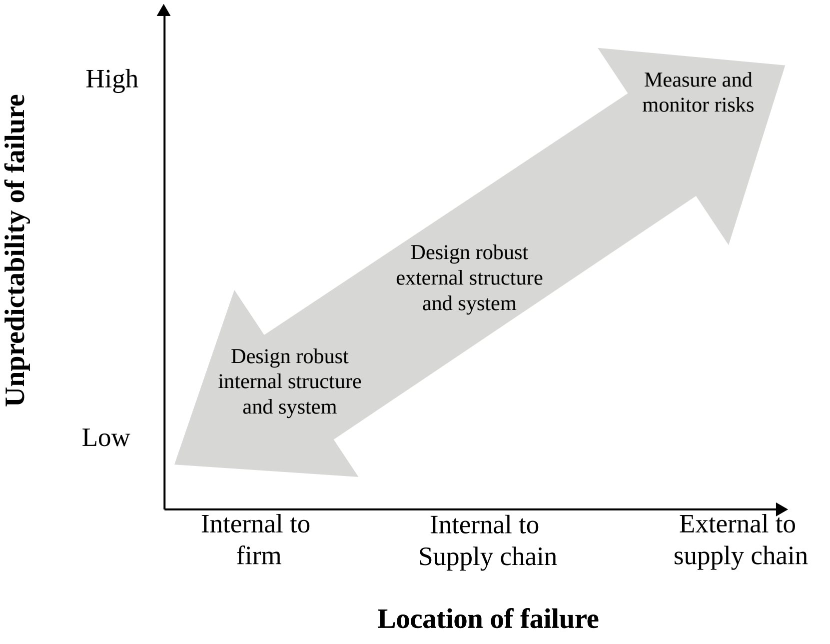
Sometimes, what starts as an internal failure can have far-ranging effects. Natural disasters can impact locally, as when a fire guts a building, though the impact may be significant when that building houses the sole supply for another organization, as in the case of a lightning-bolt-based fire at a Philips semiconductor plant that supplied Nokia and Ericsson (Latour, 2001) and at Aisin, a supplier of Toyota (Reitman, 1997).

Thus location and unpredictability of failure appear to be dimensions that warrant investigation. In the following sections we elaborate on the strategic issues in the proactive and reactive management of supply chain failure in JIT systems. As mentioned earlier it is hoped that this discussion will lead to future empirical research into this topic, leading to more specific management suggestions.

PROACTIVE MANAGEMENT OF SUPPLY CHAIN FAILURE

How can firms anticipate, avoid, or minimize supply chain failure before it occurs? In Figure 1 we map proactive risk mitigation strategies in our location/unpredictability framework (see Kelindorfer & Saad, 2004; Chopra & Sodhi, 2004; Lee, 2004; Johnson, 2001; Sinha et al., 2001). Based on examples of strategies and tactics that firms have adopted, and suggestions of strategies from the literature, we derive three main proactive options for firms along the shaded arrow depending on the location and unpredictability of the failure. These range from: (1) designing a robust internal structure and system, through (2) designing

Figure 1. Proactive management of supply chain failure



a robust external structure and system, to (3) measuring and monitoring risks in the external environment.

Robust Internal Structures and Systems

To manage highly predictable (i.e., low unpredictability) and internal potential failures, firms *design robust internal structures and systems.* For example, when companies believe that a supply chain failure may be coming, they may have a policy of stockpiling parts; that is, they implement failure anticipation inventory (Chopra & Sodhi, 2004; Sheffi & Rice, 2005). When GM speculated that its unions might go on strike, it tried to prevent supply chain failure; it stockpiled in advance, had contingency plans, and maintained backup data from the suppliers on the components of their products (Becker, 1998).

Another aspect of internal system design is business continuity planning (Zsidisin, Ragatz, & Melnyk, 2005; Zsidisin, Melnyk, & Ragatz, 2005; Sinha et al., 2004; Kleindorfer & Saad, 2004; Chopra & Sodhi, 2004). Steps such as risk analysis, contingency plans, logic charts and tabletop exercises, and failure modes and effect analysis (FMEA) would be useful in planning to deal with supply chain failure. This type of system planning becomes even more important when the company knows that the probability of a failure occurring may be higher than usual. For example, locations that suffer snowstorms, hurricanes, and the like with known probabilities can plan for disaster recovery within certain tolerances. Internally, if a strike is expected or if a labor contract is coming up for renewal, the company can choose to make "just in case" plans.

Lee (2004) emphasizes the great importance of agility, adaptability, and alignment in building robust supply chains (he calls it the Triple-A supply chain). Honda is a leader in flexible assembly plants, producing more than one model on the same line, and the same model at more than one plant. The Honda plant in Ontario, Canada, can build the Odyssey van and two types of SUVs on the same assembly line, while the Honda plant in Alabama can also produce the Odyssey (Keenan, 2003). While this increases Honda's flexibility from a competitive viewpoint, it also protects against supply chain failures. In case of a supply chain failure in Ontario, production at Alabama could be ramped up. Similarly Toyota is following a strategy of spreading out the location of its plants in North America to reduce what it teams as "geographic risk" (Shirouzu, 2005).

Another strategy is to minimize variability, that is, increase the ability to manage the process consistently. An example of variability would be the breakdown in machinery that might delay a shipment. Variance reduction and process improvement allow the organization to become better at supply chain management, which can result in fewer supply chain failures. If waste and variability can be removed (the JIT philosophy), the chain becomes more robust and it becomes easier to prevent problems from occurring. For example, the JIT practice of small batch sizes and reduced lead times helps reduce variability, or risk, in supply (Lee, Padmanabhan, & Whang, 1997). This could help avoid spikes in the supply chain that often creates a domino effect leading to supply chain failure.

Reducing the size of the product line through rationalization and the use of modularity will help duplicate production capacity (Kleindorfer & Saad, 2004; Chopra & Sodhi, 2004). This will allow production shifts in the case of supply chain failures.

For instance, in 1999 Unilever made plans to trim away 1,000 of its 1,600 brands to focus on global/regional brands instead of local/national brands. The primary focus would become 400 brands that account for almost 90% of its annual revenue (Beck, 1999). Part of the rationale was to simplify the supply chain, which should make it more robust. When there are fewer products, it is also easier to duplicate production. Producing the same product at multiple locations allows the company to shift production when the supply chain fails at one facility. Even if a product is not duplicated, standardized components (modular design) and processes make it easier to locate an alternate source when the chain fails, as compared to totally customized components. An auto manufacturer was caught short recently because it failed to do this. It had a single supplier for rubber radiator gaskets that used unique machinery to produce these gaskets. When a fire destroyed the gasket supplier's machines, the only option left was to remanufacture the machines with much cost and time delay, as no alternative supplier could be found due to the uniqueness of the machines (Martha & Subbakrishna, 2002). In contrast, Toyota made use of the Aisin fire to improve its system by launching a project to increase parts standardization. In the case of the Philips fire, among its customers, Nokia was able to recover more quickly since it could find alternate sources of supply because its phone was more modularly designed than that of another customer, Ericsson (Tang, 2006).

Firms can also design their internal systems to manage product design and product portfolio for supply chain robustness. Innovative product manufacturers often use flexibility or postponement to deal with rapid changes in demand (Lee, 2004). Dell is able to circumvent the negative effects of components partially, by offering promotions and price discounts for other products for which components are available. Thus operations continue as normally as possible and the standardized modular components are being used rather than being left to accumulate dust and cost in inventory.

Other aspects of internal system design can include analyzing risk early in the product lifecycle. Teradyne Inc. incorporates supply chain analysis at the product design stage (Atkinson, 2003). The company tries to identify potential failures early in product design. The goal is to create a product sourcing plan that becomes a roadmap that anticipates and generates mitigation plans for every risk identified. Risks could relate to technology, suppliers, and parts. Naturally, suppliers should be involved in the product design stage to maximize the flexibility in the design for supply chain robustness (i.e., *external structure and system*, which is discussed later).

Designing a robust internal system can be helped by a formalized process (Hauser, 2003). Companies can seek to optimize supply chain performance by analyzing supply chain risk and making sound business decisions based on this analysis. This helps companies identify, quantify, and prioritize risks (sometimes hidden) in their supply chain and take proactive action to mitigate these risks. Hauser's model involves the following steps: (1) identifying risks, (2) understanding which risks can lead to significant supply chain disruption, (3) quantifying the economic impact, (4) determining the organization's desired risk profile, (5) conducting simulations and identifying key performance measures, (6) developing risk mitigation initiatives along with timing and sequences, and (7) measuring and monitoring performance. A similar process is used in business continuity planning (Barnes, 2001; Zsidisin, Ragatz, & Melnyk, 2005; Zsidisin, Melnyk, & Ragatz, 2005). A utility in the Midwestern United States was able to recover from the effects of a very major storm much better than other utilities in the same area because it had a plan in place that outlined what suppliers were to do in the event of a storm. While other utilities struggled to get power back to customers within four weeks, this utility was able to get power back to all its customers within two weeks. Other strategies to prevent supply chain failure could involve carrying critical parts at strategic locations (Atkinson, 2003; Aichlmayr, 2001).

Robust External Structures and Systems

The best defense when risk of failure is outside the firm but in the supply chain, and the risk is fairly predictable, is to *design robust external structures and systems* (Johnson, 2001; Kleindorfer & Saad, 2004; Chopra & Sodhi, 2004). This might include alternate sources of supply and distribution. A comparison of Japanese and American auto manufacturers in 1990 showed that while Japanese companies in Japan had about a third of the suppliers per assembly plant compared to their American counterparts, they only had 12% of their parts single-sourced compared to 69% for the Americans (Womack, Jones, & Roos, 1990, p. 157). This is confirmed by a study by Shin, Collier, and Wilson (2001) that found that dual or multiple sourcing was common. Increased globalization in the logistics industry and information technology is making it more feasible to find alternate sources of supply; not only are there more logistics providers, these providers are also global. This increases the chances of locating a supplier worldwide who is able to supply the affected facility.

Craighead et al. (2007) discuss the effect of supply chain density, supply chain complexity, and node criticality on the possibility of disruptions. Thus when one designs the supply chain structure, these factors must be analyzed in order to come up with a resilient design. Sinha et al. (2004) and Tang (2006) address external supply chain structure from a risk perspective.

Another example of a robust structure is the use of collaborative planning, forecasting, and replenishment (CPFR), which these days involves supply chain management (SCM) software and can help avoid problems (Tang, 2006). Greater visibility in the supply chain can be a successful mechanism to prevent disruptions (Christopher & Lee, 2001). If a supplier or one of its partners goes through a merger, acquisition, plant expansion, or software installation, operational planning with the supplier is critical. Texas Instruments uses CPFR to manage items on a JIT basis (Roberts, 2004). If disruptions do occur, real-time information available in SCM software also allows quick what-if analysis. This will help the organization make alternate plans to combat the disruption, whether it is alternate suppliers, routes, or logistics providers. Technologies like Internet marketplaces allow for quick identification of alternate sources of supply, while technologies such as Geographical Positioning Systems (GPSs) and Radio Frequency Identification (RFID) will allow companies to monitor the location of inventory within the supply chain, an important requirement in a JIT system where there is no excess inventory.

It is important to select supply chain partners carefully and strategically when structuring the supply chain based on their capability (Johnson, 2001). The partners in the supply chain, whether suppliers or customers, will have an impact on the chain. When their part of the chain fails, the whole supply chain is affected. Thus, the primary selection criteria should be their capability to maintain supply and their ability to respond in case of supply chain failure. For instance, it is important to examine a potential supplier's financial viability. In addition their plans in case of supply chain disruption should be examined. The example of the utility in the Midwest is a good illustration of this. When power fails, manufacturing will be significantly affected. Thus even the capability of utility partners within the supply chain is important.

Measurement and Monitoring

Prescription from the literature is weakest on how to deal with highly unpredictable events, especially those events external to the supply chain. Perhaps the best solution for highly unpredictable failures is consistent *measurement and monitoring*. Authors such as Hauser (2001), Zsidisin, Ellram, Cater, and Cavinato (2004), and Sinha (2004) include monitoring as part of their risk management process. In highly unpredictable situations this takes on added importance since it is difficult to plan ahead for something that is not known. Such monitoring can include early warning systems to discover internal system operations that exceed normal planning parameters (for internal to the firm); screening and regularly monitoring current suppliers for possible supply chain risks (for external to the firm, but internal to the supply chain situations); and scanning the external environment possibly through the use of scenario analysis (for external to the supply chain situations). The most recent literature in this area has begun to develop prescriptions on how to manage highly unpredictable failures (e.g., Rice & Caniato, 2003; Zsidisin, Ragatz, & Melnyk, 2005; Zsidisin, Melnyk, & Ragatz, 2005; Sinha et al., 2004; Craighead et al., 2007). The emphasis in these prescriptions is on upfront planning and monitoring so that the firm is in a good position to improvise if the unpredictable does occur. For example, one company seeing the potential for disruption in the supply chain leased additional transportation equipment, just in case (Craighead et al., 2007). While the inability to predict or take proactive action may be frustrating, it is important to note that highly unpredictable failures such as weather, acts of war, and other natural causes are likely to be more widespread with wide-ranging effects. So partners in the supply chain as well as customers themselves may be affected and are more likely to be understanding. In this situation the focus moves to reactive options in the post-failure stage outlined below, where it is important to be able to respond quickly to restore the supply chain.

Planning and buffering can be useful in managing failure. Though it is easier to buffer when the unpredictability is low, it has been used in highly unpredictable situations if the situation warrants it. During the Y2K warnings, the Cap Gemini Group commissioned a survey; it found that about 40% of the U.S. companies surveyed planned to stockpile inventory. Xerox Corp. built up a month's supply of raw materials (about four times the usual amount) and made sure suppliers were Y2K compliant (Aeppel, 1999). Similarly, when Toyota expects major demand changes within the year, it knows that its supply chain needs to be more responsive than usual. It sets the load of the machine at half of its future capacity; each worker operates several machines. This gives the capacity flexibility and buffer.

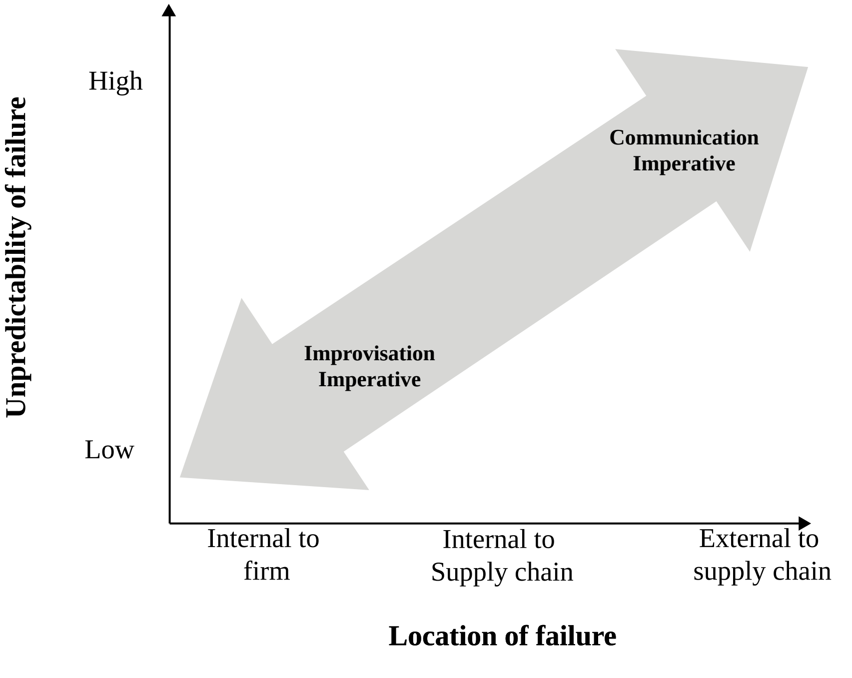
REACTIVE MANAGEMENT OF SUPPLY CHAIN FAILURE

What can companies do in the immediate aftermath of the failure to mitigate the damage? We suggest that it should vary according to the location and unpredictability of the recovery from failure (see Figure 2). The two core strategies suggested are communication and improvisation. Companies can also use a combination of these two core strategies.

The appropriateness of each strategy depends on the location of the failure. In Figure 2 as the location of the failure moves closer to being internal to the supply chain and unpredictability is lower, customers may feel that the failure could have been predicted and so be less forgiving. Thus they would expect the company experiencing the failure to act quickly to fix the problem (an 'improvisation imperative'). On the other hand for failures that are more external to supply chain and are more unpredictable, customers would be more willing to accept slower improvisation, but will expect communication on progress toward normalization (a 'communication imperative').

Consider two examples of internal failure discussed earlier. In the case of failure due to new software implementation, customers might expect that those problems were predictable (as there are many cases of firms experiencing this type of disruption). So they expect the company to have done some proactive planning to prevent such failures and to have recovery plans. In this situation, firms need to improvise quickly to fix the software problem. On the other hand if the failure was due to a factory fire resulting from a freak lightning strike,

Figure 2. Reactive management of supply chain failure



customers may be more forgiving and be satisfied with immediate communication and later improvisation.

The Communication Imperative

A example of the *communication* imperative situation due to freak events was experienced by Mitel Corp. (a semiconductor manufacturer) in 1998 during the ice storm. Mitel had to rent generators to produce electricity; even so, it could not recover lost time, as it was a 24-hour-a-day operation. So, Mitel communicated with its customers daily on the telephone to update them on the situation, and rescheduled production and shipment carefully to satisfy their customers as much as possible (Chipello, 1998). Kleindorfer and Saad (2004) and Craighead et al. (2007) also emphasize communication and information sharing in these circumstances.

Communicating with downstream customers helps alleviate the customer's anxieties, and they may be more likely to be willing to accept delays. If there is no communication, then their supply chain could also be severely disrupted, giving rise to strained relationships with their customers. Customers understand that supply chains do not always run smoothly and thus are going to be more forgiving if they are kept informed rather than if they are left in the dark. This communication strategy is particularly effective when the failure has its origins external to the supply chain. Customers may be more understanding if the whole system is down due to events external to the supply chain such as a flood, earthquake, or Teamsters Union strike, since many companies in the industry would be affected.

The Improvisation Imperative

As mentioned, when the failure is more predictable, the core strategy is to *improvise.* This relates to the business continuity planning (BCP) process discussed in Zsidisin, Ragatz, and Melnyk as well as Zsidisin, Melnyk, and Ragatz (2005, 2005). Sometimes companies will find room for additional capacity through improvement within the current system (*internal improvisation*). Tri-City Heat Treat Co. is a tier-two automobile supplier of heat-treated wheel nuts. To satisfy its customers' needs, it agreed to increase production, but the ordered equipment became delayed. Tri-City did its best to cope; besides asking customers with less pressing orders to wait, it worked round the clock to generate ideas to increase capacity. It used process improvement to eliminate gaps in a production line, turning the batch process into a continuous process (Petzinger, 1995). Similarly, Nishin Kogyo, a minor supplier of valves to Toyota, found a way to increase its efficiency permanently by 30% during the Toyota-Aisin crisis (Reitman, 1997).

Alternatively, companies can increase capacity by increasing labor hours (a type of *internal improvisation*). Many JIT plants tend to have excess capacity (Knod & Schonberger, 2001; Korgoankar, 1992), which allows time for activities such as maintenance, process improvement, and employee training. So if a crisis hits, it is possible to use this as a temporary alternate source to make the required parts or to increase production after the failure is rectified. This can be done by using a third shift, by working overtime, or by hiring temporary workers.

Another option to improvise internally is to not waste existing capacity. Such improvisation might include producing incomplete units. For example, when Johnson Controls went through a strike, it produced seats with management and temporary workers to maintain production. Multifunctional workers also help manage supply chain failure since production may be shifted to other products when one product's supply chain has failed. Demand shifts from one model to another can be influenced through the use of promotions and price incentives, as was done by Dell during a parts shortage (Martha & Subbakrishna, 2002).

Alternately a firm can *improvise externally* around the failure. One way to do this is to find an alternate source of supply and delivery. Although this may be more costly than the normal source, it still can be less expensive than the chain not functioning. This may include shifting sourcing locations, finding alternate routes, and using alternate modes of transportation (Aichlmayer, 2001). Naturally, this would have to involve the cooperation of the logistics provider. After the Kobe earthquake, some companies considered altering their supply routes. Nissan Motor Co. and others investigated costly new alternate routes to avoid supply bottlenecks. Seven-Eleven Japan Co. considered using helicopters to supply convenience stores in the region (Shirouzu, Williams, Sapsford, & Reitman, 1995). If the failure is likely to delay the shipment enough that it will miss a crucial deadline, one may have to find faster alternatives. For example, when a shipment of Sony PlayStations being transported by sea got delayed at the Suez Canal, the company chartered Russian cargo aircraft in order to deliver to customers on time for the crucial Christmas season (Maitland, 2005).

EXTENSIONS AND CONCLUSION

In the past two decades many organizations have embraced JIT and faced challenges of operations protection during supply chain failure since there is little inventory buffer. We presented an organizing framework for some of the structural designs and mechanisms that companies have used to prevent supply chain failure, and to mitigate the effects when the supply chain has broken. We have illustrated that many successful strategies and tactics used by firms, together with several risk mitigation strategies from the literature, can be usefully mapped on a two-dimensional framework anchored on the location and unpredictability of the failure. Since companies plan to persist with JIT even with the possibility of supply chain failure, we hope that our framework will be useful in positioning risks of failure and mitigation options.

While we have initially separated proactive from reactive responses, these may be dynamically connected over time. Firms may learn based on reactive experience. Gulliver (1987) discusses British Petroleum's appraisal of the management of the completed projects so that the lessons can be applied to future projects. The same principle could be applied in the case of supply chain failure. Through reactive improvisation, firms could learn which types of improvisation were effective, and use this to improve the proactive tactics in the future.

Similarly, it is important to note that the ability to reactively manage the supply chain failure is contingent on proactive planning. For example the ability to rely on suppliers to improvise depends on the relationships built within the supply chain. If the company's supply chain structure was not built on long-term strategic relationships, the ability to rely on suppliers to react may be diminished. Within the company, the ability to improvise may be improved by ensuring that employees are trained in process improvement and critical analysis skills, and if crisis planning is done up front.

Even after the fire at the Aisin plant, Toyota plans to keep its policy of single-source suppliers for certain parts despite the dependency, or strategic risk, to which this exposes them. However, the company is building fail-safe mechanisms such as improving the ability of the supplier to shift production to another site if a disaster strikes (Reitman, 1997). Hajime Ohba, general manager of the Toyota Supplier Support Center in Kentucky, publicly responded with Toyota's rationale for JIT after the fire. He said that a better solution is to keep the company's resources at a consistently low cost level, and then rely on the cooperative relationships in the supply network if anything does go wrong (Ohba, 1997). In fact JIT also helps maintain supply chain flexibility when deployed properly. Toyota believes that small lot production allows for flexibility to meet changes in demand, regardless of the cause. This flexibility develops the capability of the supplier to rapidly respond to any crisis (Ohba, 1997).

The evidence points to the fact that over the long term, the benefits of reduced waste and variability through JIT more than offset the disadvantages of being caught without inventory in the unlikely event of a supply chain failure. Accordingly, consultants such as Mercer Management Consulting still advise clients to carry on with JIT since it is estimated that in the auto industry alone, companies are saving $1 billion in carrying costs due to JIT policies (Aichlmayer, 2001). What is required is to make the appropriate adjustments for any unreliability in supply that cannot be avoided. Even from an insurance perspective, implementing JIT systems can have benefits. While some premiums may increase due to increased risks such as that of non-conformance in a supply contract and the increase in road accidents due to more frequent deliveries, the philosophy of focusing on perfection can reduce the premiums related to the risk of product liability and warranty claims (McGillivray, 2000). Also the lack of inventory means lower losses in the case of disasters such as fires.

Given the fact that JIT is likely to be a popular philosophy in the foreseeable future, it is important to provide guidance to organizations using JIT to manage the risk of failure in their supply chains effectively. The proposed framework should help companies manage the risk in JIT-based supply chains. We suggest that managing supply chain failure within JIT systems involves a two-pronged approach. Before the event, JIT involves making the production system as foolproof as possible and forming close relationships with capable suppliers. We have argued that a variety of structures and mechanisms can be used to mitigate the low-to-medium unpredictability events at the firm, supply chain, and external locations. However, some highly unpredictable events can occur despite a well-functioning JIT system. Before the event, firms can monitor and measure events in their internal system, supply chain, and external environment. After a failure occurs the options are more limited to a combination of improvisation and communication with the supply chain. In the ideal case, a well-designed JIT supply chain can use its high visibility, communication, and group problem-solving approach to cooperate to quickly find solutions to supply chain failure. In this article we have illustrated the framework using company experiences and previous supply chain risk research. Further research could attempt empirical validation of the proposed framework.

In the meantime, we hope that our strategic framework encourages managers to consider the location and unpredictability of supply chain failure as they devise strategies to cope with this crucial decision arena in JIT systems. We also hope that researchers will explore the framework using empirical research to validate it, and provide specific guidance to managers regarding the management of location and unpredictability issues in JIT supply chain failure.

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