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# Interpreting Resilience: An Examination of the Use of Resiliency Strategies within the Supply Chain and Consequences for the Freight Transportation System

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*Abstract - With continued increases in trade volumes, lengthening of supply chains due to globalization, and an increased focus on disruptions, resiliency has become an issue of concern within the supply chain community. Resiliency is formally defined as the ability to recover from or adjust easily to change or disruption. For this research and within the supply chain community, resiliency also includes the ability to avoid disruptions. In the past, resiliency has been discussed in nebulous terms, typically focusing on the overall concept of resiliency, past resiliency successes and failures, and generalized frameworks and flowcharts to help assess risk and mitigate for it. Absent is the discussion of how companies perceive resiliency and by what methods are they currently integrating resiliency strategies into supply chain and goods movement policies. This research explores and evaluates resiliency efforts, focusing on the goods movement within the supply chain, currently being used in practice by importing companies. Additionally, the information gathered in this research may be utilized to improve resiliency within freight transportation systems.*

*Through a series of eleven interviews with personnel responsible for transportation and supply chain activities and operations, information was gathered to understand how companies are attempting to improve the resiliency within their supply chain in the face of increasing vulnerabilities. Responses to questions about resiliency, vulnerabilities, disruptions, and disruption procedures were used to identify fifteen resiliency strategies which were categorized as enablers or strategic resiliency strategies. Enablers, such as communication, relationships, and use of information and technology, were identified as ways to increase the effectiveness of other resiliency efforts and are often an integral part of supply chain operations prior to concerns about resiliency. Strategic resiliency strategies, including using expedited transportation, using multiple ports and/or carriers to move goods, becoming C-TPAT certified, and delivering during off-peak hours, are typically part of a long term plan of action, but are often implemented on a day to day or as needed basis. Both enablers and strategic resiliency strategies result in the reduction of exposure to supply chain disruptions and/or the mitigation of disruption impacts.*

*Relationships between the strategies are revealed, highlighting the importance of enablers as a means of promoting the success of many other reported resiliency strategies. The strategies used by a given company are often a reflection of the company's current exposure to risk, and therefore experience with resiliency. For example, companies with existing supply uncertainty have already implemented resiliency strategies to mitigate the impact of sourcing difficulty. Examination of resiliency strategies as a means to reduce exposure to supply chain disruptions has shown that the use of these strategies helps spread the risk of disruptions, either geographically, temporally, or across personnel. In addition to improving resiliency, many identified strategies can provide an added value to supply chains, improving operations and efficiency on a daily basis.*

*This research provides a summary of existing strategies, but also presents a framework for discussing resilience in terms of enablers and strategies. Enablers, which allow a company to improve resilience, are the nebulous concepts often associated with resilience such as flexibility and communication. The strategies are specific actions that can have a measurable impact on an enterprise's ability to tolerate disruptions. Understanding the implications of employing various resiliency strategies can assist companies in making strategic decisions which are in the best interest of a resilient and successful supply chain. The research also discusses how knowledge of these strategies can assist freight transportation system planners, designers, and managers in improving system resilience for the benefit of all users.*

## INTRODUCTION

As global trade volumes continue to increase and supply chains lengthen, enterprises in all sectors of the economy are facing increased likelihoods of supply chain disruptions. Vulnerabilities exist in every segment of the supply chain, including the transportation network. Recent events within the United States, such as September 11th, the West Coast ports lockout, and Hurricanes Katrina and Rita, have highlighted the potential for transportation disruption within supply chains, and the consequences of being unprepared. With the increased focus on disruptions and the continued desire to reduce cost, resiliency has become an issue of concern within the supply chain community.

**Resiliency** is defined as “an ability to recover from or adjust easily to misfortune or change” (Merriam-Webster, 2008). Within the supply chain community, resiliency also includes the ability to avoid or reduce exposure to disruptions.

### Importance of Resiliency

Resiliency within supply chains is not a new concept for importing enterprises, but recent trends in trade and supply chain operations have made resiliency more important, especially when considering transportation disruptions. Supply chains are becoming more complex as they are lengthened and leaned, and most supply chains are a dynamic network that is ever-changing (Christopher and Peck, 2004). Global supply chains mean longer transport distances and more participants, which leads to more opportunities for disruptions (Sheffi, 2005). For example, when sourcing or labor moves abroad, another mode of transportation, either water or air, is introduced to the supply chain, and the length of the supply chain is increased, introducing new potentials for disruption. Additionally, disruptions abroad now have as much capacity to effect supply chains as domestic disruptions. New languages, currency, and cultural traditions add complexity to supply chain operations. In addition, customs and security regulations must be met to move goods into or out of the country. These factors associated with lengthening the supply chain lead to an increased potential of disruptions to the goods movement system.

Lean operations, instituted as a means of reducing logistics cost, leave little slack in the system to handle unforeseen problems. In a lean system there is less safety stock to cope with disruptions and a minor disruption has the potential of shutting down the entire supply chain (Sheffi, 2005). Enterprises which operate on a Just-in-Time (JIT) strategy, where supplies or components arrive at the exact time they are needed instead of being held in inventory, are also extremely vulnerable to transportation disruptions.

With increasing of global competition, profit margins are reduced and lean operations are required to compete. However, these leave enterprises exposed to disruptions. This is especially true in a commodity market (Sheffi, 2005).

### Objectives

This research structures the discussion of resiliency and provides a common language. The research also aims to understand how enterprises are attempting to improve the resiliency within their supply chain in the face of increasing risks. Questions which this research addresses include:

1. What resiliency strategies, with respect to goods movement, are enterprises currently using?
2. How do enterprises use these strategies to improve resiliency?
3. How do strategies used relate to an enterprise's current operating conditions?
4. How does enterprise resiliency relate to transportation system resiliency?

### Contribution

In the existing literature resiliency is often discussed in nebulous terms, typically focusing on the overall concept of resiliency, past resiliency successes and failures, and generalized frameworks and flowcharts. Absent is the discussion of how are currently integrating resiliency strategies into supply chain and goods movement policies. This research provides a summary of existing strategies, but also presents a framework for discussing resiliency. Understanding the implications of employing various enabler and resiliency strategies can assist enterprises in making strategic decisions which are in the best interest of a resilient and successful supply chain. Additionally, the information gathered in this research may be utilized to improve resiliency within freight transportation systems as the enterprise and its behavior are key elements of the transportation system.

## LITERATURE REVIEW

Literature regarding the management of supply chain disruptions has become increasingly more prevalent as the threat of disruptions has become more visible. Sources of information on the topic either take a widespread approach to examining supply chain resiliency, or focus on narrow topics such as supply and demand, developing relationships, physical and digital security, or organizational culture.

### Supply Chain Resiliency

The Resilient Enterprise (Sheffi, 2005) is a comprehensive overview of the changing focus of supply chains in a post 9/11 world. He explains the importance of resiliency and explores potential vulnerabilities in supply chains, including introducing ways to decrease vulnerability and increase flexibility (as a means of increasing resiliency) through improved supplier relationships and communications, collaborative security efforts and flexible production operations. Additionally, on the general topic of supply chain resiliency, Pickett (2003) examines numerous past disruptions, including earthquakes, hurricanes, floods, accidents, labor strikes, and terrorist attacks, to understand the impact they had on supply chains. The study of these past events yielded lessons regarding preparation and reactions to future disruptions and provides recommendations to strengthen supply chains, reduce disruptions, and maximize resilience in the future. Christopher and Peck (2004) notes that research efforts into supply chain vulnerability were initiated in the United Kingdom prior to the United States' deep interest in the area after 9/11. Disruptions such as the UK fuel protests in September of 2000 and the Foot and Mouth Disease outbreak in February, 2001 led to an increased interest in the subject. Their work examines supply chain risks, and suggests way to create a resilient supply chain through supply chain risk management efforts such as re-engineering the supply chain to value resiliency, increasing collaboration between supply chain partners, focusing on agility, and developing a culture which embraces the risk management concept.

### Supply and Demand Disruptions

Snyder and Shen (2006) discusses managing disruptions to multi-location supply chain systems. They suggest that while the underlying issue with both supply uncertainty and demand uncertainty is having too little supply to meet demand, there are significant differences between the two uncertainties and the optimal disruption management strategies take into account both types of uncertainties and their interaction. Hopp and Yin (2006) includes the development of an analytical model to reduce the risk of "catastrophic" supply failures by balancing the cost of inventory and capacity protection to the cost of lost sales. Tomlin (2006) looks at supply uncertainty using a mitigation and contingency framework to evaluate supply-side tactics such as sourcing mitigation, inventory mitigation, and contingency rerouting.

### External Disruptions

Shifting to external disruptions exogenous to the supply chain, Kleindorfer and Saad (2005) developed a framework to identify sources of, assess, and mitigate external risk, such as natural disasters, economic disruptions or terrorist activity. Rice and Caniato (2003) focuses on disruptions at all levels of the supply chain due to terrorist activities and governmental responses due to these potential threats. Through a series of interviews with firms in the United States, the report details corporate risk assessment and corporate response to recent terror activities, namely 9/11. Firms indicated resiliency measures adopted to address potential disruptions in key failure modes, including a failure through transportation. Ravi (2006) looks at security and the supply chain, including governmental safety regulations, the connection between security and technology, and general suggestions for action to improve supply chain security.

### Resilient Culture

Benson (2005) specifically discusses the importance of organizational culture in resilient supply chains. Similar to this research, Benson (2005)'s study consisted of interviews focusing on work infrastructure and practices, human resources practices, education, communication, and measurement systems to examine enterprise policies and how this impacts security and resiliency of supply chains.

### Network Structure

Finally, research exists regarding network structure and the impact of disruption on costs and flow over the network. Latora and Marchiori (2005) discusses a method of finding the critical components of an infrastructure network. These nodes and the links, which are fundamental to the perfect functioning of the network, are the most important to protect from disruptions such as terrorist attacks. Snyder, et. al. (2006) discusses models for planning supply

chain networks which are resilient to disruption. These models attempt to allow supply chain infrastructure to be designed to operate efficiently and at low-cost both during times of normal and disrupted operations.

### Literature Gap

Despite the extensive amount of literature available on topics related to supply chain disruptions and resiliency, these focus on planning and design issues. There is a gap in the literature concerning resiliency strategies commonly used in practice, specifically those which address transportation concerns. Resiliency strategies have not been examined to determine utilization and the relationships between strategies and within industry sectors. Additionally, literature addressing freight system resiliency has not been found.

## METHODOLOGY

### Data Sources

Data, or information, collected for the thesis was gathered through eleven informational interviews conducted with personnel responsible for transportation activities and operations in enterprises spanning a broad range of industries. In addition to being responsible for daily supply chain and transportation operations, many interviewees also take part in strategic decision making regarding the transportation system of their enterprise's supply chain. Interviews were conducted in person, or over the phone, and typically lasted 60 minutes. In many cases additional questions were asked after the initial interviews were asked over the phone or via email.

As required by the University of Washington Human Studies Division, confidentiality of the interviewees and enterprises represented was maintained by generalizing key attributes of each enterprise. Enterprises are referred to as Enterprise A through Enterprise K, as seen in Table 1, which provides information on the enterprises interviewed in this study.

Table 1: Enterprise Descriptions

Enterprise	Industry*	Annual Sales Range (\$ billion)*	Goods Value	Perish-ability	Leanness	Technology
A	Retail	1-10	Low/Mid	Mid	Mid	Mid
B	Retail	50-100	Low	Mid	Mid	Mid
C	Retail	1-10	Low/Mid	Mid	Low	Low
D	Retail	50-100	Low/Mid	Mid	Mid	Mid
E	Food/Beverage	1-10	Low	High	Mid	Mid
F	Food/Beverage	NA	Low	High	Mid	Mid
G	Chemical	0.1-0.5	Mid/High	Mid	Mid	High
H	Manufacturing	10-50	High	Low	High	High
I	Manufacturing	50-100	High	Low	High	Mid
J	Manufacturing	NA	Mid/High	Low	Mid	Mid
K	Manufacturing	0.1-0.5	Mid/High	Low	High	Mid

\*Source: Hoovers, Inc.

Enterprises interviewed were characterized by six key attributes. Industry sectors were generalized as Chemical, Retail, Food and Beverage, and Manufacturing. Enterprise D and Enterprise E operate in multiple industry sectors with the dominate sector listed in the table. Industry sector and annual sales information was gathered from Hoovers, Inc. (<http://premium.hoovers.com>).

The four remaining attributes, goods value, perishability (shelf-life) of goods sold by enterprises, leanness of supply chain, and use of technology within the supply chain reflect characteristics of enterprises. Relative values of these attributes were based on information gathered both directly and indirectly from interviews and assigned by the author.

The discussions regarding resiliency during interviews focused on a national company-wide strategies and operations, and many of the resiliency strategies examined in this research are effective independent of geographic region. While the type and likelihood of disruption vary by location or geographic region, the disruptions themselves are unpredictable and successful resiliency strategies prepare a supply chain to react to any disruption as opposed to specific disruptions.

#### Research Methods

Eleven exploratory interviews were conducted in this study. The questions were related to transportation priorities, vulnerabilities, and supply chain resiliencies. The interviews were semi structured and all questions were not necessarily asked of each interviewee. Additional questions were asked to clarify, elaborate, or further discuss, as necessary.

#### Limitations of Data Use

The qualitative data collected during the above-mentioned interviews provides insight into the resiliency strategies being used by interviewed enterprises but does not provide a basis to make universal conclusions on supply chain resiliency. Despite this, the data presented is useful in understanding the response of enterprises to an increased interest in supply chain disruptions and resiliency.

Additionally, this research focused on an enterprise's perception of their resiliency in addition to their actual resiliency strategies; therefore interviewees were not asked directly which resiliency strategies they did or did not employ. In some instances, what an interviewee did not say provided valuable insight, such as in their level of resiliency maturity. The information both provided and absent from interviews was used to draw conclusions about enterprise resiliency. We do not attempt to document the entire set of strategies used across all enterprises engaged in the movement of goods, or their frequency of use, which would require a more comprehensive sample, but are interested in company perceptions of effective resiliency strategies, the relationships between resiliency strategies and between strategies and enablers, and the relationship between resiliency strategies and other company attributes.

## DEFINITIONS

#### Supply Chain

As defined by Reference (Christopher and Peck, 2004), a supply chain is “the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.”

Resiliency strategies may be utilized at most points along the supply chain, but this research focuses on resiliency within the goods movement segment of the supply chain.

#### Disruption

The term disruption is used extensively within this research and is defined as follows:

**Disruption:** an event which has the potential to cause an undesirable impact to the goods movement within a supply chain.

Supply chain disruptions can be divided into three main categories: natural disasters, accidents, and intentional attacks. Natural disasters include events such as earthquakes and hurricanes. Accidents include incidents such as fires or equipment failures. Intentional attacks include terrorism, sabotage, computer hacking and labor issues (Sheffi, 2005). This research focuses on disruptions which impact the transportation segment of the supply chain.

#### Resiliency

For the purposes of this research, resiliency is defined as follows:

**Resiliency:** the ability of an enterprise to avoid or recover from a change or disruption to their supply chain, maintaining or returning to normal operating conditions.

## Resiliency Strategy

This research focuses on the resiliency strategies employed by enterprises to reduce the exposure to or mitigate the impacts of disruptions to the supply chain. For the purposes of this research, resiliency strategy is defined as follows:

**Resiliency Strategy:** a tactic used to reduce the occurrence or mitigate the effects of disruptions, allowing a supply chain to maintain or return to normal operating conditions.

## RESILIENCY STRATEGIES

### Introduction

Interview questions inquired about vulnerabilities within the supply chain, resiliency within the supply chain, and procedures used to handle disruptions. From the information gathered during the interviews, fifteen resiliency strategies were identified. The strategies were both directly and indirectly identified during interviews. If a enterprise did not report a strategy it can be assumed that (1) the enterprise does not practice the strategy, (2) the enterprise does employ the strategy but does not find it significant to their resiliency efforts, or (3) the enterprise does employ the strategy but fails to mention its use because it has become commonplace within supply chain operations.

The majority of strategies are characterized as strategic, meaning they are tactical decisions, but may also be implemented on a day to day basis. Other strategies are categorized as enablers and do not directly improve resiliency, but instead facilitate the success of strategic resiliency strategies. They enable or encourage resiliency. The resiliency strategies identified within the interview process are listed in Table 2.

Table 2: Identified Resiliency Strategies

STRATEGIES	CATEGORY	REPORTED BY (ENTERPRISES )
Relationships	Enabler	A, D, F, G, J
Use of Information & Technology	Enabler	B, D, G,H, I
Communication	Enabler	A, B, D,F, G
Flexible Culture	Enabler	A, F, H
Flexible Transportation	Strategic	A, F, G, H
C-TPAT Certification	Strategic	A, E
DC Structure, Size of Network	Strategic	D,E, H
Resilient Nature of Suppliers	Strategic	F
Expedited Freight	Strategic	A, D,H, I
Use of Multiple Ports/Carriers	Strategic	B, E, H
Employees Overseas	Strategic	B
Extra Capacity at DC	Strategic	C
Off-Peak Deliveries	Strategic	E
Domestic Sourcing	Strategic	E
Premium Transportation	Strategic	H, I, J

The explanations and evaluations of strategies below consist of a combination of perceptions gathered at interviews and research interpretations. The interview data conveys the information provided by the enterprises which lead to conclusions regarding utilized strategies.

### Enablers

Enabler strategies do not directly reduce or mitigate disruptions. Instead, enablers often help identify disruptions and lead to further action or aid in response to a disruption. Four enablers were identified during the interviews and are examined below.

### Relationships

Definition: An enterprise develops and maintains relationships with suppliers, carriers, and customers, with the belief that strong relationships will result in increased assistance and flexibility during disruptions. Relationships may be developed through activities such as retreats as well as networking and social events.

Evaluation: As an enabler, developing strong relationships improves resiliency by making partners more likely to aid an enterprise when a disruption occurs in order to continue to do business. A strong relationship could both reduce the potential for disruptions to impact a supply chain and mitigate the impacts of a disruption that does have an effect on a supply chain. Beyond having a strong relationship, an action must be taken to avoid or mitigate the disruption, which often comes in the form of an additional resiliency strategy such as flexible transportation, described later. Strong relationships do not guarantee that partners can or will act in the best interests of the enterprise in the face of a disruption.

#### Use of Information and Technology

Definition: An enterprise gathers information, generally through increased technology, to manage disruptions. Tools such as Transportation Management Systems (or similar enterprise management software) and procurement agents may help track goods and detect potential or actual disruptions.

Evaluation: The use of information and technology, improves resiliency by gathering and presenting information regarding disruptions, which can be communicated between parties within the supply chain. This can occur by increasing the amount and level of detail of information available, making information easily accessible, providing information to all members of the supply chain, and providing information in a time sensitive manner. Information can provide knowledge of a disruption and gives an enterprise the opportunity to act to avoid or reduce the effects of the disruption. Early detection helps stop the spread of disruption and reduce the extent of damage. As with relationships, an action must be taken, beyond the gathering of information in order to improve resiliency.

#### Communication

Definition: An enterprise relays information, gathered previously, about supply chain status and activities, including potential or actual disruptions, to those who have the authority to take action in order to prevent or mitigate disruptions.

Evaluation: Communication improves resiliency by a transfer of knowledge regarding disruption between parties within the supply chain. Communication is specific to the exchange of information, where as technology provides information. Having the knowledge of a disruption gives an enterprise the opportunity to act to avoid or reduce the extent of damage. As with relationships, an action must be taken, beyond the communication in order to improve resiliency.

#### Flexible Culture

Definition: The culture of an enterprise can simply be stated as the way we do things around here (Sheffi, 2005). Flexible culture involves developing a business environment that encourages and promotes innovative and creative ideas to improve supply chain resiliency and resiliency practices.

Evaluation: Key traits of enterprises with flexible culture include: extensive communication between informed employees, distributed/decentralized power, a passion for the work, and experienced with/conditioned for disruptions. Enterprises with flexible cultures are more aware of the potential for disruptions and more likely to implement additional resiliency strategies. Like the previous enablers, flexible culture encourages activities which reduce exposure to or mitigate the impact of disruptions.

#### Strategic Resiliency Strategies

Strategic resiliency strategies are typically part of a long term plan of action, but are implemented on a day to day, or as needed basis. Eleven strategic resiliency strategies were identified and are examined below.

#### Flexible Transportation

Definition: An enterprise has the ability to make last-minute changes to transportation providers, routes or schedules in case of disruption.

Evaluation: Flexible transportation policies have the ability to help an enterprise both avoid exposure to disruptions and mitigate the impacts of disruptions. For example, faced with a weather disruption, an enterprise may choose to



send freight earlier to avoid any potential weather delays, or if freight has already been delayed by weather, to run teams of drivers in order to speed delivery. In both scenarios, flexible transportation involves having the ability make changes such as moving goods sooner than planned or using more drivers in order to avoid or mitigate the impact of a disruption. Other examples of using flexible transportation to improve resiliency include using detours to avoid disruptions, and having backup carriers, such as non-union drivers, to reduce the effects of a disruption which affects primary carriers.

#### C-TPAT Certification

**Definition:** An enterprise is Customs-Trade Partnership Against Terrorism (C-TPAT) certified with the belief that this status will reduce or mitigate disruptions. C-TPAT is a voluntary government-business initiative that aims to improve U.S. border security. In order to be certified an importer must meet criteria that falls under the categories of: business partner requirements, container security, container inspection, physical access controls, personnel security, and procedure security.

**Evaluation:** Based on the claimed benefits of C-TPAT compliance, which include reduced inspections and priority after a port shutdown, participation can both reduce exposure to disruptions and mitigate the effects of disruptions. Disruptions caused by inspection delays are reduced because C-TPAT certified enterprises are less likely to undergo an inspection. Impacts of disruptions such as port closures are mitigated by having priority to get freight out of the ports as soon as possible after the event. It is inevitable that all goods would be delayed during a shutdown, but those certified would move through faster after the shutdown ended. In theory, a certified enterprise will have a more transparent supply chain, which can improve supply chain operations.

#### Distribution Center Structure, Size of Network

**Definition:** An enterprise has a network structure that has the ability to serve, on short notice, a destination/store from a different distribution center than typically served to handle product shortages due to disruptions.

**Evaluation:** Having a large network allows an enterprise to avoid or mitigate the effects of disruptions by moving products around as needed with more flexibility. If final destinations (stores) are located within close proximity to several distribution centers and there is available inventory, distribution patterns can be modified to react to potential or actual disruptions in a timely manner. An enterprise has the ability to route around problems. Figure 1 illustrates this.

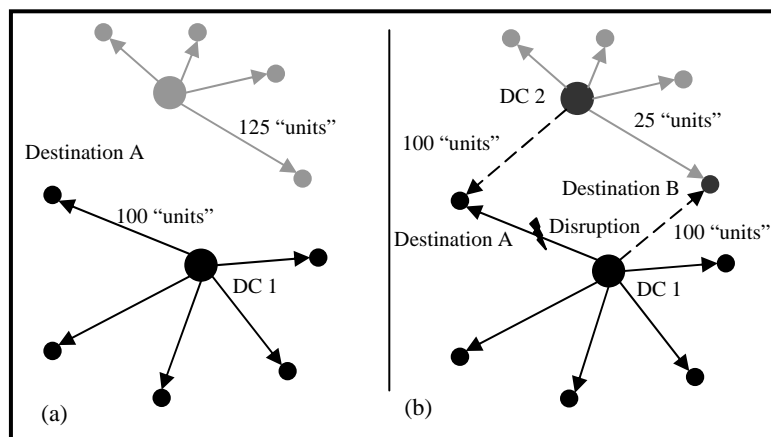


Figure 1: Distribution Center Network Application

In Figure 1

Figure 1(a), the 100 units of goods demanded by Destination A is typically served by DC 1. When a disruption occurs, or is expected to occur along the goods movement path between DC 1 and Destination A, units can temporarily be rerouted so that DC 2 serves the demand of Destination A, as seen in Figure 1(b). The units at DC 1

typically destined for Destination A can then be used to serve the now unmet demand of Destination B. Once the disruption has been removed, goods can be routed through their normal paths.

### Resilient Nature of Suppliers

Definition: An enterprise does business with suppliers.

Evaluation: If having resilient supply chain partners encourages an enterprise to increase their own resiliency in order to improve overall supply chain resiliency, this strategy is successful and allows an enterprise to avoid or mitigate the effects of disruptions. The supplier and the enterprise are often both vulnerable to the same risks.

### Expedited Freight

Definition: An enterprise, upon identifying a disruption, uses accelerated freight transportation to move additional freight or to speed up delivery of an existing shipment.

Evaluation: Expediting freight mitigates the effects of a disruption by reducing the magnitude of a disruption. If a disruption occurs within the supply chain, there can be a shift to an accelerated mode of transportation to make up for time lost in early segments of the supply chain, or a second shipment sent via accelerated mode. Figure 2 illustrates how expedited freight can be used to mitigate disruptions.

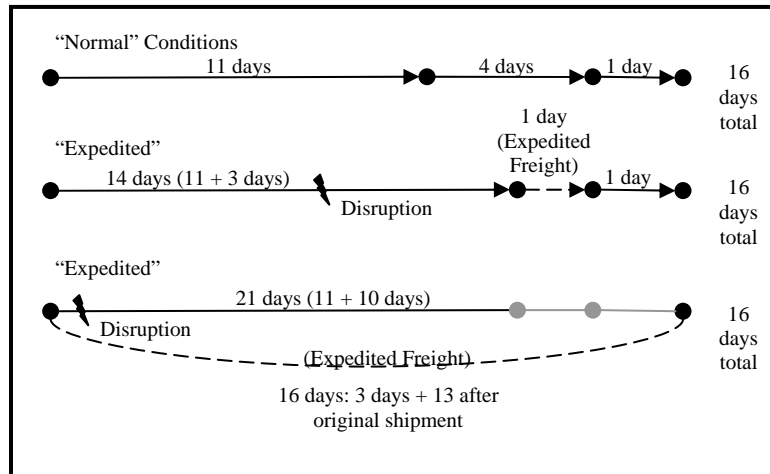


Figure 2: Expedited Freight Application

In this example, under "normal" conditions, goods travel from origin to destination, with a total trip time of 16 days. In the second example of an "expedited" condition, the disruption within the first leg is expected to be long enough (10 days) to justify sending a second shipment via accelerated freight. Despite being sent significantly after the first shipment, the expedited shipment still arrives at the destination with a total trip time of 16 days.

### Use of Multiple Ports/Carriers

Definition: An enterprise imports goods through more than one port or using multiple carriers (marine, truck, rail), as part of regular supply chain operations in order to avoid having a disruption affect the entire supply chain.

Evaluations: Using multiple ports and/or carriers can both reduce exposure to and mitigate effects of some disruptions. Assuming that the likelihood disruptions along multiple paths is small, when good move to a single destination port via multiple carriers, a larger percentage of goods are likely to reach their destination on time. For example, if two carriers are used equally and a disruption occurs along one path, 50% of the goods will reach their destination on time. With three carriers, the percentage increased to 66%. Figure 3 illustrates the application of this strategy.

While using multiple ports and/or carriers can improve resiliency, it also results in increased risks. When including additional ports to a supply chain, an enterprise takes on the extra risks associated with importing into that port, which may be distinct from risks at previous ports and therefore must also be accounted for in additional resiliency planning.

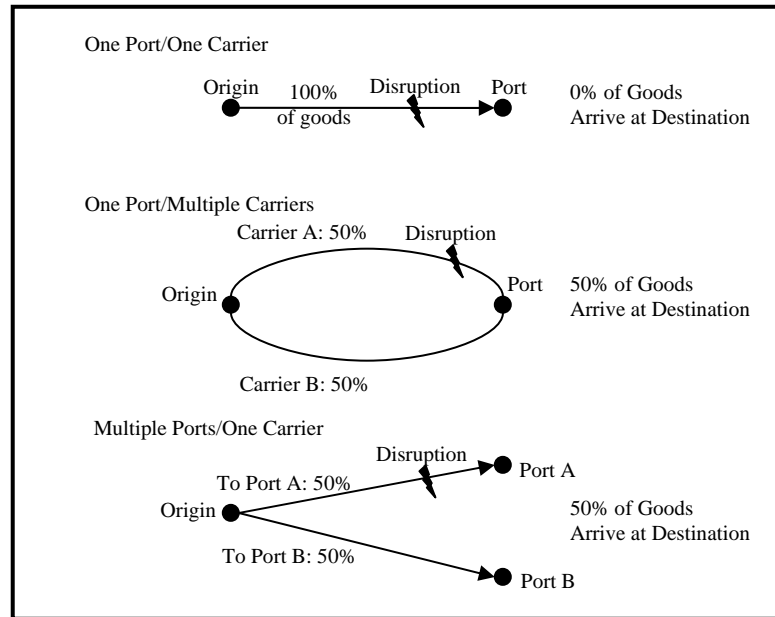


Figure 3: Multiple Ports and Carriers Application

#### Employees Overseas

**Definition:** An enterprise locates employees overseas, in countries which are part of the supply chain, to oversee and manage operations.

**Evaluation:** Assuming that direct and frequent communication is more efficient and less error-prone than communication that takes place via technology (phone, e-mail, and internet) and less regularly, this strategy improves communication and may act as a catalyst for additional action. Locating employees overseas means they are in closer contact with the suppliers/carriers and also report directly to the enterprise. Having early knowledge of disruptions gives an enterprise the opportunity to act to avoid or reduce the effects of the disruption. There is also a presumed benefit of local knowledge that can be utilized by overseas employees.

#### Extra Capacity at Distribution Centers

**Definition:** An enterprise scales distribution centers to have a greater capacity than required for current volumes of goods moving through the distribution center in order to increase the ability to hold inventory as needed to improve resiliency.

**Evaluation:** Having extra capacity at distribution centers does not reduce exposure to or mitigate the impacts of disruptions. While extra capacity at a distribution center allows for holding more inventory, which increases resiliency by mitigating the impacts of a disruption, the extra capacity alone does not increase resiliency. This strategy improves resiliency through redundancy.

#### Off-Peak Deliveries

**Definition:** An enterprise delivers goods during off-peak hours to distribution centers or stores to avoid delivering at times when the risk of disruption is higher (e.g. peak traffic hours).

Evaluation: Making local, urban freight deliveries during off-peak hours reduces exposure to disruptions. Making deliveries during times where congestion is minimal reduces the risk of disruption or delay by the congestion. This strategy is best implemented when an enterprise makes small deliveries to stores in urban areas on a regular basis.

#### Sourcing of Components Domestically

Definition: An enterprise acquires components/goods from domestic suppliers instead of from suppliers overseas (where they may be cheaper) due to a reduction in the likelihood of disruption in transit.

Evaluation: If you assume that the longer the supply chain, the more potential for disruption, then shortening a supply chain by sourcing domestically will reduce exposure to disruptions. Sourcing a component domestically removes ocean travel, movements through two ports, and dealings with customs and border protection. This resiliency strategy is most effectively for goods which are critical to operations of an enterprise, such as a component which would stop a production line if not available or a product which would prevent sales of a focal component which had no reasonable replacement.

#### Premium Transportation

Definition: An enterprise uses a more expensive mode of transportation, such as air or z-trains, assuming they offer a service which is more reliable or can move goods in a more efficient fashion.

Evaluation: Using premium transportation both reduces exposure to and mitigates the impact of disruptions. Carriers providing premium service often offer guarantees on the level of service. For example, in return for paying more to ship goods upon z-trains, shippers are guaranteed to have their goods moved to the front of the line if there is a disruption which halts movement for a period of time – thus reducing the effects of the disruption. Premium air freight is typically managed by a third party logistics provider who works to provide a high level of service to customers by pre-qualifying carriers, negotiating rates, and handling the details of the shipment. Pre-planned air freight often has better visibility than other modes of transportation, allowing disruptions to be spotted easily.

## DISCUSSION

### Outcomes

As stated earlier, there are two distinct outcomes to the implementation of resiliency strategies: (1) reduction of exposure to or frequency of disruptions and (2) mitigation of the impacts, or size and severity, of disruptions. Strategies can both reduce and mitigate, depending on the circumstances of the disruption.

The distinction between reduction and mitigation is most clearly seen temporally. Reduction is proactive and action is taken prior to the disruption physically affecting the supply chain. Mitigation is reactive and occurs when exposure to the disruption cannot be avoided. The supply chain is affected by the disruption and the resiliency strategy serves as a means of returning the supply chain to previous, or normal, operations.

All of the strategies can be considered strategic decisions although many are employed operationally. For example, a decision to use multiple ports to import goods is made at a strategic level, as is the decision to allow goods movement to shift between ports as necessary and as capacity allows. However, the decision to actually shift goods from one port to another is made on an operational basis as events develop. Likewise, it is a strategic decision to allow for expedited freight transportation to be used when needed, but the decision to send goods via an expedited service is made on a day-to-day basis.

### Spreading Risk

Ideally, members of a supply chain would eliminate all sources of disruption if possible. Unfortunately, disruptions such as natural disasters and intentional attacks cannot be controlled by enterprises within the supply chain. Instead, as stated earlier, enterprises attempt to reduce their supply chain's exposure to disruption. In doing so, resiliency strategies spread the risk of a disruption temporally, geographically, or across people. Table 3 identifies how resiliency strategies spread the risk of disruption.

The strategic resiliency strategies of flexible transportation, expedited freight, and off-peak deliveries spread the risk of disruption over time. Flexible transportation policies allow for goods to be shipped ahead or behind schedule in order to avoid potential disruptions. For example, when there is knowledge of an impending snowstorm, an enterprise may choose to send an available shipment of goods in advance of a previous delivery date to avoid risking

a pass or other road closure. Expedited freight reduces the time needed to transport goods along the supply chain. The concept off-peak deliveries relies on the fact that deliveries made overnight are less likely to be disrupted by congestion or other urban disturbances.

Table 3: Spreading Risk Through Resiliency Strategies

Strategies	Temporally	Geographically	Across People
Relationships			
Information and Technology			
Communication			
Flexible Culture			
Flexible Transportation			
C-TPAT Certification			
DC Structure, Size of Network			
Resilient Nature of Suppliers			
Expedited Freight			
Use of Multiple Ports/Carriers			
Employees Overseas			
Extra Capacity at DC			
Off-Peak Deliveries			
Domestic Sourcing			
Premium Transportation			

Many strategic resiliency strategies, including flexible transportation, distribution center structure, the use of multiple ports, extra capacity at distribution centers, and sourcing components domestically, spread risk geographically. These strategies are based on the assumptions that disruptions will not occur simultaneously in multiple geographically separated locations, and that the geographic length of a supply chain is directly related to the potential risk of disruptions to that supply chain. While often true, disruptions may affect large geographic areas making them virtually unavoidable. Additionally, a supply chain, regardless of how short, will never be completely free of the threat of disruptions. Flexible transportation, distribution center structure, the use of multiple ports, and extra capacity at distribution centers allow for goods to be moved around areas of disruptions through areas not currently experiencing disruptions. Sourcing domestically reduces the distance goods travel and removes aspects of the supply chain such as border crossings, which also hold a potential for disruption.

Strategic resiliency strategies, including include flexible transportation, C-TPAT certification, resilient suppliers, use of multiple carriers, employees overseas, and premium transportation, in addition to the four enablers may spread risk across personnel. Spreading risk across personnel entails involving more people into the supply chain, and informing and empowering multiple people within the supply chain to react to potential disruptions. Flexible transportation, resilient suppliers, and use of multiple carriers spread the risk of disruptions across more people within the supply chain. Similar to assumptions made regarding geography, it can also be assumed that non-geographically related disruptions will not occur simultaneously to multiple carriers. Premium transportation shifts the risk to the premium transportation providers who guarantee service. The enablers of relationships, use of information and technology, communication, and flexible culture, in addition to C-TPAT certification and employees overseas spread risk across personnel by decentralizing. By decentralizing, people are given the authority to respond quickly to problems, often being able to avoid a disruption instead of having to later mitigate the impacts of one.

### Relationship to Current Operating Environment

The enterprises interviewed can be divided into three general business sector categories: manufacturing, retail, and food/beverage. Examining strategies utilized by each enterprise, the resiliency strategies used do not appear to be linked to the nature of the business but more so to the maturity and natural likelihood for disruptions within the supply chain. Enablers are the easiest, least cost-prohibitive strategies, and also provide many other benefits to company operations; therefore are often the first strategies implemented by an enterprise when trying to improve resiliency. As a supply chain develops and matures, it responds to frequent problems which occur due to the operating environment the enterprise is works in. These responses often double as resiliency strategies. An enterprise may not directly identify certain strategies, such as enablers, when discussing resiliency efforts because these strategies have become commonplace to operations. The strategies reported are often a reflection of the mature of an enterprises experience with resiliency. Enterprises which are prone to disruptions, often unrelated to transportation, have more experience with disruptions and therefore are more resilient to transportation-related disruptions. Table 4 summarizes the strategies indicated by enterprises directly during interviews. Most enterprises are likely to actually employ more strategies than those listed below, but the information gathered in the interviews provides an understanding of what strategies are the focus of resiliency efforts within the enterprise

Table 4: Interview Reported Strategies

Strategy	A	B	C	D	E	F	G	H	I	J
Relationships										
Information & Technology										
Communication										
Flexible Culture										
Flexible Transportation										
C-TPAT Certification										
DC Structure/Size of Network										
Resilient Nature of Suppliers										
Expedited Freight										
Use of Multiple Ports/Carriers										
Employees Overseas										
Extra Capacity at DC										
Off-Peak Deliveries										
Domestic Sourcing										
Premium Transportation										

Enterprise A, Enterprise B and Enterprise D are classified as retailers, and while all three make use of enablers, other strategies mentioned vary widely. Within the retail sector there is the most diversity of businesses and business models, meaning each supply chain has different resiliency needs. These enterprises interviewed do not operate supply chains which are exceptionally lean or are volatile, forcing resiliency to be a top concern. Instead, these enterprises understand, in the general sense, that resiliency can benefit a supply chain, and have chosen to explore how resiliency can best be implemented into their own supply chain to address their specific needs.

Enterprises such as Enterprise C and Enterprise K have not suffered from disruptions and have few to no resiliency strategies to speak of. The rapid and recent growth of Enterprise C has left its supply chain scrambling to catch up. Due to the lack of previous disruptions, future disruptions do not appear to be a large threat. Enterprise C has chosen to focus on expanding and increasing the efficiencies of their supply chain without considering the importance of resiliency. Additionally, due to the lower costs of goods produced, Enterprise C can afford to hold more inventory than enterprises with higher costs goods such as Enterprise I and Enterprise H. Enterprise K is not mentioned in Table 3 due to their lack of use of resiliency strategies. Self-admittedly, Enterprise K has a brittle supply chain with no immediate resiliencies because they have been fortunate to yet experience any major problems due to disruptions within the supply chain.

The products provided by Enterprise E can be loosely classified as commodities which are consumed upon purchase. Additionally, a small number of components are used to make a limited number of products, and if any of these critical components are delayed, the products themselves cannot be produced. As with other commodities, if Enterprise E cannot deliver their products another enterprise is waiting and able to provide a very similar one, costing Enterprise E business and possibly damaging their reputation. Also, because these critical components are

perishable and there is limited storage space in Enterprise E's facilities, deliveries are made on a near daily basis. The frequent delivery required for perishable, typically food, products means more exposure to disruption due to more overall time in transit. Enterprise E has developed a mature resiliency approach due to the severe consequences of disruption and high competition associated their supply chain and operations. The strategies employed by Enterprise E, such a sourcing many critical components domestically and making off-peak deliveries, display this maturity.

Enterprise F also deals with food products, but displays less resiliency maturity than Enterprise E due to previous lack of experience with disruptions. Having a domestic supply chain reduces the potential for disruption, as previously mentioned, and may be a reason for Enterprise F's lack of experience with disruptions. A recent weather disruption, and subsequent breakdown within the supply chain, encouraged Enterprise F to evaluate and improve their resiliency procedures. As a relative newcomer to the area of resiliency, Enterprise F is beginning to integrate more general resiliency strategies such as communication, relationships, and flexibility into the supply chain. When faced with a second weather disruption a year after the first, Enterprise F utilized recently established strategies and believes their supply chain response improved due to the strategies in place. One can expect that as Enterprise F continues to explore and understand the importance of resiliency within their supply chain, the strategies they chose to implement will be similar those of Enterprise E. Enterprise F's actions align with previous research asserting that enterprises that have experienced a previous disruption are more likely to be proactive in an attempt to improve resiliency (Rice and Caniato, 2003).

The large manufacturing enterprises use similar strategies, such as use of information and technology, expedited freight, and premium transportation, but they do not employ these strategies solely for the sake of resiliency. Both Enterprise H and Enterprise I manufacture expensive products using a JIT strategy, meaning the precise delivery of goods is essential to being able to operate with minimal inventory. While JIT is foremost an inventory strategy, its success hinges on the ability to operate with low volumes of inventory and still keep assembly lines moving. By removing safety stock, a supply chain is automatically less resilient and depends more on the reliability of other aspects of the supply chain like the transportation network. A JIT supply chain needs actively increase resiliency and able to respond to delays, potential and actual, in order to be successful. Given the size and value of the good produced by both these enterprises, the extra expenditures required to implement information technology systems and use expedited and premium freight are inconsequential to the costs of holding increased inventory and potential assembly delays. Enterprise J does not operate as a JIT supply chain but provides service to enterprises who value expedited service very highly. As with Enterprise H and Enterprise I, whose manufactured goods cost in the hundred thousands and hundred millions respectively, the cost of transportation is negligible when concerned to the cost of customers' delays of business due to delayed goods. Similar to Enterprise J, Enterprise G provides products to enterprises that operate JIT and therefore value high levels of service. Higher values goods incur high inventory costs and therefore it is most efficient to produce finished goods to be sold as quickly as possible.

A supply chain which operates with a JIT strategy can be considered mature due to concerns beyond solely ensuring that goods arrive at the destination as expected. Enterprises using JIT have made the decision to improve efficiencies to an already established supply chain, thus reducing supply chain costs. Disruptions are more consequential within these supply chains, and therefore resiliency efforts are more established. The strategies most commonly reported by these enterprises are the most appropriate and effective means of establishing resiliency given the requirements of a JIT, large manufacturing supply chain.

#### Relationships between Strategies

Upon examination of strategies, it was evident that some strategies compliment, and may even be necessary to execute, other strategies. For example, the use of a distribution center structure as a resiliency strategy assumes the use of expedited freight in order to reroute products between distribution centers and stores in a timely manner. Additionally, a flexible transportation policy encourages the use of numerous other strategies such as expedited freight, premium transportation, and use of multiple ports/carriers. While not mentioned as a strategy by interviewees, increased inventory is required to execute identified strategies such as distribution center structure and extra capacity at distribution centers.

Conversely, inconsistencies are also evident among the strategies identified during the interviews. For example, the strategy involving locating employees overseas is not compatible with the strategy to source domestically because

one encourages operating globally while the other aims to avoid it. Therefore, it should be noted that not all of the strategies identified during the interviews can be implemented at once by one enterprise.

#### Resiliency as a Nebulous Concept

As mentioned earlier, resiliency has been discussed in nebulous terms in the past. One of the aims of this research was to present a framework for discussing resiliency in more specific terms, which was accomplished using concepts such as enablers and strategies. While evaluating resiliency strategies and understanding enterprise implementation, it became clear that there was a need for the nebulous discussion. Given the multitude of disruption possibilities and supply chain structures both between and within enterprises, it is difficult to discuss resiliency in absolute terms. It is impossible to develop a prescribed plan to improve resiliency in supply chains as a whole and strategies are not universal. Resiliency is best explored at the individual enterprise level, and therefore, when discussed in general terms, a rather vague concept.

#### Adding to Supply Chain Strength

In addition to improving resiliency, these strategies may also be able to add value to the supply chain in other ways. Several of these strategies, including use of information and technology, communication, and C-TPAT certification increase visibility in the supply chain, as well as impact other supply chain concerns such as insurance rates. With respect to resiliency, these strategies allow enterprises to identify disruptions earlier. Increased visibility also allows enterprises to identify inefficiencies within the supply chain, and could potentially lead to a reduction of inventory due to increased knowledge of goods flow.

As stated earlier, more volatile supply chains with existing disruption experience such as supply and demand fluctuations are often more mature, resiliently speaking. To complete the circle, supply chains which employ resiliency strategies become more capable of handling other disruptions such as supply and demand fluctuations. An enterprise who aims to be resilient to large scale disruptions typically increases their resiliency to daily vulnerabilities (Sheffi, 2005). For example, a flexible transportation strategy not only allows for changes to contracts of scheduling due to events such as closed ports and large weather events, but also for last-minute order changes or congestion.

#### RELEVANCE TO TRANSPORTATION SYSTEM

The enterprise view of supply chain resiliency cannot be isolated from the resiliency of the transportation system which includes infrastructure, government policy and regulations, and users. An enterprise could have extensive resiliency plans in place, but most often requires assistance in the form of information or infrastructure to successfully implement the plans. Supply chains are dependent on mostly public infrastructure (railroads and some ports are privately maintained), and often enterprises rely on governmental agency policies in order to move goods efficiently. Additionally, knowledge of the strategies used by enterprises can assist freight transportation system planners, designers, and managers in improving system resiliency.

Much of the infrastructure which goods move on is designed, built, and managed by a Department of Transportation (DOT), whether it be at the city, state, or federal level. During normal conditions, enterprises know what to expect from and how to best use the infrastructure, due to experience. During a disruption, an enterprise's level of resiliency may depend on understanding how the infrastructure has been affected, what alternatives have been provided, and how other users respond. Additionally, if the DOT understands how enterprises use the infrastructure to move goods, they can make better decisions on how to handle disruptions in order to reduce impacts on users. These groups can use a resiliency enabler, communication, to improve the transportation system.

From the strategies identified during the interviews the following conclusions can be made about the impact of these strategies on the transportation system. Broadly speaking, the transportation system benefits from efficient freight operations, as fewer vehicle miles and vehicle hours are spent producing the same good. Less infrastructure capacity is required to perform the same work of moving goods from origin to destination. The impacts of the use of the identified strategies on the transportation system are examined in detail below:

- Developing **relationships** with the agencies or personnel who manage the components of the transportation system helps facilitate communication and information sharing between the enterprise and the



transportation system. With better information about user behavior, the agency can make better investment decisions regarding system operation and improvement.

- The **information** gathered by enterprises through technology, and shared with the agency through **communication**, allows the agency to managing the transportation system more effectively
- If an enterprise maintains a **flexible transportation policy**, the managing agencies can rely on the enterprise having the ability to reroute around problem areas if given proper notice, relieving the stress or demand to these areas during a disruption.
- When enterprise becomes **C-TPAT certified**, it helps to facilitates security procedures within the port, assisting the port managing agency in improving the efficiency of the safe movement of cargo through the port.
- Having a wide-spread **distribution center structure** spreads the transportation demands of the enterprise over the infrastructure, lessening the burden on any one region or segment of the transportation system. Using **multiple ports or carriers** also achieves this end.
- When an enterprise **delivers during off-peak hours**, it is utilizing the infrastructure at a time when there is typically excess capacity and reducing demand on the transportation system during peak flow periods. This allows the transportation system to provide better service to other users.
- An enterprise which **sources domestically** may increase the demand for domestic transportation, but lessens the burden on U.S. points of entries such as ports. The net effect depends on the relationship between current demand and capacity of these system elements.
- Some forms of **premium transportation**, such as previously mentioned z-trains, demand a higher level of service from the managing agencies in the event of a disruption.

Another concern to enterprises is that government response to disruptions can often have a greater impact on supply chains than the disruption itself. For example, the closure of U.S. airspace and delays at the borders immediately following the attacks on September 11th were more disruptive to supply chains than the actual attacks themselves (Rice and Caniato, 2003). With regards to both large-scale and daily disruptions, the policies of the federal, state and local governments impact an enterprise's ability to move goods. These policies include federal policies such as C-TPAT and the Container Security Initiative (CSI), and local policies such as hazard mitigation plans. From the enterprise's perspective, it is important to understand and anticipate government reactions to disruptions in order to improve resiliency. The most successful government policies are the product of an interaction between the enterprises and agencies because are most successful when embraced by industry and therefore require industry input.

In the interviews conducted, several enterprises voiced concerns regarding interactions with governmental agencies. Enterprise J, Enterprise D, Enterprise A and Enterprise E identified security measures such as the Customs and Border Protection's (CBP) 10+2 initiative and the Transportation Worker Identification Credential (TWIC) program as potential transportation challenges. Enterprise J commented that since September 11th, the Department of Homeland Security and the Transportation Security Administration have made commerce more difficult. Enterprise E remarked that they understood the purpose of such initiatives but felt they were difficult to comply with. Enterprise H identified border controls, especially at the southern border, as an issue. Being required to switch trucks, and often carriers, at the border introduces more room for disruption or incident within the supply chain. These initiatives have been put into place to deter disruptions and protect trade, but they also introduce challenges to supply chains.

With regards to both infrastructure and policy, successful interactions between the private and public sector require communication and information exchange (both enablers) to occur before, during, and after the disruption. In order to effectively accomplish this exchange, relationships (another enabler) must be developed between the two entities. The fourth enabler, flexible culture, is also an important trait for a DOT to embody in order to best react to disruptions and interact with enterprises moving goods. Enterprise resiliency and systems resiliency are not stand alone concepts and interactions between the two are necessary for either to achieve resiliency.

## CONCLUSIONS AND FUTURE STUDY

This thesis was motivated by the continued increases in trade volumes, lengthening of supply chains, and increased focus on disruptions and resiliency within the supply chain community. As enterprises attempt to improve resiliency,

it is important to understand their perception of the concept and the means by which they attempt to achieve resiliency. Through interviews it appears that while resiliency was in the field of vision of interviewees, the concept was not a supply chain priority. While resiliency can impact supply chain costs and efficiency, and enterprises often cited costs and efficiency as supply chain priorities, there appeared to be a disconnect between the impacts of resiliency and enterprise priorities. Resiliency, while acknowledged, was not part of most enterprises' daily language, or discussed using other terms such as reliability and consistency. Despite this, evidence of resiliency within enterprise supply chains, specifically the transportation component, was encountered.

As mentioned earlier, resiliency has been discussed in nebulous terms in the past. Defining types of strategies, such as enabler and resiliency, provides consistency within a vague concept. Upon deeper examination of implementation of resiliency into enterprise supply chains, it became clear that the vague discussion regarding resiliency is necessary due to the multitude of scenarios regarding both disruptions and strategies. It is difficult to develop a prescribed plan to improve resiliency in supply chains as a whole and strategies are not universal. Resiliency is best explored at the individual enterprise level, and therefore, when discussed in general terms, a rather vague concept.

The list of identified strategies within this research is not all-inclusive. The strategies evaluated were drawn for the interviews conducted and it is acknowledged that additional strategies may be used by both these and other enterprises not interviewed. As strategies identified within the interviews, it can be assumed that these strategies are commonly utilized among supply chains in various industries such as the ones considered here.

While understanding of the enterprise role in creating a resilient supply chain is critical, a better understanding of the agencies (i.e. DOT) role improving resiliency is also required. As stated earlier, the enterprise view of supply chain resiliency cannot be isolated from the resiliency of the transportation system which includes infrastructure and government policy and regulations. Enterprises depend on agencies to provide and manage the transportation system and decisions which either party makes regarding resiliency affects the other.

Agencies have only just begun to focus efforts onto resiliency of the transportation system. Frameworks or models can be developed to assist these agencies in incorporating resiliency into planning and operations. Further research into the interaction between agencies and enterprises can help determine the best methods to improve overall freight system resiliency. Additionally, chains of command and assignment of responsibility should be formalized for cases of disruption and plans for disruption response and recovery should be developed and evaluated.

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