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碩士論文

提升國際快遞業回復力之策略模式

Modeling Resilience Enhancement Strategies for International Express Industries

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摘要

人們普遍意識到天然災害和人為災害具有突發性，當擾動發生時，原先的營運計畫可能偏離最佳化的結果甚至導致原先的計畫不能使用，所以調整的手段或重新最佳化的工具是需要的，這些手段或工具可以有效率地使用資源，讓偏離最佳化的營運及時地回到運行的軌道上。

國際快遞業相較於其他運輸服務是一個對時間高度敏感的產業，需要快速的反應供應鏈的擾動，否則可能會失去競爭能力。相較於在擾動發生的階段武斷地做出匆促的決定，本研究提出一個量化的方法，不論在路網上有多少可用的資源或有多少運能可供租借，此方法可根據整合資源分配的概念最佳化回復策略。本研究之問題被模式化為一個多樞紐、多運具、多運輸業者和多商品的路網問題，此量化分析模式可幫助國際快遞業在擾動發生時決定新的替代路線和租賃活動(包括運具的選擇與業者的選擇)。考量到國際快遞業對時間敏感的特性，模式也加入了貨物價值時間函數，讓不同價值的貨物可以以不同方式來運送，獲得較高的顧客滿意程度。

最後，我們執行數值的試驗和敏感度分析。數值試驗的結果證實模式可以應用在實際路網上，並且可提供具實用性的回復策略; 敏感度分析的結果則顯示回復成本的增加對目標式的影響大於運輸時間，而當運輸時間超過某一門檻值後，運輸時間的增加對目標式的影響會急遽上升。

關鍵字: 國際快遞業，回復策略，混合整數非線性規劃，貨物價值之時間函數

Modeling Resilience Enhancement Strategies for International Express Industries

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ABSTRACT

There has been a general awareness that natural and man-made disasters may occur suddenly. When disruptions occur, the previously operational plans may become far from optimal or even infeasible, and means are needed for adjusting or re-optimizing the original plan to adapt the changing environment and to get back on track in a timely manner while effectively using the available resources.

International express is one most time-sensitive industry, which may need to respond disruptions quickly so as to improve service quality and to avoid losing their competitiveness with other express service providers. Instead of arbitrarily making rush decisions during the post-disruption phase, this paper contributes a method for quantifying and optimizing the resilience strategies based on an integrated resource assignment concept, regardless of how the available resources are located with respect to the studied logistics network or how many capacities we can rent from others.

The studied problem is formulated as a multi-hubs, multi-modes, multi-carriers, and multi-commodities network problem. The analytical model is developed for determining the alternative routes and rent activities (including the mode choice and carrier selection) after the disruption occurs. It also takes into account nonlinear cargo value functions of time to reflect the feature of the express industry that allows company transport different types of cargo with different ways to achieve higher customers' satisfaction. Numerical experiments are conducted to examine our model applied in more complex networks and real world cases. Through a series of sensitivity analysis, some managerial implications are suggested to decision makers and potential stakeholders.

Key Words: International Express, Resilient Strategy, MINLP, Time Dependent Cargo Value Functions

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最後是我的愛人，謝謝你一直在身邊支持我，為我加油，謝謝上天讓我遇見你。

套用「謝天」裡的一句話，因為需要感謝的人太多了，就感謝天罷。感謝上天給予我人生的磨練，感謝上天讓我遇到非常多的貴人，經過兩年的研究生生活，我知道我逐漸成長與茁壯，已經做好準備迎接更大的衝擊。

蔡亞璇 謹誌

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Table of Contents

Figures Catalogue

Tables Catalogue

I. Introduction

1.1 Research Background and Motivations

The supply chain currently is threatened by natural disasters and artificial disruptions. The possible reasons may be twofold. First, if we put the emphasis on the natural disasters, we can find the number of natural disasters shoot up during last ten year in Figure 1.1 . Secondly, due to global supply chains, ever-shrinking product lifecycles, and volatile and unpredictable markets, the effect of these disasters to the supply chain are heightened. (Sheffi, 2005) The information implied behind these phenomenons is that supply chain is much easier to be disrupted than before.

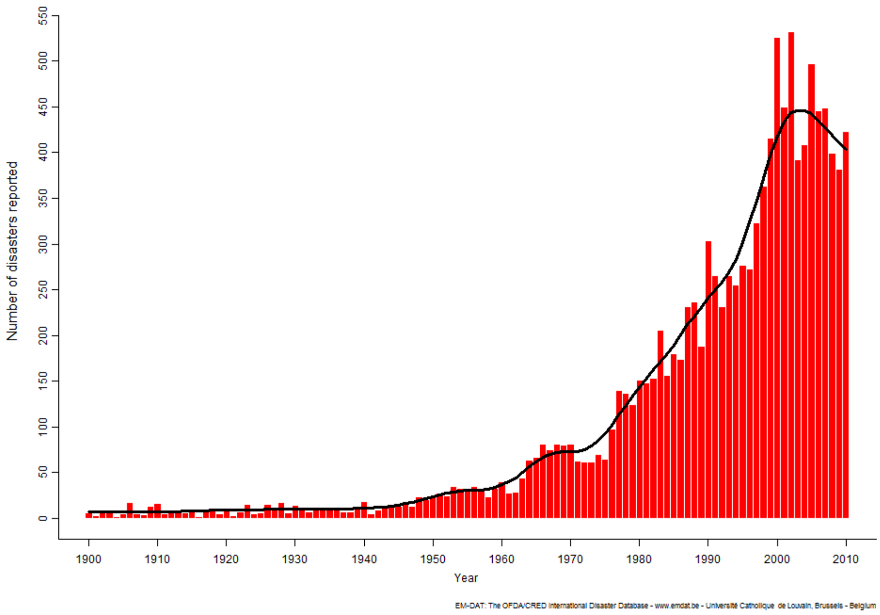


Figure 1.1 Natural disasters reported from 1900 to 2010 (EM-DAT, 2010)

As soon as the major disruption happens, it usually cause catastrophic consequences in the supply chain, for instance the event of the tsunami in 2004, the hurricane Katrina and Rita in 2005, Haiti Earthquake in 2010, Iceland volcano in 2010, Japan earthquake in 2011 and 9/11 attacks in 2001. We pick the Japan earthquake event to illustrate the impact it makes. The 8.9 magnitude Japan quake and ensuing tsunami destroyed infrastructures and caused plant closures and production outages among Japan's high-tech companies combined with port closures. The event threated to the supply chain operation and forced the firms around the world to slow production due to a lack of parts. Sony Ericsson, for example, suffered a loss of 50 million euro during the three months after Japanese earthquake happened and is cut sales by 1.5m phones in the quarter because of supply chain constraints. (BBC News) Not only the production side was affected, but also transportation. The demand of air freight industry fell because most technologic companies or semiconductor enterprises were closed. Another factor to affect the transportation industry is the destruction of the transportation infrastructures. Japan quake caused the closure in Narita International Airport and Haneda International Airport. Six ports were broken. The flights were canceled and works were all delayed. Executive Director of Hactl indicated that the quake and the subsequent tsunami crisis made a significant decline in export and import volumes to and from Japan in March.

According to its catastrophic impacts, many enterprises are motivated to draw up different recovery strategies to prevent the natural and man-made disasters affecting the entire supply chain, especially for the transportation system. Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer's handle. It is one of key element in a logistics chain. (Tseng et al., 2005)The efficiency of a transportation system help a supply chain closed to the success. Conversely, if goods delivery is delayed, it can shut down the entire production process and part of supply chain. Thus, enterprises should pay attention to the disruption in transportation system when they want to enhance the supply chain resilience.

The subject in this research, the international express industry, is one of the fastest growing sectors in the global economy. Express operators provide guaranteed, fast, reliable, on demand, world-wide, integrated, door-to-door movement of shipments which are tracked and controlled throughout the journey. They simplify and speed the process of transporting goods and belong to "Business Class" of cargo services. (OE Forecasting, 2009) In summary, the core business of the express industry is the provision of value-added, door-to-door transport and highly time-sensitive shipments, including documents, parcels and merchandise goods. If the disaster disrupts the system or process, express service can't realize its core value, especially time-sensitive delivery, to satisfy the customers demand. Therefore, the international express industry is more threatened than other transportation services in the face of severe disruptions, for example, natural and man-made disaster . (Other services involve air freight, ocean freight and overland transport) Setting up the recovery plans or resilient strategies is important to the express company, particularly international express, and can mitigate the impact in effect.

Nowadays the express companies or transportation companies rarely respond the severe disruption through the systematical measure to decide how to transport the cargos in the efficient way. The decisions are usually made by discussion, case by case, and unsystematically. The most common way to meet an emergency is to post the disaster information in the website and inform the customers that cargos would be delayed. We believe there is still substantial room for improvement. Thus, according to the above mentioned findings we are going to develop a quantitative method which is used to find the adequate resilient strategies for the express company after the disruption happens.

We consider that express company concerns not only how much they spend in the recovery activities but also how many cargos they deliver in the aftermath of a disruption. Although not to complete freight missions due to natural disasters or terrorist attacks is not the carrier’s responsibility, we still believe that recovering the transportation service actively even during the disruption is the better way to run a business.

1.2 Research Objectives

Based on our motivations, the aim of this research is to study what resilient strategies should be taken by express companies when the delivered activities are broken off by the natural and man-made disruptions and provide a quantitative method to find these strategies.

The purposes and contributions can be described respectively as follows:

1. Sort out the materials for proactive and reactive recovery strategies in the transportation domain by literature reviews, expert interviews and the information available online. Afterwards, obtain the possible recovery strategies which can be employed by international express.
2. Develop a quantitative resilience model considering the feature of express industry which is highly time-sensitive. The model is able to search the optimal reactive actions.
3. Provide strategic directions and actions that help decide investment balance between proactive and reactive resilient strategies in the way of sensitivity analysis.

1.3 Research Scope

1. Disruption category

Decision makers of the enterprise need to have a clear understanding of the sources of uncertainty and consequences of the risks to the system in order to prevent disruptions and respond to disturbances, shocks, or incidents timely and efficiently. (Mansouri et al. 2009) Thus, we need to identify the threats that make the supply chain disruption in this research in order to develop the resilient strategies. The threats are categorized by different sorting methods from the literatures but in our studies we focus on the external disruptions including the natural disaster (e.g. tsunamis, earthquakes, floods, landslides, hurricanes) and the man-made disaster (e.g. arson and terrorist attacks). These disruptions are infrequent and cause catastrophic consequences in the transportation system which fall on the Quadrant I in

Figure 1.2.

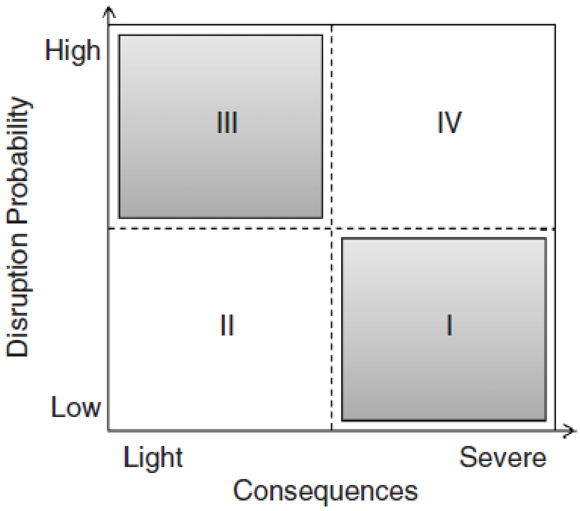


Figure 1.2 Generic vulnerability matrix (Ta et al. 2010)

2. Geography scope

The research focuses on the global delivery network from the service centers in original country to the service center in destination country. It means we consider the intermodal transportation including the ground and air transport and put the stress on handling the international problem. The other available networks are also considered after the disruption, for example rail and sea.

3. Time scope

The resilient strategies we discuss in this study are used in recovery phase. The aim of the recovery phase is to take appropriate strategies to regain operability as fast as possible after the occurrence of a disastrous event. The strategy taken in the recovery phase is called the reactive strategy.

4. Research object

In this study, international express company which has their own aircrafts and trucks is our research object. The service it provides is highly time-sensitive.

Typically, the types of goods transported by express services are high-value and low-weight items such as electronic components, designer fashions, and pharmaceutical products. However, express delivery is sometimes called on to delivery urgent shipments of large articles such as parts for aircraft and equipment for mining, construction, and manufacturing operations. (Oxford Economic Forecasting, 2009) We identify the products delivered by express company in our research is the high value-added, low-weight and urgently-needed items.

In this article, the resilience model is based on the international express delivery network from international express company perspective, focusing on one kind of threat: external disruptions. Moreover, the reactive strategies are taken as the methods to enhance the resilience.

1.4 Research Procedure

The research is organized by five chapters as follows in Figure 1.2.

In chapter 1, the motivation and objective for the study subject is described. Chapter 2 presents an overview of the literature related to resilience concept in supply chain and transportation. We also provide an overview of resilient strategies and quantitative methods on resilient supply chain and transportation system. The mathematical model we proposed is developed simultaneously considering the international express industry characteristics in Chapter 3 while in Chapter 4 we conduct numerical experiments to illustrate the application of the model and provide the applied example to the model. The final chapter, we conclude with a discussion of the implications of our research and outline directions for future research.

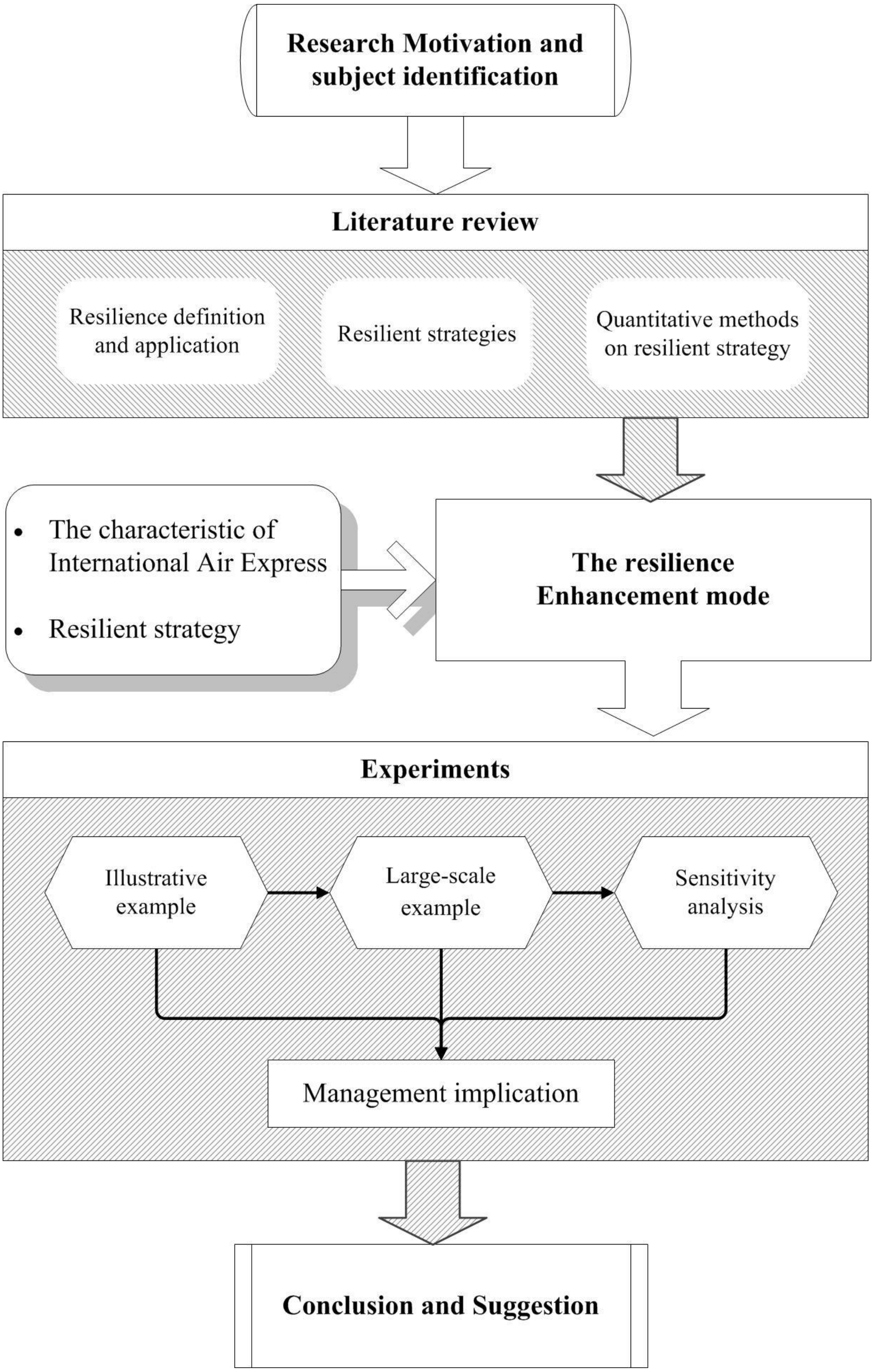


Figure 1.3 Research Procedure

II. Literature Review

2.1 Resilience Concept

In this section, we will introduce the concept about resilience from general, supply chain and transportation aspects first. Generally, the topic of supply chain resilience emerged from about 2004 and has become more widely recognized recently. (Christopher & Peck, 2004, Sheffi, 2005). The resilience of transportation has been addressed to a limited degree before 2006 (Murray-Tuite, 2006). Only in recent years has it emerged as an attribute which is concerned by state departments of transportation (DOTs) on the transportation infrastructure and freight transportation systems (Ta et al., 2009, Ta et al., 2010).

Finally, the literatures about disaster resilience and its quantitative measure will be reviewed.

2.1.1The General Resilience Concept

By no means is resilience a new concept or a new theoretical perspective. The concept of resilience has been used extensively in engineering, ecological sciences, and organizational research. The term resilience was first proposed in ecological research (Holling, 1973) to distinguish between a system (an ecosystem, society or organization ,for example) that persists in a state of equilibrium (stability) and how dynamic systems behave when they are stressed and move from this equilibrium.

In engineering, a very basic definition of resilience can be found: the tendency of a material to return to its original shape after the removal of a stress that has produced elastic strain (Merriam-Webster, 2007). However, when an organization focuses on resilience, it is prepared to adapt to a new set of circumstances following a disturbance. The organization should not aim to recover and rebuild itself to be the same as it was before disaster struck, but should recover to a new equilibrium. (Dalziell & McManus, 2004)

The study written by Gunderson and Pritchard (2002) characterize two general types of system resilience, termed engineering resilience and ecological resilience.

1. Engineering resilience is measured by the time required to return to prior steady state operations after a disruption. Implicit in engineering resilience is the notion that the system is stable and has a single equilibrium condition representing the longterm steady state behavior of the system.

2. Ecological resilience is defined as the magnitude of disturbance that can be absorbed before the system restructures, which implies a focus on maintaining existence of function.

2.1.2 Supply Chain Resilience

The concept of resilient supply chain is formed by several scholars, including Sheffi, Christopher, and Peck. Before we introduce the concept, the origin of vulnerability and resilience and their relation will be referred to because they are closely related to the formulation of resilience concept in supply chain management.

1. The origin of vulnerability and resilience

The terms, vulnerability and resilience, used in supply chain are derived from disruption risk management. (Kleindorfer & Saad, 2005) However, the framework of disruption risk management builds on the supply chain risk management theory. The definition of Supply chain risk management(SCRM) is to collaborate with partners in a supply chain apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics related activities or resources (Norrman and Lindroth, 2002). In contrast, Disruption risk management and SCRM have the same process that are understanding the risks (risk estimation and risk evaluation) and then minimizing their impact(Norrman & Jansson, 2004), but they focus on different risk categories. There are two broad categories of risk in the SCRM area affecting supply chain design and management: (1) risks arising from the problems of coordinating supply and demand, and (2) risks arising from disruptions to normal activities. (Kleindorfer & Saad, 2005) Disruption risk management is concerned with the second category of risks including operational risks (equipment malfunctions, unforeseen discontinuities in supply, human-centered issues from strikes to fraud), and risks arising from natural hazards, terrorism, and political instability. (Kleindorfer & Saad, 2005)

Vulnerabilities could be explained as situations where organizations are not prepared for the magnitude of the risks or uncertainties (and therefore their impacts). (Asbjornslett, 2008) In other words, it is a representation of lacking robustness or resilience to internal and external threats. From risk management aspect, decision makers can prevent disruptions and increase resilience relying on understanding of the vulnerability in supply chain. Nair et al. (2010) also mentions from maritime transportation, if someone wants to determine the best set of recovery actions that can be taken to enhance port resilience, measuring the port vulnerability is required.

In general terms, the relationship between vulnerability and resilience is inseparable.

2. The concept of supply chain resilience

Supply chain resilience is defined as the ability of a system to quickly react to the undesired events when they happen and quickly return to its original state or move to a new, more desirable state after being disturbed(Christopher & Peck, 2004). Falasca (2008) also defines supply chain resilience to be the ability of a supply chain system to reduce the probabilities of a disruption, to reduce the consequences of those disruptions once they occur, and to reduce the time to recover normal performance.

SC managers today need to manage risks in a complex, dynamic and highly vulnerable environment. They are becoming increasingly aware of the concept of vulnerability and resilience. How to make the enterprise become flexible is the issue managers concerned with. From the organizational aspect, Rose (2004) describes that a resilient organization is able to quickly return to normal (or even improved) operations after such an event has occurred. The notion of organizational resilience is the ability of an organization to successfully confront the unforeseen. It has always been a core element of success. (Sheffi, 2005)

In the past, supply chain resilience was thought to be the ability to manage risk. To date, it is not only the ability to manage risk but also making business be better positioned than competitors to deal with disruption and even gain advantage from disruption. (Sheffi, 2005)

Though we emphasize the importance of resilience, it is worthy to note that many recovery actions that can increase resilience conflict with the business goals such as reducing costs and increasing operational efficiency. (Falasca, 2008)

2.1.3 Transportation System and Infrastructure Resilience

The freight transportation system resilience is defined as ‘the ability for the system to absorb the consequences of disruptions to reduce the impacts of disruptions and maintain freight mobility’. (Ta et al. 2009) He also provides a definition for resilience including the physical, user, and organizational dimensions of a freight system presented in Table 2.1. He thinks there is an intricate relationship between the three dimensions. Murray-Tuite (2006) also considers several dimensions but from different angles. He states a resilient transportation system has ten properties: redundancy, diversity, efficiency, autonomous components, strength, adaptability, collaboration, mobility, safety, and the ability to recover quickly. He measures the transportation resilience through the evaluation matrix of last four dimensions in the context of vehicular traffic network performance.

Concept	**Definition of resilience**
Infrastructure resilience	Ability of the network to move goods in the face of infrastructure failure, either through a reduction in capacity, a complete failure, or a failure in the information infrastructure to provide information
Enterprise resilience (user)	Ability of an enterprise to move goods in a timely and efficient manner in the face of infrastructure disruption

Managing organization resilience	Capacity to meet priorities and achieve goals in a timely and efficient manner in order to contain losses. (G. D. Haddow, & J. Bullock, 2004)

Table 2.1 Resilience definition from three dimensions of the freight transportation system (Ta et al. 2009)

More researches would define the resilience concept from the perspective of infrastructure system. (Mansouri et al., 2009, Nair et al., 2010) Both they think the inherent capacity is important. The resilience definition adopted by Nair et al. (2010) captures the impact of the inherent capacity redundancy and short-term recovery actions to an Intermodal (IM) component. The inherent capacity redundancy of an IM component can mitigate the effects of disruptions. Short-term recovery actions taken to reverse, contain, or ameliorate conditions on the ground help in prompt resumption of component activities. Thus, the resilience is the innate ability of the IM component to weather the disruption and the positive effects of short-term recovery plans to increase component capacity. Mansouri et al. (2009) define the resilience of an infrastructure system such as the MITS (Maritime Infrastructure and Transportation Systems) as a function of system's vulnerability against potential disruption, and its adaptive capacity in recovering to an acceptable level of service within a reasonable timeframe after being affected.

2.1.4 Disaster Resilience

Because our research focuses on the natural and man-made disruptions, we simply introduce the meaning and application of natural disaster resilience as following.

Different aspects of the concept of disaster resilience are currently being studied from a number of viewpoints within the academic research community. Many studies focus on the physical (technological) aspects of a system or the social (human) aspects of a system. But there is still significant discussion on combined human–environment interactions (socio-ecological systems). (Zobel, 2011) Due to the diversity of perspectives presented in these different subjects, the concept of disaster resilience has developed a large number of different working definitions. (Zhou et al., 2010). We will not go into particulars here.

As mentioned before, the concept of resilience is related to the capacity of physical and human systems to respond to and recover from extreme events, and it has gained prominence in recent years as a topic in the field of disaster research (Bruneau et al., 2003; Rose & Liao, 2005).Resilience also can be thought of as an extension of the traditional concept of resistance, defined as the measures that enhance the performance of structures, infrastructure elements, and institutions, in reducing losses from a disaster. But while disaster resistance emphasizes the importance of pre-disaster mitigation, the concept of resilience needs to be extended in order to include improvements in the flexibility and performance of a system both during and after a disaster. (Falasca, 2008)

The definition of resilience from Subcommittee on Disaster Reduction (2005) is the ability of a community or system to adapt to hazards so as to maintain an acceptable level of service. Bruneau et al. (2003) also describe the resilience is the ability of social units such as organizations to mitigate hazards, to contain the effects of disasters when they occur and to carry out recovery activities in order to minimize social disruption and to mitigate the effects for potential future disasters.

As initially proposed by Bruneau et al. (2003), disaster resilience is characterized by four properties, which are robustness, rapidity, resourcefulness and redundancy. Zobel (2010) rewrites the meaning of them as following.

1. Robustness—the strength of a system, or its ability to resist the impact of a disaster event, in terms of the amount of damage or loss of functionality that results because of the event.

2. Rapidity—the rate or speed at which a system is able to recover to an acceptable level of functionality, after the occurrence of a disaster event.

3. Resourcefulness—the level of capability for dynamically responding to a disaster event, by identifying and implementing solutions to improve rapidity and/or robustness.

4. Redundancy—the extent to which components of the system are substitutable, and therefore able to be replaced or augmented when functionality has been lost or reduced.

Bruneau et al. (2003) also proposed the resilience triangle, which use the characterization of system performance to conceptualize of resilience illustrating in Figure1.

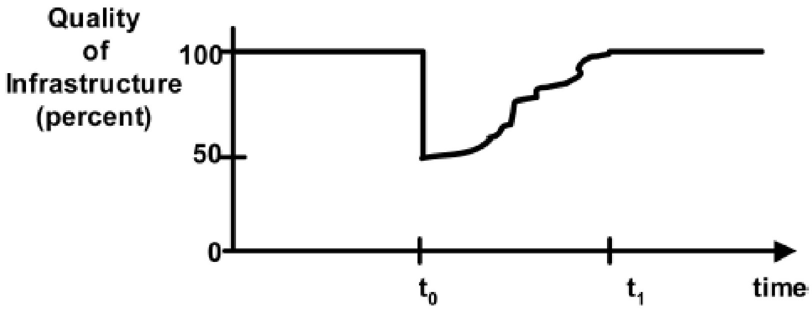


Figure 2.2 Original resilience triangle (Bruneau et al., 2003))

The community earthquake loss of resilience, R, can be measured by the size of the expected degradation in quality over time (time to recovery). The mathematical expression is

$$\mathrm{R} = \int_{t_0}^{t_1} [100 - Q(t)]dt$$

where Q(t) presents the quality of the infrastructure of a community at a given time t. Performance at the vertical axis can range from 0% to 100%, where 100% means no degradation in service and 0% means no service is available. When an earthquake occurs at time t_0 , it could cause sufficient damage to the infrastructure such that the quality is immediately reduced. Restoration of the infrastructure is expected to occur over time until time t_1. At time t_1 , it is completely rebound to the former state.

This concept was adapted by Dorbritz (2011) to assess the disaster resilience of public transportation systems (Figure 2.3). He states that initial reduction of the system performance when a failure occurs can serve as a measure for robustness and redundancy. Rapidity impacts the duration of recovery and resourcefulness can present the shape of the system performance curve after the event occurs.

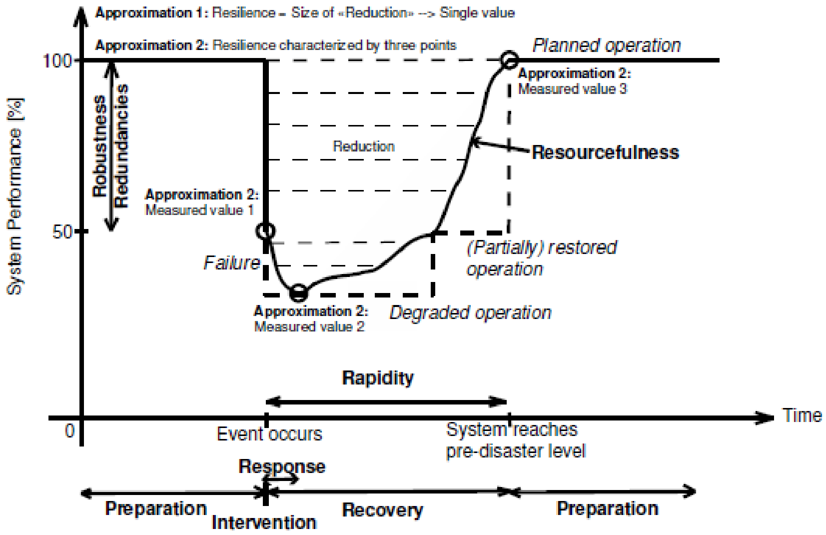


Figure 2.3 System performance, degraded operation state and disaster impacts(R. Dorbritz, 2011)

Dorbritz (2011) thinks the resilience concept should consider prevention, intervention and recovery and divides the time period into three phases.

1. The prevention phase

This phase aims to increase the ability of systems to withstand the impacts of disastrous events on the system performance before such an event occurs. Systems should be designed in a way such they are maximally robust and the impacts on the system performance are minimized

2. The intervention phase

In this phase, the organization tries to suggest appropriate strategies to positively influence the disaster spreading process during the impacts of them. Catastrophe management and anticipating order of failures are example for intervention measures.

3. The recovery phase

After the occurrence of a disastrous event, large parts of the system may fail such that even the entire network might blockade. Recovery strategies try to regain operability as fast as possible. Usually, recovery measures induce much higher costs than preventive ones. Experiences made in a recovery phase can be used to enhance the disaster resilience before a next occurrence. (Dorbritz, 2011)

Essential characteristics of resilience

According to above literature, we can sort out the relative properties of resilience from Murray-Tuite (2006), Tierney et al. (2007), Dorbritz (2011) and C. Ta el at. (2009) as the following table 2.2.

Resilience properties	**Definition**	**the application area**
Robustness (Strength)	Ability of systems to withstand disaster forces without significant degradation or loss of performance	disaster resilience
	System's ability to withstand an event	Cities resilience
Redundancy	Extent to which systems are substitutable, that is capable of satisfying functional requirements, if significant degradation occurs	disaster resilience
	Availability of more than one resource to provide a system function	freight transportation system resilience
Resourcefulness	Ability to diagnose and prioritize problems, to initiate solutions by identifying and mobilizing material, monetary, informational, technological	disaster resilience

	and human resources	
Rapidity	Capacity to restore functionality in a timely way, containing losses and avoiding disruptions	disaster resilience
	An acceptable level of service can be restored rapidly and with minimal outside assistance after an event occurs	Transportation network
Autonomous components	Parts of a system that have the ability to operate independently	freight transportation system resilience, Cities resilience
Collaboration	Engagement of stakeholders and users in a freight transportation system to promote interaction, share ideas , build trust, and establish routine communication	freight transportation system resilience
	Information and resources are shared among components or stakeholders.	Cities resilience
Efficiency	Optimization of input against output	freight transportation system resilience, Cities resilience
Adaptability	System flexibility and a capacity for learning from past experiences	freight transportation system resilience, cities resilience
Interdependence	Connectedness of components of a system or the dimensions of a system, including the network of relationships	freight transportation system resilience

	across components of a system, across dimensions of a system, and between components and dimensions	

Table 2.2 The properties of resilience

We find the properties, autonomous components and interdependence, are a little contradictory. The property of autonomous components asks the system to operate independently. However, interdependence hopes that there is connectedness across dimensions of a system or components.

2.2 Resilient Strategies in the Supply Chain and Transportation

In this section, we will review the literatures about recovery strategy before and after the disruptions occurs.

There is less recovery strategies provided for private transportation carriers. Most of researches and materials discuss it from the enterprise in supply chain and government perspectives. Thus, we will organize the recovery strategies from these two perspectives in order to develop our resilient strategies in the next chapter. While reviewing the literatures, we try to focus on transportation part even.

2.2.1The Government Dimension

The government of the nation is given the responsibility to protect the community from harm when a major disaster happens. Several organizations, for example, Office of Disaster Management, Executive Yuan in Taiwan, National Fire Protection Association (NFPA) in America, would publish documents relating to preparedness for, response to, and recovery from disasters. These programs consider the response for emergency relief to the community and what the government and private sections should do to spring back to normal situation from the government's point view, if the critical infrastructures shut down. Moreover, different departments will enact relative plans and strategies in the detail, for example United Stated Department of Transportation which provides the transportation recovery rules to reduce the consequences of a disruption.

"Standard on Disaster/Emergency Management and Business Continuity Programs"(2007) is published by the National Fire Protection Association (NFPA) from America. It is developed through a consensus standards development process approved by the American National Standards Institute. The standard provides disaster and emergency management and business continuity programs, the criteria to assess current programs from varied viewpoints. It can apply to public, not-for-profit, and private entities on fire and other safety issues.

The program shall follow a planning process which is the strategy, prevention, mitigation, emergency operations/response, business continuity, and recovery plans. The objective of each plan is described in Table 2.3.

Plan	objectives
The strategic plan	define the vision, mission, goals, and objectives of the program.
The emergency operations/response plan	assign responsibilities for carrying out specific actions in an emergency.
The prevention plan	establish interim and long term actions to eliminate hazards that impact the entity.
The mitigation plan	establish interim and long term actions to reduce the impact of hazards that cannot be eliminated.
The recovery plan	provide for short-term and long-term priorities for restoration of functions, services, resources, facilities, programs, and infrastructure.
The continuity plan (business continuity plans)	identify stakeholders that need to be notified, the critical and time-sensitive applications, alternative work sites, vital records, contact lists, processes, and functions that shall be maintained, as well as the personnel, procedures, and resources that are needed while the entity is recovering

Table 2.3 The objective of each plan

The prevention plan and mitigation plan are similar, but the prevention plan emphasizes on how to reduce the occurrence of hazards, however, the mitigation plan emphasizes on how to reduce the impact of hazards when we can’t avoid hazards.

Recovery planning in continuity plans for public sector normally includes bringing infrastructure and individuals back to pre-incident conditions through implementing mitigation measures to facilitate short- and long-term recovery. In addition, continuity of operations plans might use business impact analysis to identify critical governmental functions. Business continuity planning in the private sector incorporates both the initial activities to respond to an emergency situation and the restoration of its functions to pre-incident levels. The meanings of both plans in public sector and private sector are much the same, but still have difference.

In this study, recovering plan and continuity plan are much close to what we want to explore.

From the government viewpoint, the transportation network takes millions of people to and from work, school, and vacation destinations every day, and transports goods and services from one coast to the other. (Office of Intelligence, Security, and Emergency Response, 2009) Critical infrastructures in transportation systems play an essential role in communitywide disaster mitigation, response, and recovery. Therefore, they are high-priority targets for resilience enhancement. (Tierney & Bruneau, 2007)

Private transportation industry stakeholder, defined in "The National Transportation Recovery Strategy (NTRS) (2009)", is an owner or manager of a private company specializing in transportation services, assets, systems, or infrastructure, for example, transportation carriers and third party logistics in Taiwan. For the government standpoint, the role of private transportation industry stakeholder is responsible for the local community to deliver goods and play an assistance role in rescue when a disaster occurs, so it is vital to the effective, safe, and timely recovery and restoration of its own transportation system or infrastructure. NTRS (2009) provides the recommendations on how private transportation industry stakeholders can prepare for and manage the transportation recovery process. We review the recovery actions that are took before and after an incident.

Before an incident

1. **Enter into Mutual Aid Agreements:** In accordance with applicable laws and regulations, entering into mutual aid agreements can obtain assistance with other transportation industry stakeholders.

2. **Coordinate with Government and Other Transportation Industry Stakeholders:** Coordination efforts among all private companies or organizations and government involved in the transportation network recovery process are vital to ensuring that restoration occurs safely and quickly.

3. **Train:** Train the staff to serve as technical or subject-matter experts in the response and recovery phases. Pre-identify these essential employees for the transportation operation and set expectations and requirements so they can respond the incident quickly with no confusion.

4. **Improve Materials and Construction Methods:** Through risk assessments for the transportation entity, it can understand what those risks are and the probability of occurrence on the infrastructure. In order to mitigate these risks, the transportation entity can use the result of risk assessments to make improvements to the materials and construction methods when building and maintaining the transportation asset or infrastructure.

5. **Develop a Business Impact Analysis:** Develop a business impact analysis (BIA) for the company to determine the financial losses that could incur if the company and the transportation system or infrastructure were to be damaged or destroyed. Consider the economic, logistical, and social impacts that the loss would inflict on the community at large.

6. **Develop a Continuity of Operations Plan:** Using the results from BIA, the companies are strongly encouraged to develop a business continuity and recovery plan for the transportation service, system, or infrastructure. Further, companies are encouraged to review, exercise, and enhance the continuity of operations plans on a

regular basis. There are several approaches needed to consider in continuity plans. (National Fire Protection Association, 2007)

(1) **Succession:** To designate at least three successors for each position to ensure that the leadership will continue to function effectively under emergency conditions.

(2) **Pre-delegation of emergency authorities:** To ensure that sufficient enabling measures are in effect to continue operations under emergency conditions. Emergency authorities have been enacted that specify the essential duties to be performed by the leadership during the emergency period and that enable the leadership to act if other associated entities are disrupted, and to re-delegate with appropriate limitations.

(3) **Emergency action steps:** Actions that facilitate the ability of personnel to respond quickly and efficiently to disasters/emergencies. Checklists, action lists, and/or standard operating procedures (SOPs) have been written that identify emergency assignments, responsibilities, and emergency duty locations. Procedures should also exist for alerting, notifying, locating, and recalling key members of the entity. The SOPs and notification procedures should be integrated.

(4) **Primary and alternate emergency operations centers:** A facility or capability from which direction and control is exercised in an emergency. This type of center or capability is designated to ensure that the capacity exists for the leadership to direct and control operations from a centralized facility or capability in the event of an emergency.

(5) **Alternate operating or backup facilities:** Provisions also exist for alternate site(s) for departments or agencies having emergency functions or continuing operations.

<u>During Recovery</u>

After the incident occurred, the government suggests the private transportation industry stakeholder doing the following actions to respond it.

1. **Conduct Damage Assessments:** Be prepared to assess the impact of the incident on your transportation service, system, or infrastructure and the impact this damage has on the overall transportation network.

2. **Help the government to implement the recovery actions :** During the recovery period, the private transportation industry stakeholder should be fully involved in all means of information sharing in coordination with government and other private companies. Company's employees may be asked to advise government decision-makers, so the company may provide subject-matter expertise's suggestions to the government. The company also should prepare to provide critical transportation resources to community for critical facilities, such as hospitals, during the initial response and recovery phase.

3. **Implement Improved Materials and Construction Methods:** The new, improved materials and construction methods may be strongly encouraged or required by regulators to prevent similar damage from occurring again.

2.2.2 The Private Sectors Dimension

The approaches of mitigating the supply chain disruptions can be divided into the two broad categories of proactive and reactive response from the corporate enterprise perspective. A reactive response has minimal redundancies as supplies are acquired and delivered only in real time and a proactive response is based upon building ex ante capacity (Knemeyer, et al., 2009). Most researches place emphasis on proactive rather than reactive actions because 'prevention is better than cure'. (Weichselgartner, 2001, Kleindorfer & Saad, 2005)

We then classify the proactive and reactive response strategies as following:

<u>Proactive response:</u>

The aim of proactive response is to reduce the probabilities of a disruption and reduce the consequences of those disruptions once they occur. If the firm takes the proactive action in advance of a disruption, it incurs the cost of the action regardless of whether a disruption occurs. (Tomlin, 2006) It is called the mitigation approach in the study of Tomlin (2006) and Colicchia et al. (2008).

There are some manners as following.

1. **Supply chain network engineering**

This method is kind of risk assessment measure. Through risk assessment exercise, business can find the vulnerabilities of critical nodes and links in the network. Business uses mapping tool to help in identification of 'pinch point' and 'critical paths'. Pinch points are defined as bottlenecks where there is a limit of capacity and where alternative options may not be available. For example, ports capable of taking large container vessels or central distribution facilities which if they were to become unavailable would place a heavy strain on the rest of the system. Critical path in the supply chain network may have the characteristics like long lead-times, poor visibility and high levels of identifiable risk. (Christopher & H. Peck, 2004)

2. **Supply management**

(1) Flexible supply base

Single sourcing, where one supplier is responsible for the supply of a specific item, is dangerous in terms of resilience, although it will enable a firm to reduce cost. It may be desirable to have a lead supplier, but possible alternative sources should be available wherever. (Christopher & Peck, 2004) A flexible supply base not only enables a firm to handle regular demand fluctuations, it can also be used to maintain continuous supply of materials when a major disruption occurs. (Tang, 2006)

(2)Make-and-buy strategy

A supply chain is more resilient, if certain products are produced in-house while other products are outsourced to other suppliers. When a supply disruption occurs, the make-and-buy strategy offers flexibilities that allow firms to shift production quickly. (Tang, 2006)

3. **Product management**

(1) Postponement

Postponement strategy utilizes product or process design concepts such as standardization, commonality and modular design, to delay the point of product differentiation. (Tang, 2006) It enables a firm keeps products in semi-finished in generic form and customizes them until the demand information is more accurate. (Sheffi,2005) In the context of disruption recovery, the postponement strategy offers a cost-effective and time-efficient contingency plan that allows a supply chain to use a slightly different component from other suppliers for the generic products and reconfigure them quickly in the event of supply disruption. (Tang, 2006)

(2) Strategic stock

Traditionally, a firm considers carrying additional inventories of certain critical components to keep the supply chain from a disruption in supply. In the "just-in-time" era, a firm may consider storing some inventories at certain "strategic" locations (warehouse, logistics hubs, distribution centers) to be shared by multiple supply chain partners (retailers, repair centers, etc.). This strategy can deal with regular demand fluctuations problem. When a disruption occurs, the shared inventories at strategic locations will allow a firm to deploy these stocks quickly to the affected area as well. (Tang, 2006)

4. **Supply chain collaboration from upstream to downstream (visibility)**

Due to the increased globalization of supply chains and the prevalent use of subcontract manufacturing and offshore sourcing, the members of supply chain and the length of time took to complete all the works are increased. (Christopher &Lee, 2004) The situation leads supply chain to the lack of visibility and to explore in the risk, like demand fluctuation, because the member of a supply chain has no detailed information of what goes on in other parts of the chain.

Visibility implies a clear view of upstream and downstream inventories, demand and supply conditions, and production and purchasing schedules for example. It is the ability that makes supply chain respond rapidly to unpredictable changes in demand or supply. (Christopher & Peck, 2004)

On the other hand, the achievement of supply chain visibility is based upon collaborative working across supply chain members. The underlying principle of collaborative working is sharing the information to mitigate risk. Further, the information sharing can aid the creation of supply chain resilience to identify the sources of risk and uncertainty at each node and link in the supply chain. (Christopher & Peck, 2004)

5. **Process improvement**

Companies can achieve the aim of reducing the likelihood of disruption occurrence based on the analysis of the processes. (Colicchia et al., 2008) Sheffi (2005) suggests that a company can adopt standardized processes to increase supply chain flexibility. The method is to move production among plants by using interchangeable and generic parts in many products, relying on similar and identical plant designs and cross-training employee. It allows a company to respond quickly to a disruption by reallocating resources to the greatest need place.

Another measure is simplified processes by reducing the number of stages or activities involved, perform these activities in parallel rather than in series and e-based rather than paper-based. At the same time these simplified processes are designed around minimal batch sizes. The emphasis is on flexibility rather than economies of scale. (Christopher & Peck, 2004) Company also can inspect the non-value adding time from a customer perspective to simplify processes.

6. **Enhance transportation resilience**

Chen and Miller-Hooks (2011) depict that pre-event actions can reduce the time and cost required to complete post-event recovery activities, for example,

(1) Creating the robust network : adding additional links to the network.

(2) Building ex ante capacity : ordering spare parts or backup equipment; prepositioning resources in anticipation of potential recovery activities.

(3) Assistant with technologies: implementation of advanced technologies.

7. **Organization culture**

Organization culture is a factor that clearly distinguishes those companies that recover quickly from those that falter after a disruption. (Sheffi, 2005) There is a requirement to create a risk management culture within the business today.

(1) Deliver the information to the leader

As in every case of culture change at an organizational level, nothing is possible without leadership from the top of the organization. A supply chain risk management team should be created within the business and charge with the regularly updating supply chain risk register to report to the main Boardroom through the supply chain director on a least a quarterly basis. The team will need to be cross-functional and to be able to audit risk using the frameworks and tools. (Christopher & Peck, 2004)

(2) Continuous communication among informed employees

Organization keeps all personnel aware of the strategic goals, tactical factors, and day-by-day pulse of the business. When a disruption takes place, employees know the company's status and can make better decisions in the face of the unforeseen. (Sheffi, 2005)

(3) Distributed power to the team and individual

Make teams and individual be empowered to take necessary action before a potential disruption is visible. The organization can respond risks quickly, significantly enhancing the chances of reducing the damage. (Sheffi, 2005)

(4) Conditioning for disruptions

Resilient and flexible organizations will regard disruption as normal situation. (Sheffi, 2005)

<u>Reactive response:</u>

In generally, the reactive response that business usually gets after a disruption is the contingency plan. In the supply chain, it is viable only if suppliers have volume flexibility, that is, the ability to temporarily increase their processing capacity. (Tomlin, 2006)

Christopher and Lee (2004) propose to define contingency plans in case shipment schedules are deviated from plan. In the explorative study of Norrman and Jansson (2004), they describe how Ericsson has implemented a supply chain risk management process and define the contingency plans as business continuity management plans. In other words, the contingency plans are plans and actions which provide alternative modes of operation for those activities or business processes which might bring a damaging or loss to the supply chain if the processes are interrupted. However, Craighead et al. (2007) have different views on contingent plan. He depicts that a contingent response operates in a proactive mode for low values of disaster intensity, and activates a reactive response if the intensity exceeds a certain threshold. In the pertinent literature, we find that contingency plan approach is generally considered a reactive response in order to manage catastrophic risks rather than minor impact risks. (Kleindorfer & Saad, 2005) Thus, we will identify the contingency plan as the proactive response in our research.

Norrman and Jansson (2004) further divide contingency plans into:

- **response plans** (immediate reaction to a problem),
- **recovery plans** (actions needed to resume the essential parts of a process or a business)
- **restoration plans** (starting up the whole organization from scratch).

From literature reviews, we categorize the reactive responses as two sorts: customers demand management and transportation strategy.

1. Customers demand management

Sometimes business decreases the risk of disruption relying on influencing the customers demand. We also can use these methods to deal with the customers demand when the disruptions occur. Tang (2006) introduces two strategies:

(1) Revenue management

Revenue management via dynamic pricing and promotion can be an effective way to manage demand when the supply of a particular product is disrupted. Specifically, a retailer can use pricing mechanism to entice customers to choose products that are widely available. For example, when Dell was facing supply disruptions from their Taiwanese suppliers after an earthquake in 1999, Dell immediately deployed a contingency plan by offering special “low-cost upgrade” options to customers if they chose similar computers with components from other suppliers.

(2) Assortment planning

The assortment planning means how to decide the set of products on display, the location of each product on the shelves and the number of facings for each product. The retailers usually used it to influence consumer product choice and customer demand. When certain products are facing supply disruptions, companies can utilize assortment planning to entice customers to purchase products that are widely available.

2. Transportation recovering strategy

Another method to quickly return system’s capability to original state in reactive manner is to implement potential transportation strategies. Nair et al. (2010), for example, propose a quantitative measure to determine the best set of post-disaster recovery actions to improve security at nodal facilities in an IM network. These potential recovery activities include reconstruction of damaged section and rent big ship for example.

Tang (2006) also provides three basic approaches to add more flexibility to the transportation system.

(1) Multi-modal transportation

To prevent the supply chain operations from coming to a halt when disruptions occur in the ocean, in the air, on the road, some companies prepare multiple modes of transportation in advance to maintain a flexible logistics. For example, Lee (2004) presents the Seven-Eleven Japan's case study, able to assure supply continuity through the use of different modes.

(2) Multi-carrier transportation

Companies can form an alliance to ensure continuous flow of materials.

Various air cargo companies such as Aeroméxico Cargo, KLM Cargo, Delta Air Logistics, Air France Cargo, CSA Czech Airline Cargo, Korean Air Cargo, etc. have formed an alliance called SkyTeam Cargo that will enable them to switch carriers quickly in the event of political disruptions (landing rights, labour strikes, etc.). Moreover, this alliance has enabled SkyTeam Cargo to provide low-cost global deliveries to 500 destinations in 110 countries.

(3) The alternative routes

We also can implement the alternative routes so as to increase the efficiency of the transportation and ensure smooth material flows along the supply chains. For example, due to long delays at the west coast ports and heavy traffic jams along various west coast freeways, some east coast companies are encouraging shippers to develop new routes in addition to the traditional route. Specifically, after the west coast ports were shut down for 2 weeks in 2002, some shippers considered shipping various manufacturing goods from Asia to east coast ports via Panama Canal. (Tang, 2006)

Some studies compare the proactive action with reactive actions with regard to the cost that companies pay. There are discussions below.

Proactive costs include investment in building an adequate level of inventory and storage facilities, and investment in a robust infrastructure. However, proactive response may result in underutilized resources if the disasters are not frequent or if the demand is volatile. In contrast, the real-time (reactive) response requires agility, implying rapid response and flexibility. Although the utilization of resource in reactive response is high, the cost of procuring resources at a short notice and in a chaotic environment can also be very high. (Chakravarty, 2011)

Thus, there is a trade-off between efficiency and redundancy.

Conventionally surplus capacity and inventory have been seen only as ‘waste’ and are therefore undesirable. However, the strategic disposition of additional capacity and/or inventory at potential critical points can be extremely beneficial in the creation of resilience within the supply chain. The trade-offs inevitably involve the judgemental balancing of the cost involved in maintaining slack capacity and inventory, against the probability and likely impact of a negative event. (Christopher & Lee, 2004) Christopher & Lee (2004) consider that company doesn’t need to save the days of buffering every stage in the supply chain with safety stock or excess capacity. They suggest the strategic and selective use of ‘slack’ to increase supply chain resilience. The cost of proactive decisions must be balanced with the cost of reactive decision. (Chakravarty, 2011)

However, Weichselgartner (2001) thinks the approaches of mitigating natural disasters must place emphasis on pro-active rather than reactive actions. But other scholars like Colicchia et al. (2008) and Tomlin (2006) believe that a firm is not limited to choosing a single tactic. An effective risk management strategy should consider a combination of tactics.

2.3Quantitative Methods on Resilience

Despite the increasing number of researches published on supply chain and transportation resilience, there has been little application of quantitative modeling techniques to both topics. (Falasca, 2008) Nonetheless, we try to provide a review of the quantitative methods on resilience in this section and lay more stress on transportation resilience than supply chain resilience. We then find that there are different methods to measure the resilience.

Most quantitative researches in transportation area develop the methods to explore the network resilience. (Murray-Tuite, 2006, Dorbritz, 2011, Chen and Miller-Hooks, 2011, Nair et al., 2010)

Murray-Tuite (2006) combines methods of multiple metrics and simulation to provide a promising approach for transportation network resilience. The contribution of this paper is to address the measurement of transportation resilience through the evaluation of four dimensions (adaptability, mobility, safety, and the ability to recover quickly) by multiple metrics that will aid future development of a single measure of resilience. It is also the first paper to examine the impacts of traffic assignment on resilience. The simulation methodology is used to generate the user equilibrium (UE) and system optimum (SO) traffic assignments for a test network. The UE assignment presents minimizing travel time for individuals, while the SO assignment presents minimizing the travel time for all vehicles in the network. The output of the simulation is then used to evaluate four dimensions. In this study, the user equilibrium results perform better in adaptability and safety while system optimum yields better mobility and faster recovery.

Dorbritz (2011) analyzes the topological and operational disaster resilience of transportation networks. The study aims to anticipate order of large-scale failures and to suggest resilience enhancements for increasing the disaster resilience by assessing the topological and operational consequences of failures. The Swiss railway and Zurich’s tramway network are modeled and represented. Two different aspects of the disaster resilience can be analyzed: the infrastructural and operational aspect. The infrastructural aspect is the resilience analysis of infrastructure topologies which successfully showed that they share the topological features of the “scale-free networks“. The infrastructural aspect does not consider any operational data such as line paths, track and station capacities and frequencies of the lines. The second aspect, operational resilience, will be assessed by giving above information that can present which extent and where the system performance is reduced in degraded operation. The results indicate that the topological importance of infrastructures and the operational one often do not coincide.

Both Chen & Miller-Hooks (2011) and Nair et al. (2010) propose quantitative measures for the intermodal (IM) freight transport system. The methodology used by Nair et al. (2010) is based on Chen & Miller-Hooks’ (2011) concept.

To address the need for a tool for such measurement for quantifying the vulnerability of IM freight systems, L. Chen & E. Miller-Hooks (2011) designed an indicator of network resilience that quantifies the ability of an IM freight transport network to resist and recover from disruptions due to natural or human-caused disaster. Their resilience indicator considers the network’s inherent ability to cope with the negative consequences of disruptions and accounts for the impact of potential recovery activities that might be taken in the immediate aftermath of the disruption while adhering to a fixed budget. They propose a stochastic combinatorial program for quantifying network resilience as a function of throughput that can be reached post-disaster. Solution of the program also aids in identifying the optimal post-event action to achieve the maximum resilience level. No prior work provides such means of quantifying an IM network’s vulnerability with consideration for the recovery actions, which is critical for developing insights necessary for improving IM freight transportation security

The aim of a quantitative measure of resilience in Nair et al. (2010) is to determine the best set of actions to improve security at nodal facilities in an IM network. Resilience accounts for both the innate reliability of a facility and the ability of short-term recovery actions to mitigate negative effects. It also develops the necessary steps to apply this concept to an existing port through a case-based analysis. First, a network representation for the system with all its essential processes and stakeholders is generated. Second, the disruption scenarios are developed. The third step is the evaluation of all recovery tools at the disposal of the facility operator. Each recovery activity is analyzed to determine the time and cost needed to execute the activity and its potential benefit to the system.

Nair et al. (2010) is the extension of Chen &Miller-Hooks (2011). It considers the application of Chen and Miller-Hooks' concept of resilience to ports, terminals, and other nodal IM infrastructure, which are treated as simple nodes with no properties or specific structure. We can say that Chen & Miller-Hooks (2011) focus on a system-level application of their resilience concept and Nair et al. (2010) propose a framework at the IM component level. The reason why the author considers the IM component level is that IM networks are seldom managed by one single entity. As an IM terminal operator, facility specific resilience measures can be more targeted than a network-wide measure because the former is directed at operators of facilities. The analysis result can lead to proactive decisions by operators on recovery options and reconfiguring their facilities to mitigate the effects of disruptions.

There is another paper to analyze the network resilience but it isn't for transportation network. It studies the resilience of logistic networks for aircraft maintenance and service. (W ang & Ip, 2009) Firstly, a resilience evaluation approach is proposed based on the redundancy and distribution of supply resources for logistic networks. Then, the optimal structure of the network, with resource constraints, is studied. A model optimizes the allocation of resources with connections, distribution centers or warehouses. The research results have been provided to the decision makers of the aviation management sector

Different from the quantifying network resilience, Mansouri (2009) develops a systematic process for making strategic and investment decisions. Since cost-effectiveness plays a key role in making decisions during the process of system design and infrastructure development, evolvement of a comprehensive framework for measuring the multiple aspects of resiliency in Maritime Infrastructure and Transportation Systems (MITS) is essential for better systems-level decision-making. The framework called Risk Management-based Decision Analysis (RMDA) consists of three phases, Assessing Risks, Devising Resilience Strategies, and Valuing Investment Strategies. In second phase, strategies are devised to make

MITS resilient in accordance of System of Systems (SoS) management techniques. In order to analyze the cost of investment alternatives in MITS, this paper suggests applying decision analysis methodologies such as DTA or the economic theory of real options in third phase. The RMDA framework enables the decision-makers to identify, analyze, and prioritize risks and to define ways for risk mitigation, plan for contingencies, and devise mechanisms for continuously monitoring and controlling risk factors and threats to the system.

Colicchia et al. (2008) studies the resilience of the supply chain with reference to the global sourcing process, because companies are easily affected by a wider exposure to risk sources in the global sourcing context currently. The contributions on supply chain resilience mainly concerned with the outbound flow before, but this paper focus on the supply risk analysis of inbound flow. Supply lead time (SLT) variability is assumed as a proxy of the supply chain resilience in this paper. The reason is that a resilient supply chain can quickly react to the undesired events and consequently reduce the delays.

Although Colicchia et al. (2008) discuss the resilience of the supply chain, they focus on the transportation process. First, this article conducts an in-depth analysis of international supply process vulnerability on the transportation phase, and then, identifies a set of approaches for managing risk in order to enhance supply chain resilience. The approaches include the contingency plans, which provide alternative ways of transport after the disruption, and mitigation actions, which are the risk management approaches put in place beforehand. The method it uses is a simulation-based framework for assessing the effectiveness of the proposed approaches and applies on a real case. The result is that the contingency plans have the greater effectiveness than the mitigation actions. It’s converse to the before-mentioned concept by scholars in section 2.2.

We sort out above quantitative literatures as following Table 2.4, which includes methodology, resilience level, resilience indicator and the application subject. According to the literature reviews, we know that they develop different indicators to their research subjects. .

Table 2.4 Quantitative literatures

Literature	**Methodology**	**System**	**Resilience indicator**	**Research subject**
Murray-Tuite (2006)	1. Traffic assignment simulation 2. Metrics	Road transportation network	Adaptability, safety, mobility, recovery metrics	Evacuating vehicles (passenger transport)
Colicchia et al. (2008)	Simulation	Transportation process	Supply lead time variability	Materials or semi-finished products Transport
Wang & Ip (2009)	Mathematical programming	Airline logistic network	The percentage of its demand to the total demand	Aircraft service and maintenance system
Mansouri et al. (2009)	Risk management decision analysis framework	Maritime infrastructure and transportation system	×	Help to make investment decision
Nair et al. (2010)	Mathematical programming	Port and Intermodal components	The percentage of the flow that is satisfied between the O-D pair to the total demand for the O-D pair	Freight transport

Dorbritz (2011)	1. Topological analysis 2. Operational analysis	Railway and tramway transportation network and system	1. Fraction of nodes in giant cluster, average shortest path length dynamics 2. Capacity utilization	Passenger transport
Chen & Miller-Hooks (2011)	Mathematical programming	Intermodal freight system network	The percentage of the maximum demand that can be satisfied post-disaster to the demand that can be satisfied pre-disaster	Freight transport

2.4 Summary

There are varieties of definitions available in the literatures, however, the resilience for international express in this research can be defined as “the ability to take opportune proactive responses to quickly recover to an acceptable level of service within a reasonable timeframe when the goods flow in the transportation network is blocked up”. The resilient strategy in our study is the set of activities that can enhance the above mentioned resilience in international express company.

In section 2.2, we mention the resilient strategies in the transportation and supply chain areas. The suggested recovery activities in transportation are reviewed from government perspective and more likely to be risk management principles. On the private sectors dimension, most reviewed supply chain resilient strategies appertain to the actual operational measures. Most of them belong to supply management and product management category and deal with supply change for inbound logistics. However, the flexible transportation is one of the possible resilient strategies in the supply chain covering both inbound and outbound flow logistics. On the whole, supply chain resilient strategies put more stress on the resistance in advance, for example network design, supply management, process improvement and product management. The transportation resilient strategies emphasize the salvage after the event. According to the literatures and expert opinions, we will develop a set of resilient strategies for the express company in next chapter and add the adequate part in our model.

In section 2.3, we review the quantitative methods of resilience and try to focus on the transportation area. We find there are different methodologies used by the scholars and most of them put the emphasis on the transportation networks when they study the problem of freight transportation. These papers can be divided into two categories. One is to optimize the structure design of network (Wang & Ip, 2009); the other is going to choose recovery activities after disruption to maximum the network freight flow (Nair et al., 2010, Chen & Miller-Hooks, 2011). The model we proposed in the next chapter combines the resilient concept from Nair et al. (2010) and Chen & Miller-Hooks (2011) and the disaster relief model. The differences are that we consider the different recovery activities and objectives and emphasize the cargo time value from the viewpoint of express company. Besides, there is no literatures considering the four decisions (route choice, trucks re-allocation, renting decision, cargo selection) together. We also arrange the mathematical programming literatures and compare the difference between their model and ours in Table 2.5.

According the sorting table, our model has different objective functions and decision variables which are tailored with express company and resilient strategies.

Table 2.5 The sorting table of mathematical programming model

Author	Objective function	Constraints	Decision variables	Decision maker
Seferlis et al. (2008) (operation level)	Minimize back-orders penalty, transportation costs ,inventory costs and changing routes penalty (The resilience concept resides in collaboration among all stakeholders so he proposes multi-echelon supply chain model .)	(1) flow conservation (2) inventory balance equation (3) back-orders balance equation (4) node capacity of carrying inventory not to exceed a maximum allowable inventory level (5) route capacity for transportation (6) the utilization of resource for manufacturing not to exceed available resource	(1) the amount of i-th product transported through route (k’, k) (2) the inventory level (3) the amount of back-orders (4) production rate	Contractual supply chain members including manufacturing companies, wholesalers and retailers
Wang & Ip (2009) (planning level)	Maximize node resilience	Investment limitation (budget)	Whether the project is selected for construction or not	Airport operator who decide to construct aircraft maintenance and service centers

Chen & Miller-Hooks (2011) (operation level)	Minimize number of shipments that cannot be satisfied for O-D pair	(1) flow on each arc to be less than the affected link capacity and recovery capacity (2) the traversal time not to exceed a given maximum duration (3) the total cost of selected recovery actions does not exceed budget (4) only one recovery activity can be selected for each arc	(1) number of shipments transported on path p (number of shipments that can't be satisfied for O-D pair) (2) binary variable indicating whether or not path p will suffice given maximum traversal time (3) binary variable indicating whether or not recovery activity is undertaken	The carrier, terminal operator, and government
Nair et al. (2010) (operation level)	Maximize the expected throughput	The same as Chen & Miller-Hooks (2011)	The same as Chen & Miller-Hooks (2011)	Terminal operator
Chen & Schonfeld (2011) (operation level)	Minimize missed-connection cost for transfer cargos and the cost generated by holding vehicle (The resilience concept resides in handling the	Total missed-connection cargos cannot exceed the available storage area at the transfer terminal	Hold for late inbound vehicle or to dispatch it immediately	

	schedule disruptions)			
Disaster relief model				
Author	**Objective function**	**Constraints**	**Decision variables**	**Decision maker**
Barbarosoglu & Arda (2004)	Stage one: Minimize transportation cost, mode-shifting cost and resource cost	(1) capacity constraint (2) flow conservation (3) mode shifting constraint (4) supplies are equal to the commodity flow	(1) amount of commodity sent over arc(i,j) by mode v in stage one and two (2) mode-shifting amount of commodity in two stages (3) excess and shortage amount of commodity in stage two	Government (relief planner)
	Stage two: Minimize transportation cost, mode-shifting cost , the penalty costs of inventory holding and shortage	(1) capacity constraint (2) flow conservation (3) mode shifting constraint (4) determine the excess and shortage amounts of demands		
Tzeng et al. (2007)	(1) Minimize setup cost and total transportation cost (2) Minimize total travel time (3) Maximize satisfaction	(1) the sum of amount of relief items doesn't exceed the available demand and available supply (2) flow conservation	(1) the amount of relief item transport from collection point to demand point (2) whether or not the candidate point is chosen as	Government (relief planner)

			the transfer depot	
Our Model	(1) Maximizing the total cargo time value (2) Minimizing the total incremental resilient costs	(1) capacity constraints (2) flow conservation (3) time constraints	(1) the amount of freights (2) the re-allocated capacities of own trucks (3) recovery capacity	International express company

III. Model Formulation

The main concern in this study is how to respond natural and man-made disruptions in transportation network for international express industry. Based on literature reviews and the opinion from employees in the express industry, we find the possible resilient strategies for the express industry and depict them in section 3.1.1. The problem is described in section 3.1.2 and the model formulation is presented in section 3.2.

3.1 Problem Statement

3.1.1 Resilient Strategy

1. Reserved capacity (proactive strategy)

To cope with disruptions, several research directions have emerged and robustness is one of them. Researches related to the robustness in the transportation domain are mostly concerned with allocating buffers times or additional resources to absorb disturbances. Through the expert interviews, we also know that international express carrier usually prepares surplus mode capacities to cope with the emergency, but the reserved capacity might not be the main researched part in our studies. The reason is that company is impossible to reserve too much space for the unexpected severe disruption practically. It costs much. However, the adequate buffers still can help company slightly reduced the queuing pressure during the disruption. Thus, we apply the sensitivity analysis in the chapter 4 to know how much impact the reserved capacity parameter has on the model.

2. Alternative route (reactive strategy)

Alternative route is the more common and appropriate strategy to respond severe disruption in contrast to the small disruption, like truck and flight delay problem. The severe disruptions usually cause the transportation system coming to a standstill, for example the regional roads network inaccessible and entire airport closure. The intuitional method to respond the disruption is changing the original route to another available route.

3. Multi-carrier transportation (reactive strategy)

The international express companies usually rent the air containers from other airlines if inland transport delays happen or their aircraft needs to repair. The same situation also happens on the trucks company. If carriers can't transport freights by themselves, they may rent the trucks from other carriers.

The capacity which is rent from other carriers' is another kind of available resources during the disruption, but they are difficult to be acquired and very expansive. Thus, we are going to discuss two kinds of rent types which are the non-contractual partner and contractual partner. What are their strengths and shortages?

(1) Renting the modes from non-contractual partners

Renting from non-contractual partners, for example, China airline and Transasia Airways, is less expensive but the flights often can't meet the schedule precisely. When the disruption occurs, the resource from this kind of partner may be rare, because there are many companies who also need to transport their cargos.

(2) Renting the modes from contractual partners

Logistics service providers are going to forge the strategic alliance because they want to reach that economies of scale and gain the utilization of unfilled space nowadays. Oum et al. (2000) described a strategic alliance as a medium- to long-term partnership formed by two or more firms with a common goal of improving competitiveness. Except for the above intentions, forging strategic alliance conduces to respond the emergent events or severe disruption event. Aligned partners can give the support of mode capacities to each other. For example, DHL and Polar Air Cargo Worldwide have contractual service agreements. The partnership transaction includes a commercial arrangement that gives DHL Express guaranteed access to Polar Air Cargo's aircraft capacity in key global markets over a period of 20 years. The long term access will significantly improve service to DHL Express' customers who ship goods between Asia Pacific and the US. The transit times are reduced and the reliability of delivery is increased on the trans-Pacific air routes. These kinds of partners can provide more time-accurate flights to partners and fill the requirement to transportation task in the emergent situation but the cost is higher than the non-contractual partners.

4. Multi-modal transportation (reactive strategy)

It's worth to note that from the literature the common recovery manner in the transportation field is using different modes, but it is not adopted for the express industry nowadays. Express company cares for timely transportation. According to its transportation process, the trucks for the inland transport need to meet time deadlines of flight at the airport, otherwise, it will delay the freights which are transported by the next flight. Even if the road system is blocked or broken partially due to disaster, the express company won't choose the rail transport. If the travel time in rail transport including transportation time and transshipment time is longer than in the truck transport when there is no disruption, can we expect more on the rail transport to catch flights in an emergency? The answer is negative. That's why the rail transport is not to be adopted in the express industry. The maritime transport to the air transport is the same.

Although the express industry doesn't regard multi-modal transportation as one of recovery strategies in practice, we still think it is an possible manner to recover the transportation activities. In our model, we consider the mode choice as one of resilient strategies.

Although we review the proactive and reactive resilient strategies in the chapter two and explore the resilient strategies which are appropriate for the international express company in the chapter three, the model that we propose below is focusing on modeling the reactive strategies. The proactive resilient strategies which involve the planning decision before the disruption are not in our research scope.

3.1.2 Problem Description

The resilient strategy in Nair et al. (2010) and Chen & Miller-Hooks (2011) is to recover link capacities from the viewpoint of terminal operator or network manager. But from the transportation carrier standpoint, the express company can't recover the link capacities, for example repairing the roads or airport runway. Thus, how to enhance the resilience under the limited choices becomes the question that we want to explore. As shown in Figure 3.1(a) (b), the original path flow will be disturbed by disruption. One of possible recovery measures is to amplify the flow on an unrelated link to achieve another state (Figure 3.1 (c)). We think it is suitable for the express companies. Thus, the concept in Figure 3.1 will play important role in our model formulation.

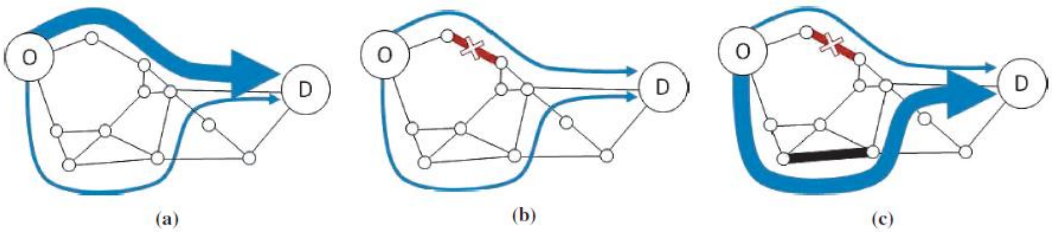


Figure 3.1 One of possible recovery method
(a) the normal operation (b) post-disruption state (c) recovery to another equilibrium

The problem we are handling is a post-event relief problem. We discuss how to re-allocate the current transportation resources and use others resources under several own limitations and the limitation of external environment and then decide the ways of transportation for shipments after the disruption occurs.

Based on the problem, the mathematical model is formulated to seek a set of optimal actions from resilient strategies during the disruption. We are modeling the reactive resilient strategies in section 3.1.1 including alternative routes, different modes, renting capacities by others into our model. Additionally, we also consider the re-allocating activities to be one of resilient strategies. The resilient strategies here are operational level, which are conducted in the short period. Although the route choice and mode choice problems are applied widely, the focus here is on the complex transportation problem combining with mode choice, route decision, carrier selection, and cargo selection. We then discuss the design of above selections in our operation model in detail.

1. Mode choice

The intermodal freight transport system in our model involves four modes (trucks , rail, aircrafts, ships) in the movement of cargo between origins and destination.

2. Route decision

In the model we want to choose the best alternative route when the disruption happens. The available routes are determined by the affected infrastructure capacity, for example, the road system and terminals.

3. Carrier selection

As mentioned before, we classify the rental types into contractual partner and non-contractual partner. The advantage of contractual partners is that they can provide more accurate flight so the dispatching and preparing time (renting time) is longer than non-contractual partners. On the contrary, the rental price of contractual partners is higher. Multi-carrier strategy is the crucial part in our study that differs from the previous literatures.

4. Cargo selection (What kind of freights have higher priority to be transport)

The concept of different time dependent cargo value function is added to our model to reflect the characteristic of express company. From the past literature, we know that Chen & Schonfeld (2010) proposed different kinds of time dependent cargo value function. They stress on the perishable cargo which may have nonlinear time value functions and assume the value of time of cargo decrease over time, for example a nonconvex piecewise linear function or a nonlinear probabilistic function. Thus, we think the cargo value decreasing over time can present the time-sensitive of express industry. The time dependent cargo value function in the model can generate the transporting priority of the different cargos. It can make the company earn more business reputation and gain the economic benefit for customers.

In our model, we assume that μ^b is cargo value function of different order b and each order b includes one type of cargo. The following is the time dependent cargo value function that we allege:

(1) Constant value commodity

The characteristic of this kind of commodities is that the values aren't easy to change with time, for example personal items and competitive products. We assume the time dependent cargo value function is the constant function of time as following and show in Figure 3.2.

$$\mu(t) = market\ price\ of\ commodity$$

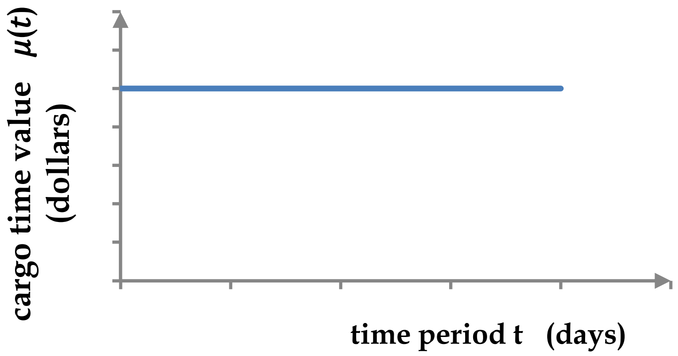


Figure 3.2 Time dependent cargo value function of constant value commodity

Market price is the economic price for which a good or service is offered in the marketplace.

(2) Perishable commodity

The perishable commodity will become spoil with time, for example flowers and seafood. The cargo value of perishable commodity decreases over time which is similar as the theory mentioned by Chen & Schonfeld (2010). We assume the time dependent cargo value function is as following and show in Figure 3.3.

$$\mu(t) = \frac{1}{\sqrt{2\pi z}} e^{-\frac{1}{2}(\frac{t}{v})^2}$$

v = the factor which is used to adjust time period
z = the factor which is used to adjust time value

When the lifetime of product is shorter, the value of v is smaller. When the market price of products is higher, the value of z is smaller.

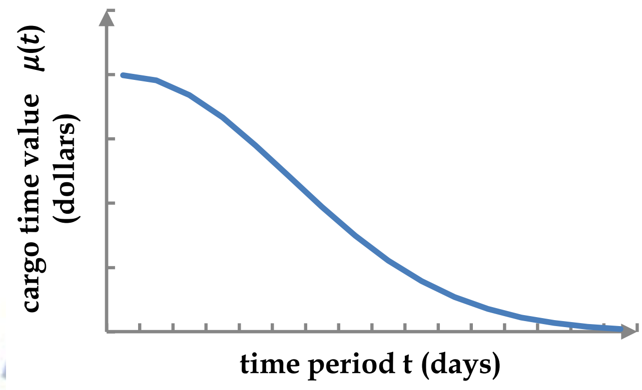


Figure 3.3 Time dependent cargo value function of perishable commodity

(3) Short life-cycle commodity

Technologic products, like smartphone and tablet, have the short product life cycles. The price may come down two to five percentage points every week because new products are going to launch to the market continuously. Certain clothing fashions also have this attribute. The popular style of clothing in each period is easy to be given a discount when time passed by because so many stores start to sell it or the clothing goes out of style. We assume the time dependent cargo value function of this kind of cargo as following and show in Figure 3.4.

$$\mu(t) = \begin{cases} market\ price & ,\ 0 < t \leq time\ threshold \\ (1-u)market\ price & ,\ t > time\ threshold \end{cases}$$

u = prices dipped factor

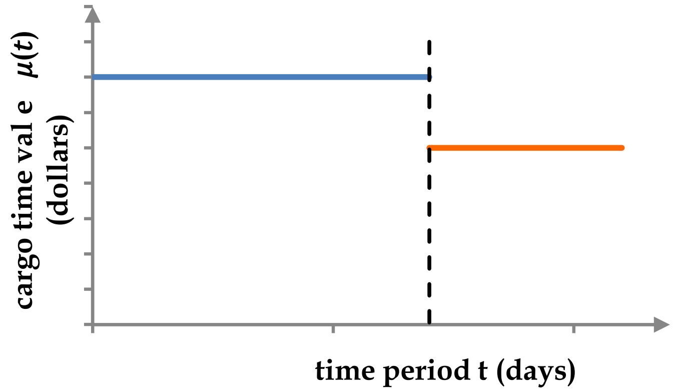


Figure 3.4 Time dependent cargo value function of short life-cycle commodity

(4) Holiday gift

The cargos which belong to holiday gifts will directly lose total cargo value if the arrival time is not within a specific time period. We assume this kind of cargos have the following time dependent cargo value function in Figure 3.5.

$$\mu(t) = \begin{cases} market\ value & , \ 0 < t \le time\ threshold \\ 0 & , \ t > time\ threshold \end{cases}$$

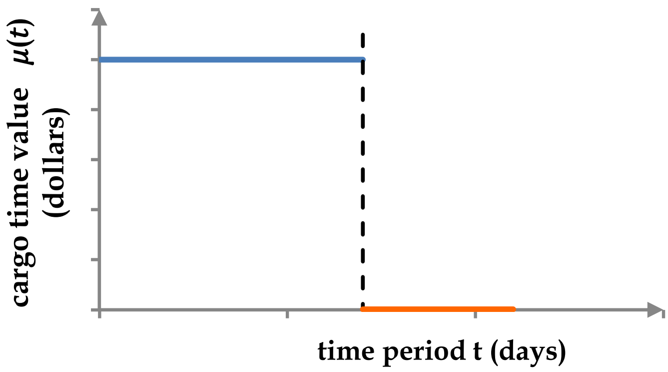


Figure 3.5 Time dependent cargo value function of holiday gift

More valuable cargos will be chosen to transport in the model reflecting on the second objective function. In our model, we assume that the freights with different order numbers have different time dependent cargo value function. It means the value of cargo depends on the order number.

The express company will try to deliver shipments as soon as possible in a best effort according to delivery schedules but it is not liable for any damages or loss caused by delays.

Only certain services will provide money-back guarantee for delay in some cases. These shipments account for two to three percent of the total shipments. Although companies don't have loss with money for most part of delayed shipments, they still need to deliver the shipments as fast as possible to reach the high level of service quality. This way, the business is able to achieve sustainable and successful development. That is also the reason why we consider the time dependent cargo value function in this study. We want shipments to be delivered in the high-valued period and satisfy the customers' demand as best as company can at same time.

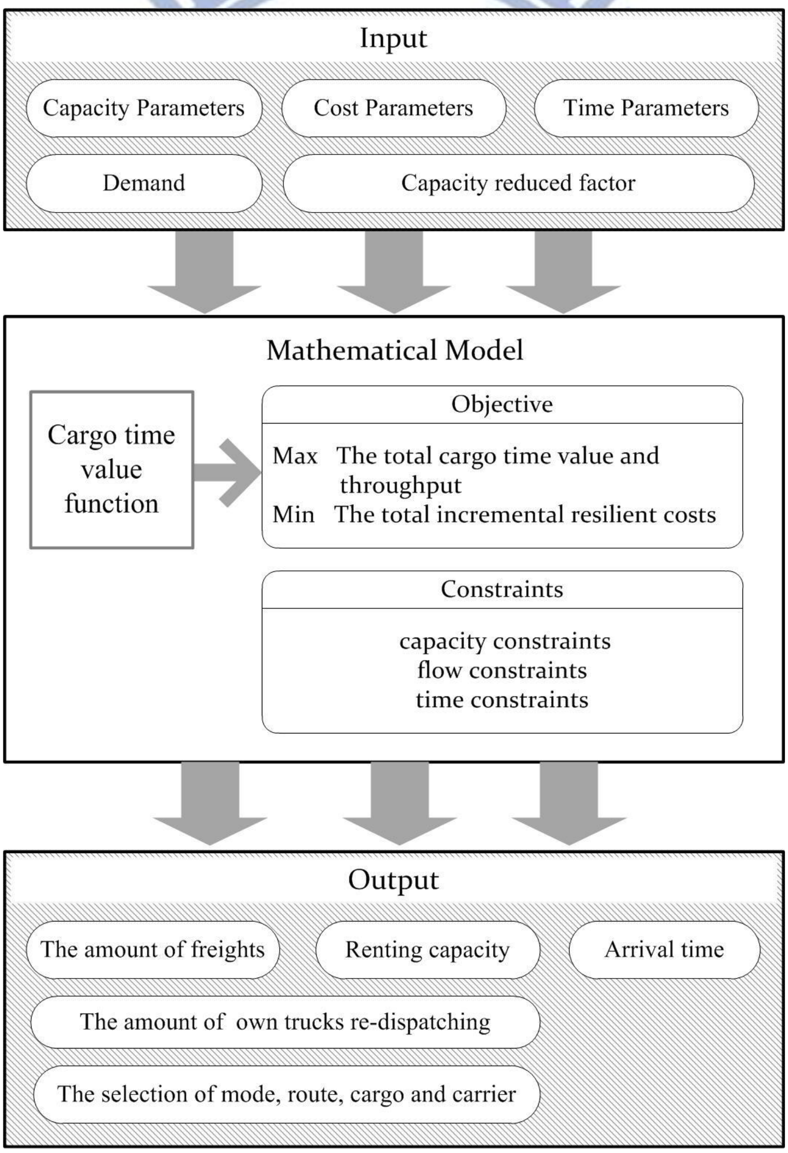
3.2 Model Formulation

The mathematical model will be depicted in this section.

3.2.1 Conceptual Framework

Figure 3.6 is the conceptual framework of our mathematical model. We put the relative parameters including capacities, cost, time, demand and reduced factors in the model which have two objective functions with several constraints. The Cargo time value function is added to the objective function in order to present the feature of express company. We can obtain the better resilient strategies in the end.

Figure 3.6 The conceptual framework of mathematical model



3.2.2 Mathematical Model

1. Model Assumptions

The basic modeling assumptions are as follows:

(1) Given all attributes of links within the studied network including cost, time, and capacities.

(2) We assume that the information of available routes and terminals is prior known in the pre-disruption phase

(3) The freights of each shipment or order are detachable. The model can transport the partial freights of each order, but it can't transport by different paths.

(4) The freights with identical shipment only can be delivered by one path. The identical shipment owns the same origin and destination.

(4) The renting time contain the dispatching time from the carriers.

(5) The schedules of different modes can link up smoothly. We don't consider the connecting or waiting time when the schedules are not fit.

2. Network Presentation

The network which we consider is presented as an intermodal logistic network with multihub, multimode,multicarrier and multicommodity. It is composed of service centers, airport and seaport terminals and links connecting these terminals.

The network is given by G=(N,L), where N={1,…,n} is set of nodes and L={(i.j)| i,j ∈ N } is the set of links. Except for the international express network, the other networks are considered in the recovery option.

The freight demand to be satisfied is given by a set of orders b ∈ B. For each order, b, the freights have specific origin, destination and cargo time value function depending on the freight characteristic. The freights form different orders may have the same origin and destination (O-D pair) or same cargo time value function. A path is defined as an acyclic chain of arcs.

3. Failure type

We divide the failure types into three categories which are link failure, mode failure , and node failure. The corresponding capacity reduced factor are α_{ij}^{m} , β_i , $and\ \gamma_i$.

We consider the situation of aircrafts and trucks damaged to the mode failure. Although it may belong to a slight disruption that is not the primary focus in this study, but we also can add it to the other failure type to discuss them together.

4. Symbol explanation

Notations employed in the problem formulation are synopsized as follows:

notation	meaning
G	(N, L)
N	is the set of nodes in the process network. i,j ∈ N
L	is the set of arcs in the process network. (i,j) ∈ L
B	is the set of shipment numbers. It can inform that freights are from which origin to which destination. b ∈ B
M	is the set of modes. m ∈ M
Tr	is the set of trucks. Tr ∈ M
Ai	is the set of aircrafts. Ai ∈ M
Sh	is the set of ships. Sh ∈ M
Ra	is the set of high speed trains. Ra ∈ M
E	is the set of multi-carrier recovery activities that include renting partner's mode capacity and renting non-partner's mode capacity. e ∈ E E={ using partner's modes, using non-partner's modes}
o	is the set of origin. o ∈ OS
d	is the set of destination. d ∈ DS
OS	is the set of service center in the origin country. OS∈N
OP	is the set of seaport or airport in the origin country. OP∈ N
DS	is the set of service center in the destination country. DS∈ N

DP	is the seaport or airport in the destination country DS is the service center in the destination country. DP∈ N
TP	is the seaport or airport in the transshipment country, including the hub airport. TP∈ N

Decision Variables are defined below:

f_{ij}^{bm}	the amount of freights with shipment number b shipped on arc(i,j) by mode m during post-disaster
WL_{ij}	the capacities of private trucks which are re-allocated to arc(i,j).
KR_{ij}^{me}	rented capacity of mode m on arc (i,j) from partner e
A^b	the total shipping time from the origin to the destination for the cargos with shipment number b

The given parameters are defined as below:

1. capacity

$K_{ij}^{m} =$	maximum allowable capacities of arc (i,j) for mode m
$KL_i =$	the available capacities of own trucks at node i
$W_{ij} =$	the capacities of original trucks allocation on arc (i,j) before the disruption occurs.
$WA_{ij} =$	available flight capacities on arc (i,j).
$AK_{ij}^{me} =$	available renting capacities on arc (i,j) of mode m by carrier e (partner)

2. capacity reduced factor

$\alpha_{ij}^{m} =$	capacity reduction factor on arc(i,j) of mode m due to the damage of links
$\beta_i =$	capacity reduction factor at node i due to the damage of modes
$\gamma_i =$	capacity reduction factor at node i due to the damage of nodes

3. cost

$RC_{ij}^{me} =$	cost of renting capacity from carrier e for mode m on arc (i,

	j) ,including transportation cost and dispatching cost
VC =	the cost of changing the allocation of own trucks

4. time

S_i =	service time and sorting time at node i.
T_{ij}^{m} =	travel time from node i to node j by mode m
RT_i^{me} =	contacting, dispatching and preparing time for mode m from the carrier e at node i if company rents partner's or non-partners' mode capacities on arc (i,j).
ET =	additional time spending on changing the allocation of trucks

5. others

DM_{od}^{b} =	total demands of cargos with shipment number b that can be satisfied from origin o to destination d during pre-disaster
$\mu(t)^b$ =	cargo time value function of commodities with shipment number b (cargo time value per unit freight)
δ_{ij}^{bm} =	indicator variable；$\delta_{ij}^{bm} = 1$ if cargo flow with shipment number b passes through arc (i,j) using mode m and $\delta_{ij}^{bm} = 0$ otherwise.
y_{ij}^{me} =	indicator variable；$y_{ij}^{me} = 1$ if recovery capacity (KR_{ij}^{me}) is not zero and $y_{ij}^{me} = 0$ otherwise.

5. Mathematical model

Based on the notation and variables, the resilient model is presented as following.

Max $$\sum_{b,j\in D}\left[\mu^b(A^b)\left(\sum_{m.i} f_{ij}^{bm}\right)\right] \quad (1)$$

Min $$\sum_{m,e,i,j}\left(KR_{ij}^{me}\right)\left(RC_{ij}^{me}\right) + \left(\sum_{i,j}\left|WL_{ij} - W_{ij}\right|/2\right)VC \quad (2)$$

subject to

$$\sum_b f_{ij}^{bm} \leq \alpha_{ij}^m K_{ij}^m \quad ,\forall m \in M, i \in N, j \in N, i \neq j \quad (3)$$

$$\begin{cases}\sum_b f_{ij}^{bm} \leq \gamma_i K_{ij}^m \quad ,\forall m \in M, i \in N, j \in N, i \neq j & (4)\\ \sum_b f_{ij}^{bm} \leq \gamma_j K_{ij}^m \quad ,\forall m \in M, i \in N, j \in N, i \neq j & (5)\end{cases}$$

Inland transportation:

$$\sum_b \sum_{m\in Tr} f_{ij}^{bm} \leq WL_{ij} + \sum_{m\in Tr}\sum_e KR_{ij}^{me} \quad ,\forall\, i \in OS \cup DP, j \in OP \cup DS, i \neq j \quad (6)$$

$$\sum_b f_{ij}^{bm} \leq \sum_e KR_{ij}^{me} \quad ,\forall m \in Ra\,, i \in OS \cup DP, j \in OP \cup DS, i \neq j \quad (7)$$

Transnational transportation:

$$\sum_b \sum_{m\in Ai} f_{ij}^{bm} \leq \beta_i\ WA_{ij} + \sum_{m\in Ai}\sum_e KR_{ij}^{me} \quad ,\forall\, i \in OP \cup TP, j \in TP \cup DP, i \neq j \quad (8)$$

$$\sum_b f_{ij}^{bm} \leq \sum_e KR_{ij}^{me} \quad ,\forall m \in Sh, i \in OP \cup TP, j \in TP \cup DP, i \neq j \quad (9)$$

$$\sum_{j \in OP \cup DS} WL_{ij} \leq \beta_i \ KL_i \quad , \forall \ i \in OS \cup DP, i \neq j \tag{10}$$

$$KR_{ij}^{me} \ \leq \ AK_{ij}^{me} \quad , \forall m \in M, e \in E, i \in N, j \in N, i \neq j \tag{11}$$

$$\sum_{j} \sum_{b,m} f_{ji}^{bm} = \sum_{j} \sum_{b,m} f_{ij}^{bm} \quad , \forall i \in N, i \neq j \tag{12}$$

$$\sum_{j} \sum_{m} f_{ji}^{bm} = \sum_{j} \sum_{m} f_{ij}^{bm} \quad , \forall b \in B, i \in N, i \neq j \tag{13}$$

$$\sum_{m} \sum_{i \in DP} f_{ij}^{bm} \leq \sum_{o} DM_{od}^{b} \quad , \forall \ j = d, b \in B \tag{14}$$

$$\sum_{m,j} \sum_{j \in OP} f_{ij}^{bm} \leq \sum_{d} DM_{od}^{b} \quad , \ \forall \ i = o, b \in B \tag{15}$$

$$\sum_{m,j} \delta_{ij}^{bm} \leq 1 \ , i \in N, b \in B \tag{17}$$

$$\delta_{ij}^{bm} = \begin{cases} o \, , & \text{if } f_{ij}^{bm} = o \\ 1 \, , & \text{if } f_{ij}^{bm} > o \end{cases} \tag{18}$$

$$y_{ij}^{me} = \begin{cases} o \ , & if \ \ KR_{ij}^{me} = o \\ 1 \ , & if \ \ KR_{ij}^{me} > o \end{cases} \tag{19}$$

$$A^{b} = \sum_{m \in M, i \in N, j \in N} \delta_{ij}^{bm} \left[f_{ij}^{bm} S_j \ + T_{ij}^{m} + \sum_{e} \left(y_{ij}^{me} RT_i^{me} \right) + \frac{|WL_{ij} - W_{ij}|}{2} (ET \quad) \right]$$

$$, \forall b \in B \tag{20}$$

To reach the maximized customers' satisfaction, we want the cargos be delivered as more as possible even during the disruption, but the cargos may not be delivered totally. Thus, we hope the express company to transport the cargos with higher value first and the cargo value depends on the time which can reflect the characteristic of the express industry. The first objective function (1) is the maximization of the product of total cargo time value and the corresponding throughput. On the other hand, when we want to deliver the cargos during the disruption, the cost of recovery must increases. This is not the expectation of the express company. It wants to lower cost. Thus, the second objective function (2) is minimization of the total incremental resilient costs including the renting cost and cost of changing truck allocation. The express company needs to balance the customers' satisfaction and the recovery cost at the same time.

It is worth noting that when the value of second objective function is equal to zero, the system may still be able to deliver cargos. Because we are not going to minimize the total transportation cost. We only minimize the additional cost caused by the recovery activities so even if we don't adopt any recovery strategies, the model can transport the cargos.

The constraints are explained as below. Constraint (3), (4) and (5) are the link capacity constraints. If link fails, constraint (3) will be affected. If node fails, constraint (4) and (5) will be affected. Constraint (6) and (7) are the mode capacity constraints for ground transportation. The freight flow doesn't exceed the own trucks capacities and renting capacities. If the freights are transported by train, the flows are less than or equal to the rent capacities (constraint (7)). Constraint (8) and (9) are the same with (6) and (7), but they are the mode capacity constraints for the transnational transportation. WA_{ij}^{me} is the own flight capacities. Constraint (10) and (11) require that the truck capacities and rent capacities don't exceed the available capacities.

Constraint (12) and (13) are the flow conservation constraints. Demand constraints (14) and (15) guarantee that the total number of shipments flowing out the origin and in the destination don't exceed the demand for the O-D pair. Constraint (17) specifies that at most one path can be chosen by the identical shipment and (18) and (19) define the binary variables of δ_{ij}^{bm} and y_{ij}^{me}.

The total shipping time of each shipment represents the cargo value. Any adopted recovery activities will increase the recovery time and reflect on the shipping time. Thus, the constraint (20) calculates the total shipping time, including handling time at nodes , transportation time , renting time, and re-allocating time. The renting time includes the transshipping time.

IV. Numerical Experiment

In this chapter, a numerical example is provided to illustrate the applicability of the proposed method for solving the recovery problem in express industry.

4.1 Solution Algorithm

In this paper we also use a compromise programming (CP) method to solve multi objective programming for our numerical experiment. In this method the distance between some reference point and the feasible objective region is minimized. (Fatemeh et al., 2011) Consider k objective functions of $\{f_1(x), f_2(x), \ldots, f_k(x)\}$ to be optimized simultaneously. We assign the design references of $\{f_1^*, f_2^*, \ldots, f_k^*\}$ for the set of objective functions. These values can be equal to the minimum of each objective functions (for the minimized objectives). $\{f_{1,max}, f_{2,max}, \ldots, f_{k,max}\}$ is the worst value of each objective functions. When we get the optimal value of each objective function, we can obtain the other objective values in this set of optimal solution. Compare the value of the same objective and find the worst one. This value is $f_{i,max}$.

The problem is formulated as follows:

$$minimize \left(\sum_{i=1}^{k} w_i^p \left| \frac{f_i(x) - f_i^*}{f_{i,max} - f_i^*} \right|^p \right)^{1/p}$$

When the property of each objective function is different, it is not reasonable to combine several objective functions. Thus, the compromise programming method is going to normalize each objective functions. The vector of w specifies how much an objective function needs to get close to its reference. Sometimes some objective functions are relatively more important and the designer needs them to be much more optimized than the others. Therefore, by specifying larger w_i to them, they will be encouraged to get closer to their references compared to others. The weighting vector also determines the direction of the search toward the optimum point in the feasible region.

We test the numerical experiment on an Intel Core (TM) i7 CPU 2.93 GHz processor with 4 GB of RAM. The model was implemented in LINGO 12.0. Because the model which we propose is a mixed integer nonlinear programming (MINLP) problem, we use the global solver in LINGO for solving our model to global optimality. The model will solve until no further improvement then stop.

The maximum allowable resilience duration is six days in our numerical experiment. The capacities of flights and trucks are set according to this duration.

4.2 Illustrative Design

4.2.1 Small Network

We provide the small network to introduce how to use this model and the meaning of the result. We also do the scenarios analysis to discover the changes in the recovery activities.

1. Network and parameters representation

In the small network example, there are 9 nodes and 12 links (Figure 4.1). We assume there are five shipments (b=1,2,…5) with two commodities, which is constant value commodity and short life-cycle commodity. The cargo time value function and shipment demand show in Table 4.1. The modes include truck (m=1), aircraft (m=2), high speed rail(m=3) and ship(m=4) . Link capacity, transportation time and original allocated of trucks list in Table 4.2 and Table 4.3. Related recovery parameters list in Table 4.4. Express company has 4 trucks in service center 1, 2, 3 and 4. If the re-allocation for trucks (WL_{ij}^{m}) is different from original allocation (W_{ij}^{m}), there is an additional cost 4 per truck (VC) and time 2 per truck (ET). The renting capacities are limited by the available capacities from the other carriers (AK_{ij}^{me}) .

The sorting times (S_i) at the nodes range from 1 to 5 per unit good. We assume that one unit good is one ton and we use weight to calculate the mode capacity and the loading of cargo. One truck can carry 5 ton; the aircraft can carry 20 ton; one aircraft cabin can carry 10ton; one ship container can carry 28 ton.

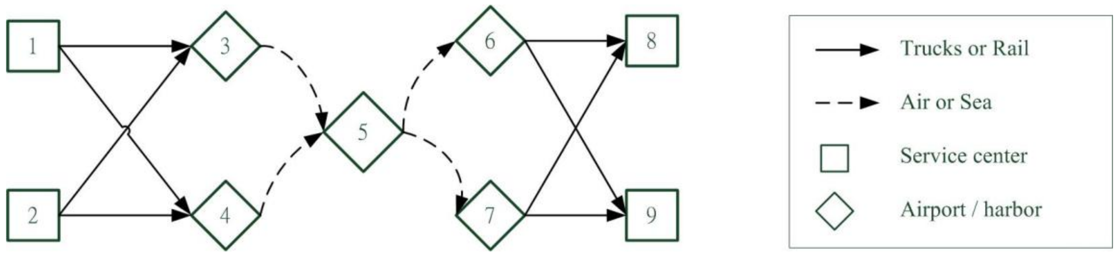


Figure 4.1 the network for the illustative example

Table 4.1 The parameters assumption of demand and time value function

b	**(origin, destination)**	**shipment demand**	**time value function**
1	(1,8)	10	$\mu^b = 20$
2	(2,9)	7	
3	(1,9)	5	
4	(2,8)	6	$\mu^b = \begin{cases} 100 & , \ 0 < t \leq 200 \\ 10 & , \ t > 200 \end{cases}$
5	(1,9)	3	

Table 4.2 The parameters assumption of link capacity and transport time

mode m	Link (i, j)	K_{ij}^m (maximum link capacity)	T_{ij}^m (transport time)
Trucks m=1	(1,3)	22	3.3
	(1,4)	23	20.6
	(2,3)	24	23
	(2,4)	18	7
	(6,8)	26	13
	(6,9)	25	2.5
	(7,8)	27	17.2
	(7,9)	18	19.2
Aircraft m=2	(3,5)	50	7
	(4,5)	40	6
	(5,6)	50	6.3
	(5,7)	40	6
Rail m=3	(1,3)	30	4.7
	(1,4)	15	11.7
	(2,3)	15	10

	(6,8)	15	5
	(7,8)	25	7.5
	(7,9)	22	10.2
Sea	(4,5)	120	96.2
m=4	(5,7)	120	96.2

Table 4.3 The parameter assumptions of original trucks allocation and own flight capacity

Link (i, j)	W_{ij} (original trucks allocation) (veh.)	WA_{ij} (capacity of own aircrafts)
(1,3)	4	
(1,4)	0	
(2,3)	0	
(2,4)	4	
(3,5)		20
(4,5)		20
(5,6)		20
(5,7)		20
(6,8)	1	
(6,9)	3	
(7,8)	4	
(7,9)	0	

Table 4.4 The parameter assumptions of renting activities

mode m	carrier e	Link (i,j)	AK_{ij}^{me} (available renting capacity)	RC_{ij}^{me} (renting cost)	RT_{i}^{me} (renting time)
Trucks m=1	1	(1,3)	15	10	5
		(1,4)	20	25	
		(2,3)	20	22	16
		(2,4)	20	6	
		(6,8)	15	12	4

		(6,9)	15	6	
		(7,8)	25	18	16
		(7,9)	10	22	
	2	(1,3)	20	11	18
		(1,4)	10	24	
		(2,3)	15	21	6
		(2,4)	15	9	
		(6,8)	20	11	14
		(6,9)	15	5	
		(7,8)	10	17	6
		(7,9)	25	21	
Aircraft m=2	1	(3,5)	20	210	4
		(4,5)	10	230	6
		(5,6)	20	210	10
		(5,7)	10	230	
	2	(3,5)	10	150	4
		(4,5)	0	170	6
		(5,6)	10	150	10
		(5,7)	0	170	
Rail m=3	1	(1,3)	27	11	10
		(1,4)	11	76	
		(2,3)	13	67	10
		(6,8)	12	27	10
		(7,8)	21	39	10
		(7,9)	20	67	
Sea m=4	1	(4,5)	56	120	20
		(5,7)	56	120	20
	2	(4,5)	56	119.3	20
		(5,7)	56	119.3	20

The other parameters are listed in Table 4.5.

Table 4.5 The parameter assumptions of trucks capacities and handling time at nodes

Node	KL_i	S_j
1	40	3
2	40	3

3		1
4		1
5		5
6	40	2
7	40	2
8		0
9		0

2. Disruption scenarios design

From the natural and man-made disasters, we can generalize that they usually cause the following affection:
(1)Terrorism: link failure or node failure
(2)Arson: nodes failure (service centers)
(3)Earthquake: links and nodes failures
(4)Flooding: links and nodes failures

We create the disruption scenarios in accordance with effected type and location and analyze the results in 4.2.1. Five types of scenarios were considered as assumptions in Table 4.6.

Table 4.6 The assumption of scenarios

Scenario	**Affected parameters**	**The description of scenarios**
1.Link failure	$\alpha_{13}^1, \alpha_{24}^1$	the failure on the links (1,3) and(2,4) with road system
2.Node failure	γ_3	the failure at node 3
3. Links and modes failure	$\alpha_{13}^1, \alpha_{24}^1, \beta_1, \beta_2$	the failure on the links (1,3) and(2,4) with road system and trucks failure
4. Nodes and modes failure	$\gamma_3, \beta_1, \beta_2$	the failure at node 3 and trucks
5.Link and node failure	$\alpha_{13}^1, \alpha_{24}^1, \gamma_3$	the failure on the links (1,3) and(2,4) with road system and the failure at node 3

4.2.2 Large-scale Network

The large-scale network example is going to provide a more complex and real existed network so that we are able to proof that our model can be applied in the real word.

1. Network presentation parameters assumption

We design our large-scale network depending on the network from DHL. DHL network has three global hubs in Hong Kong, Leipzig and Cincinnati. Shanghai Pudong Airport recently becomes the fourth global hub and services the shipments between China and countries in North Asia or the shipments from North Asia to America and Europe. The fourth global hub will share the freights volume in Hong Kong airport which handles the shipments between Asia and Europe, America originally. Thus, we choose Hong Kong Airport and Shanghai Pudong Airport to be our transshipping hub in the network and service the shipments from Taiwan and Japan to Germany which is the assumed demand for the large-scale network.

The nodes in large-scale network are presented in Table 4.7. There are 31 nodes including service centers in Taiwan, Japan and Germany, transshipping airports and seaports. Figure 4.2 is the locations of airports.

Table 4.7 The nodes in large-scale network

Service centers in the origin

- Five service centers in Taiwan :

  Neihu (Neh), Zhonghe (Zoh), Taoyuan (Tyu), Taichung (Tch), Kaohsiung(Khs)

- Five service centers in Japan

  Minato (TYM), Nerima (TYN), Nagoya Central (NGC), Namiyoke (OAA), Osaka Central (OSC)

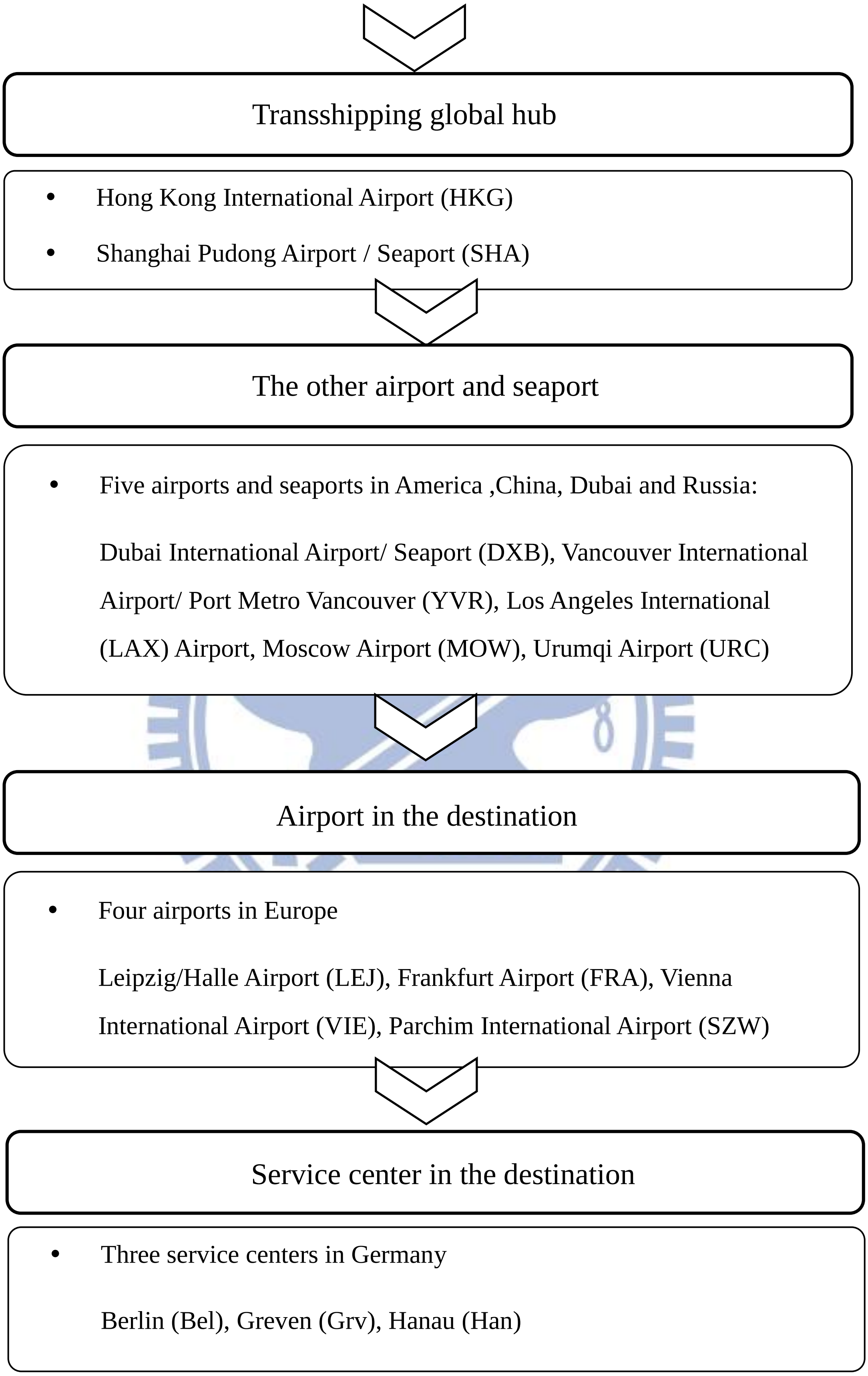
Airport and Seaport in the origin

- Two airports and two seaport in Taiwan:

  Taoyuan International Airport (TPE), Kaohsiung International Airport / Seaport (KHH), Keelung port (KEL)

- Four airports and two seaport in Japan:

  Narita International Airport (NRT), Tokyo International Airport / Seaport (HND), Central Japan International Airport/ Seaport (NGO), Kansai International Airport (KIX)



Transshipping global hub
Hong Kong International Airport (HKG)
Shanghai Pudong Airport / Seaport (SHA)
The other airport and seaport
Five airports and seaports in America ,China, Dubai and Russia:
Dubai International Airport/ Seaport (DXB), Vancouver International Airport/ Port Metro Vancouver (YVR), Los Angeles International (LAX) Airport, Moscow Airport (MOW), Urumqi Airport (URC)
Airport in the destination
Four airports in Europe
Leipzig/Halle Airport (LEJ), Frankfurt Airport (FRA), Vienna International Airport (VIE), Parchim International Airport (SZW)
Service center in the destination
Three service centers in Germany
Berlin (Bel), Greven (Grv), Hanau (Han)

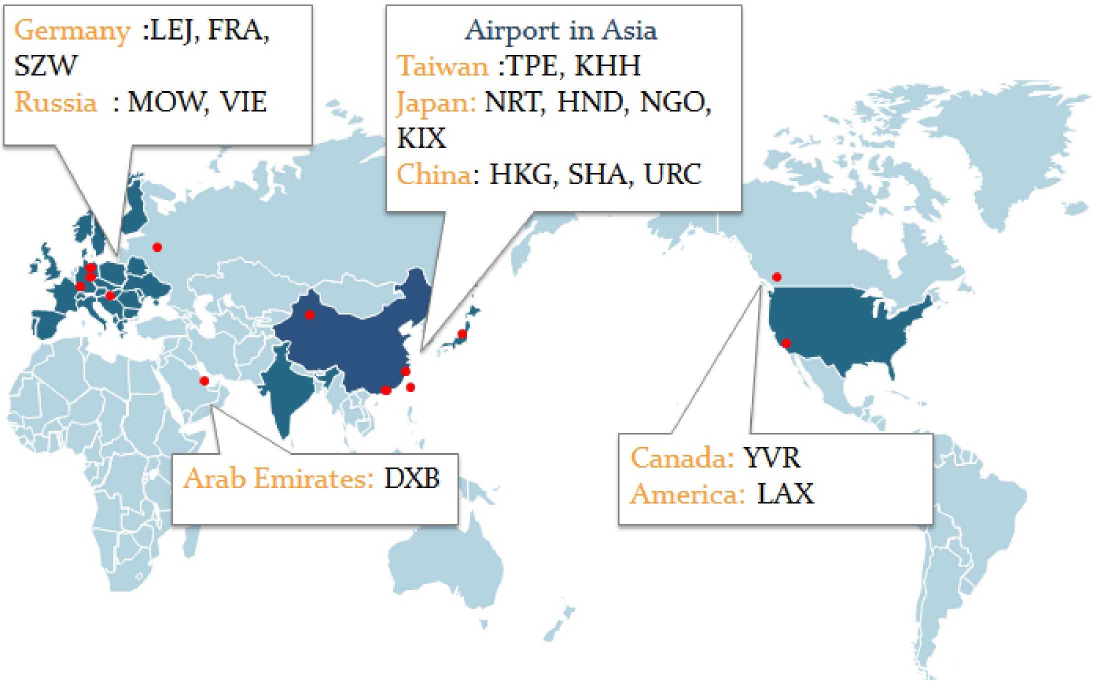


Figure 4.2 The rough location of the airports in the large-scale natwork

The network involves 30 potential O-D pairs. The intermodal connections exist at every node which are connecting the airports and seaports, highway network and rail terminals. The difference with small network is that after shipments are delivered through transshipping global hubs, the model can choose whether or not to pass by the other airports or directly arrive the airports in the destination in the large scale network. It means the more complex network it is.

Part of parameters is set according to the data from DHL. The others data are from the websites. For example, the travel time, available capacities from the other carriers and own flights capacities are set from the flight information in the airports' and airlines' websites. The demand in the large-scale network is presented in Table 4.8. The cargos with shipment number 1 belong to the constant value commodities. The cargos with shipment number 2 are the technologic products whose value will decline after six days. The cargos with shipment number 2 are the holiday gifts whose value will decline after three days.

Table 4.8 The parameters assumption of demand and time value function in the large-scale network

b	(origin, destination)	shipment demand (ton)	time value function (thousand dollars)
1	(Osaka Central Service Centre , Berlin)	28	$\mu^b(t) = 1000$
2	(Zhonghe, Greven)	20	$\mu^b(t) = \begin{cases} 15000 & , 0 < t \le 5760 \\ 13670 & , \quad t > 5760 \end{cases}$
3	(Namiyoke Service Centre , Hanau)	30	$\mu^b(t) = \begin{cases} 9000 & , 0 < t \le 4320 \\ 0 & , \quad t > 4320 \end{cases}$

2. Disruption scenarios design

Three disruption scenarios are developed for large-scale network. Scenario one is failed in Hong Kong International Airport. The real happened events, Japan earthquake and Icelandic volcano, are simulated in scenario two and three.

Scenario 1: Hong Kong International Airport failed

We know that all the shipments in DHL express need to be consolidated to the Hong Kong hub and then be transported to the destinations. The Hong Kong International Airport is the critical node in the DHL's network. Thus, we are going to design the scenario which is failed in Hong Kong International Airport and realize which recovery activities will be adopted. The company can regard this result as the reference to develop the proactive strategies in advance.

In this scenario the impacted parameter is only γ_{18}.

Scenario 2 : Japan Earthquake

The massive magnitude 9 earthquake triggered a devastating tsunami in Japan on Friday, 11 March, 2011. The tsunami brought the big catastrophe to Japan. When a wall of water struck about 400 km north-east of Tokyo, many cars, ships and buildings were swept away. Wave deluged farmland and swept cars across the airport's runway. Fires broke out in the centre of the city. Four trains are missing along the coast, says Japan Railways.

Thus, it caused many transportation terminals to be shut down. Narita International Airport (NRT) and Tokyo International Airport (HND) were closed and checked the runways. The subway didn't run. Six main harbors were destroyed by tsunami and also be closed. It predicted that they were difficult to recover in short term.

In this scenario, we consider that the links, nodes and modes failed simultaneously. The scenario depict in Table 4.9.

Table 4.9 The scenario assumption for Japan earthquake

Link failed:	Road system in Japan failed partly. Rail service in Japan doesn't work. The Flight which start from Tokyo International Airport (HND) to HKG and SHA are partly cancelled.
Node failed:	Narita International Airport (NRT) is closed.
Mode failed:	Trucks in Japan are broken.

Scenario 3 : Icelandic volcano eruptions

In April, 2010, a lingering ash which was spewed from an Iceland volcano continued to wreak havoc on air travel across Europe. It caused the largest shutdown of European air space. Major air cargo and passenger hubs were forced to be closed for days at a time and hundreds of flights were cancelled. The Emirates airline reportedly loses US$1 million in air traffic chaos. Similarly, other airlines are expected to lose hundreds and thousands of dollars.

In this scenario, we consider that all the flights which arrive airports in Europe are cancelled. The failure type belongs to failure link.

4.3 Result Analysis

The results of small network and large-scale network experiments are explained in this section.

4.3.1 Small Network Results

1. Illustrative example

Using the instance with $\gamma_3 = 0.1$ and $\alpha_{13}^1 = \alpha_{24}^1 = 0.4$, we explain the meaning of result (Table 4.10 and Table 4.11). $\gamma_3 = 0.1$ means that capacities at node 3 remain 10 percent of origin capacities. $\alpha_{24}^1 = 0.4$ means that the link (2,4) capacities remain 40 percent of total link capacity.

Table 4.10 The result of path, freight quantities and transportation time in illustrative example

b	Path (normal operation)	Path (post-disruption)	Freight quantities/ demand	Transportation time spending on delivery
1	1→3➔5➔7→8	1→4⋯5➔7→8	10/10	274
2	2→4➔5➔6→9	2→3➔5➔6→9	2/7	61.8
3	1→3➔5➔6→9	1→4➔5➔6→9	5/5	94.4
4	2→4➔5➔7→8	2→4➔5➔7→8 (the same)	6/6	103.2
5	1→3➔5➔6→9	1→4➔5➔6→9	3/3	72.4

→ truck - - - rail
➔ air … sea

In Table 4.10, the shipment 1 would be transported from node 1 to node 4 by trucks, from node 4 to node 5 by sea, from node 5 to node 7 by air, and from node 7 to node 8 by trucks. The cargos of shipment 1 are all delivered and the travel time is 274.

We find most of shipments will change the path except for the shipment 4. Under the links limitation the system gives up delivering cargos of shipment 2. We also find that part of constant value commodities change to use sea transportation and the short life cycle commodities remain to be air transport.

In Table 4.11, trucks will be allocated to the undisturbed links (1,4) and (2,3). Moreover, the system rents the ship capacities in the link (4,5) .

Table 4.11 The truck re-allocation and renting capacities in illustrative example

Link	Truck allocation (original) (veh.)	Truck allocation (after disruption) (veh.)	Renting capacities
(1,3)	4	0	
(1,4)	0	4	
(2,3)	0	1	
(2,4)	4	3	
(4,5)			Sea: 28 ton (container)

2. The results of different scenarios

The results for different scenarios are listed in the Table 4.12 to Table 4.16. We compare the value of following variables.

(1) the amounts of truck re-allocation=$\sum_{i,j}\left|WL_{ij} - W_{ij}\ \right|/2$

(2) renting quantities =$\sum_{ij}^{me} KR_{ij}^{me}$

(3) satisfied demand = $\sum_{bmij} f_{ij}^{bm} / \sum_{bod} DM_{od}^{b}$

(4)recovery cost = the value of second objective function

We test each scenario with different severe level and only show the changed paths which are different from the normal situation.

Table 4.12 The result of scenario 1 (links failed)

Capacity remaining proportion (severe level)	b	path	Changing allocation of trucks (veh.)	Renting quantities (ton)	Satisfied demand (ton)	recovery cost
Normal situation $\alpha^1_{13} = \alpha^1_{24} = 1$	1 2 3 4 5	1→3→5→7→8 2→4→5→6→9 1→3→5→6→9 2→4→5→7→8 1→3→5→6→9	0	0	31/31	0
		changed path				
$\alpha^1_{13} = \alpha^1_{24} = 0.8$	3 4	1→4→5→6→9 1→4→5→7→8	1	0	31/31	4
$\alpha^1_{13} = \alpha^1_{24} = 0.6$	3 4	1→4→5→6→9 2→3→5→7→8	3	0	31/31	12
$\alpha^1_{13} = \alpha^1_{24} = 0.4$	1 4	1→4→5→7→8 2→3→5→7→8	4	0	31/31	16
$\alpha^1_{13} = \alpha^1_{24} = 0.2$	1 2 3 4	1→4→5→7→8 2→3→5→6→9 1→4→5→6→9 2→3→5→7→8	6	0	31/31	24
$\alpha^1_{13} = \alpha^1_{24} = 0$	1 2 3 4 5	1→4→5→7→8 2→3→5→6→9 1→4→5→6→9 2→3→5→7→8 1→4→5→6→9	7	0	31/31	28

→ truck - - - rail

→ air … sea

Scenario 1 assumes that the inland links (1,3) and (2,4) failed. In this scenario, it changes the paths and re-allocates the trucks to satisfy all the demand. The recovery cost is the lowest comparing with other scenarios.

Table 4.13 The result of scenario 2 (node 3 failed)

Capacity remaining proportion (severe level)	b	path	Changing allocation of trucks (veh.)	Renting quantities (ton)	Satisfied demand (ton)	recovery cost
Normal situation $\gamma_3 = 1$	1 2 3 4 5	1→3➔5➔7→8 2→4➔5➔6→9 1→3➔5➔6→9 2→4➔5➔7→8 1→3➔5➔6→9	0	0	31/31	0
		changed path				
$\gamma_3 = 0.8$	3	1→4➔5➔6→9	1	0	31/31	4
$\gamma_3 = 0.6$	3	1→4➔5➔6→9	1	0	31/31	4
$\gamma_3 = 0.4$	1 4	1→4➔5➔7→8 2→3➔5➔7→8	4	0	31/31	16
$\gamma_3 = 0.2$	1 2 3	1→4➔5➔7→8 2→4…5➔6→9 1→4…5➔6→9	3	Link(4,5) Sea: 28	31/31	131.3
$\gamma_3 = 0.1$	1 2 3 5	1→4…5➔7→8 2→4…5➔6→9 1→4➔5➔6→9 1→4➔5➔6→9	4	Link(4,5) Sea: 28	31/31	135.3
$\gamma_3 = 0$	1 2 3 5	1→4➔5➔7→8 2→4…5➔6→9 1→4…5➔6→9 1→4➔5➔6→9	4	Link(4,5) Sea: 28	31/31	135.3

→ truck - - - rail
➔ air … sea

Scenario 2 assumes that the node 3 failed. In this scenario, it also starts from changing paths and then re-allocates the trucks, but the difference form failure in the inland link is that when the severe level is down to 0.2, it starts to rent the other modes (ships).

There is the same situation in scenario 2 and 4. Some constant value commodities are transported by sea on the link (4,5) when the capacities of node 3 remain 20%. The cost increases sharply because it use sea transportation.

Table 4.14 The result of scenario 3 (links (1,3) and(2,4) on the road system failed and trucks failed)

Capacity remaining proportion (severe level)	b	path	Changing allocation of trucks (veh.)	Renting quantities (veh.)	Satisfied demand (ton)	recovery cost
Normal situation $\alpha_{13}^{1} = \alpha_{24}^{1} = 1$ $\beta_1 = \beta_2 = 1$	1 2 3 4 5	1→3➔5➔7→8 2→4➔5➔6→9 1→3➔5➔6→9 2→4➔5➔7→8 1→3➔5➔6→9	0	0	31/31	0
		changed path				
$\alpha_{13}^{1} = \alpha_{24}^{1} = 0.8$ $\beta_1 = \beta_2 = 0.6$	3	1→3➔5➔6→9	1	Link(1,3) Truck:2 Link(2,4) Truck:1	31/31	30
$\alpha_{13}^{1} = \alpha_{24}^{1} = 0.6$ $\beta_1 = \beta_2 = 0.6$	2 3	2→3➔5➔6→9 1→4➔5➔6→9	3	Link(1,3) Link(2,4) Truck:2	31/31	44
$\alpha_{13}^{1} = \alpha_{24}^{1} = 0.4$ $\beta_1 = \beta_2 = 0.6$	1 4	1→4➔5➔7→8 2→3➔5➔7→8	4	Link(1,3) Link(2,4) Truck:2	31/31	48
$\alpha_{13}^{1} = \alpha_{24}^{1} = 0.2$ $\beta_1 = \beta_2 = 0.6$	1 2 3 4	1→4➔5➔7→8 2→3➔5➔6→9 1→4➔5➔6→9 2→3➔5➔7→8	4	Link(1,3) Link(1,4) Link(2,3) Truck:1	31/31	71
$\alpha_{13}^{1} = \alpha_{24}^{1} = 0$ $\beta_1 = \beta_2 = 0.6$	1 2 3 4 5	1→4➔5➔7→8 2→3➔5➔6→9 1→4➔5➔6→9 2→3➔5➔7→8 1→4➔5➔6→9	4	Link(1,4) Truck: 2 Link(2,3) Truck: 1	31/31	85

→ truck - - - rail

➔ air … sea

Scenario 3 is failed in the links (1,3) and(2,4) on the road system. The trucks also broke in this scenario. Comparing with scenario 1, the additional trucks will be rented.

Table 4.15 The result of scenario 4 (node 3 failed and trucks failed)

Capacity remaining proportion (severe level)	b	path	Changing allocation of trucks (veh.)	Renting quantities KR (veh.)	Satisfied demand (ton)	recovery cost
Normal situation $\gamma_3 = 1$ $\beta_1 = \beta_2 = 1$	1 2 3 4 5	1→3➔5➔7→8 2→4➔5➔6→9 1→3➔5➔6→9 2→4➔5➔7→8 1→3➔5➔6→9	0	0	31/31	0
		changed path				
$\gamma_3 = 0.8$ $\beta_1 = \beta_2 = 0.6$	3	1→4➔5➔6→9	1	Link(1,3) Truck:2 Link(2,4) Truck:1	31/31	30
$\gamma_3 = 0.6$ $\beta_1 = \beta_2 = 0.6$	3	1→4➔5➔6→9	1	Link(1,3) Truck:2 Link(2,4) Truck:1	31/31	30
$\gamma_3 = 0.4$ $\beta_1 = \beta_2 = 0.6$	1 4	1→4➔5➔7→8 2→3➔5➔7→8	4	Link(1,3) Truck:2 Link(2,4) Truck:2	31/31	48
$\gamma_3 = 0.2$ $\beta_1 = \beta_2 = 0.6$	1 2 3	1→4➔5➔7→8 2→4…5➔6→9 1→4…5➔6→9	2	Link(1,3) Link(1,4) Link(2,4) Truck:1 Link(4,5) Sea: 28(ton)	31/31	167.3
$\gamma_3 = 0$ $\beta_1 = \beta_2 = 0.6$	1 3 5	1→4…5➔7→8 1→4…5➔6→9 1→4➔5➔6→9	2	Link(1,4) Truck:2 Link(2,4) Truck:1 Link(4,5) Sea: 28(ton)	31/31	181.3

→ truck - - - rail

➔ air … sea

Table 4.16 The result of scenario 5 (node 3 failed and $\alpha_{13}^{1} = \alpha_{24}^{1} = 0$)

Capacity remaining proportion (severe level)	b	path	Changing allocation of trucks (veh.)	Renting quantities (ton)	Satisfied demand F/DM	recovery cost
Normal situation $\gamma_3 = 1$ $\alpha_{13}^{1} = \alpha_{24}^{1} = 1$	1 2 3 4 5	1→3→5→7→8 2→4→5→6→9 1→3→5→6→9 2→4→5→7→8 1→3→5→6→9	0	0	31/31	0
		changed path				
$\gamma_3 = 0.8$ $\alpha_{13}^{1} = \alpha_{24}^{1} = 0$	1 2 3 4 5	1→4→5→7→8 2→3→5→6→9 1→4→5→6→9 2→3→5→7→8 1→4→5→6→9	7	0	31/31	28
$\gamma_3 = 0.6$ $\alpha_{13}^{1} = \alpha_{24}^{1} = 0$	1 2 3 4 5	1→4→5→7→8 2→3→5→6→9 1→4→5→6→9 2→3→5→7→8 1→4→5→6→9	7	0	31/31	28
$\gamma_3 = 0.4$ $\alpha_{13}^{1} = \alpha_{24}^{1} = 0$	1 2 3 4 5	1→4→5→7→8 2→3→5→6→9 1→4→5→6→9 2- - -3→5→7→8 1→4→5→6→9	6	Link(2,3) Rail : 6	31/31	426
$\gamma_3 = 0.2$ $\alpha_{13}^{1} = \alpha_{24}^{1} = 0$	1 2 3 4 5	1→4→5→7→8 2- - -3→5→6→9 1→4→5→6→9 2→3→5→7→8 1→4→5→6→9	5	Link(2,3) Rail: 3	25/31	221
$\gamma_3 = 0.1$ $\alpha_{13}^{1} = \alpha_{24}^{1} = 0$	1 2 3 4 5	1→4→5→7→8 2- - -3→5→6→9 1→4→5→6→9 2→3→5→7→8 1→4→5→6→9	5	Link(2,3) Rail: 1	21/31	87

$\gamma_3 = 0$ $\alpha_{13}^1 = \alpha_{24}^1 = 0$	1 3 5	1→4→5→7→8 1→4→5→6→9 1→4→5→6→9	4	0	18/31	16

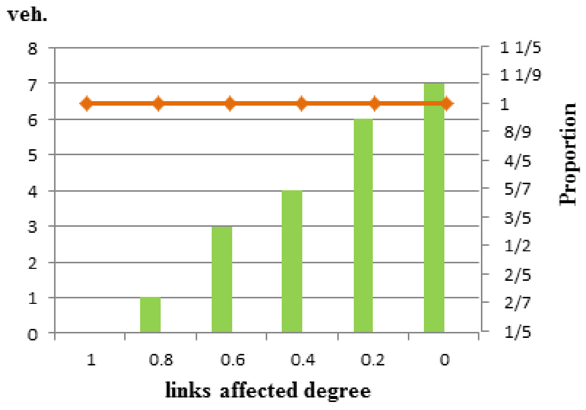
→ truck - - - rail

→ air … sea

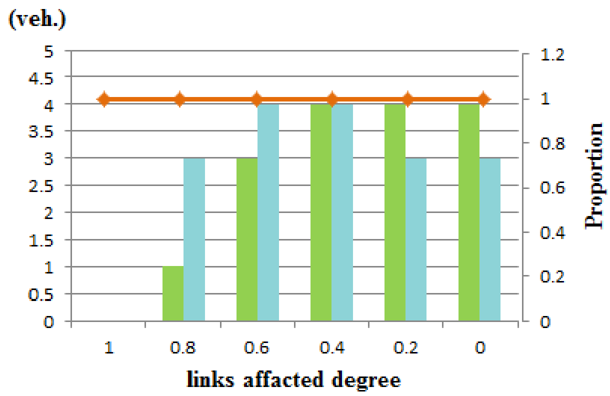
Scenario 4 assumes that both node 3 and trucks failed. In this scenario, it rents additional trucks comparing with scenario 2. The cost also increases sharply because it rents both trucks and ship capacities. Scenario 5 assumes that both node and links failed. It is worth noting that the recovery activities reach the maximum in the severe level 0.4. Then the recovery activities are reduced.

Figure 4.3 visualizes above five scenarios to show the recovery activities of trucks re-allocating, renting quantities and satisfied demand. We summarize the results of small network test in the following.

From the result of scenario 1, the truck will expand the re-allocated degree of trucks along with the disruption becoming more serious but the model doesn't rent any capacity. If both the links and modes are failed (scenario 3 , Figure 4.3(b)), the model rents the other carriers' truck capacities comparing with the scenario 1 because the trucks are broken. From the result of scenario 2 (Figure 4.3(c)), the model starts to rent the ship containers to ensure the delivering successfully when capacities of node 3 remain 20%. Comparing with link failures, node failure (scenario 2, Figure 4.3(c)) is more likely to transport the cargos by other modes, for example, train or ship. Moreover, the constant value commodities are transported by sea and the short life cycle commodities remain to be air transport. It is reasonable. If both nodes and modes are failed (scenario 4, Figure 4.3(d)), additional trucks will be rented. When it rents the ship capacities, the amounts of renting capacities and trucks re-allocation will reduce. Thus, we infer that the model will coordinate the renting activities and trucks re-allocation to find the better solutions. Scenario 5 (Figure 4.3(e)) is an extreme example to test the severe situation. If the link (1, 3) and (2, 4) totally failed, how do the strategies change when node 3 affects by different degrees of disruptions ? From the result of scenario 5, the recovery activities decrease progressively after the capacities of node 3 is smaller than the 40%. The satisfied demand also decreases progressively. Thus, if the disruption is too serious to recover, the model is possible to shrink recovering actions based on the cost concern and external environment.



(a)



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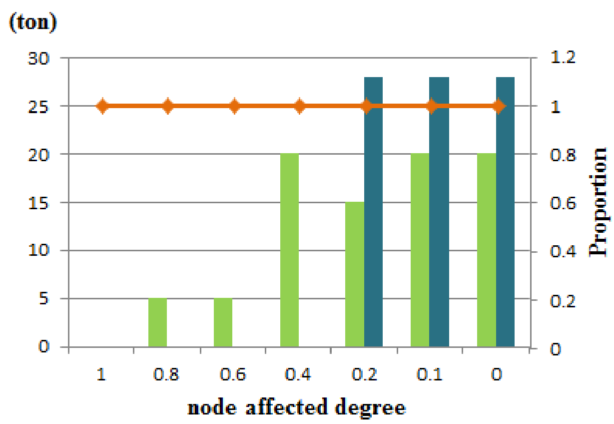

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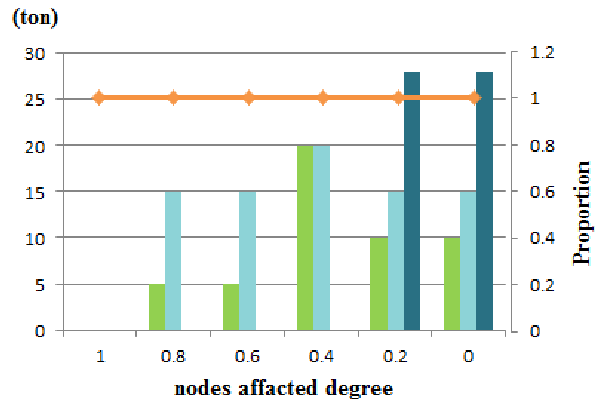
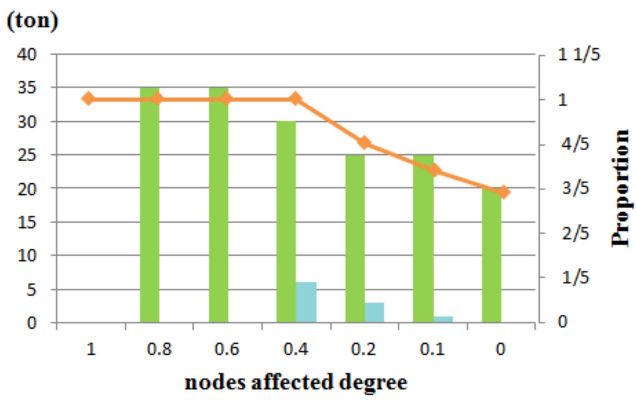


(d)

- Changing allocation of trucks
- Renting capacities (trucks)
- Renting capacities (ship)
- Satisfied demand



(e)

Figure 4.3 The scenario analysis result (small network)

(a)Scenario 1 (b)Scenario 3 (c)Scenario 2

(d)Scenario 4 (e)Scenario 5

- Changing allocation of trucks
- Renting capacities (train)
- Satisfied demand

4.3.2 Large-scale Network Results

Scenario 1: Hong Kong International Airport failed

The results of the scenario which is failed in Hong Kong Airport are given in following figures and tables.

We show the alternative routes when the disruption occurs with different severe level in Table 4.17. The shipments in the scenario $r_{18} =$ 0.75 to 0.2 have little changes in the routes. By and large they will choose the new alternative route from Hong Kong (HKG), Dubai (DXB) to Leipzig (LEJ) or remain to be transported by original route which is from Hong Kong (HKG) to Leipzig (LEJ). This is because the failed HKG limits the links capacities from HKG to the other airports. It makes the cargos transported by different routes. In the scenario $r_{18} = 0.15$ and 0.1, the rail transportation is chosen in Japan because the cost is lower than renting the trucks and the sum of travel time and renting time is just a little higher than renting the trucks.

When the HKG hub remains 10% capacity or less, the sea transportation instead of air is used between Taiwan to China. The shipment will depart Kaohsiung port (KHH) or Keelung port (KEL) to Shanghai port (SHA).Under these scenarios ($r_{18} = 0.1{\sim}0$), Hong Kong Airport (HKG) can't provide the enough capacities. When Hong Kong Airport (HKG) totally can't work, shipment 1 will not be transported and the other shipments are consolidated in Shanghai Pudong Airport (SHA), and then delivered to the Leipzig/Halle Airport (LEJ) by air directly. The trucks are still responsible for the inland transport in Europe.

We find most of shipment will be transported to the destinations before the cargo time value declines. Due to the high values of the technologic products (short-life cycle commodities with high values), the shipment 2 is always be transported with the entire amounts and on time no matter the disruption is serious or not, except for the scenario $r_{18} = 0.1$. In the scenario $r_{18} = 0.1$, the shipping time of shipment 2 (technologic products) is over 5760 minutes, so the cargo time value of technologic products decline to 13670000 dollars per ton. When the disruption becomes more severe, part of cargos in the

Table 4.17 The alternative routes for HKG hub failure

Capacity remaining proportion	**b**	**path**	**travel time (min.)**	**cargos quantities**
Normal situation $r_{18} = 1$	1	OSC → KIX ➔ HKG ➔ LEJ → Berlin	3357.75	20
	2	Zoh → TPE ➔HKG ➔ LEJ → Greven	3363.75	20
	3	OAA → KIX ➔ HKG ➔ LEJ →Hanau	3675.25	22
		(without the resilient strategies)		
$r_{18} = 0.75$	1	OSC →KIX➔HKG➔DXB➔ LEJ→ Berlin	3320.25	18
	2	Zoh → TPE➔ HKG ➔LEJ→ Greven	3383.75	20
	3	OAA →KIX ➔HKG ➔LEJ→Hanau	4304.5	25
$r_{18} = 0.2$	1	OSC →HND➔HKG➔DXB➔ LEJ→ Berlin	3763.75	18
	2	Zoh → TPE ➔ HKG➔ DXB➔ LEJ→ Greven	3461.25	20
	3	OAA →KIX ➔HKG ➔LEJ→Hanau	4304.5	25
$r_{18} = 0.15$	1	OSC →KIX ➔HKG➔DXB➔ LEJ→ Berlin	3218.5	17
	2	Zoh → TPE➔ HKG➔ DXB➔ LEJ→ Greven	3461.25	20
	3	OAA - - -NGO➔HKG ➔LEJ→Hanau	4238.25	26
$r_{18} = 0.1$	1	OSC →HND ➔HKG➔DXB➔ LEJ→ Berlin	3866	19
	2	Zoh → KHH… SHA ➔LEJ→ Greven	6763	20
	3	OAA - - -NGO➔HKG ➔LEJ→Hanau	4318	27
$r_{18} = 0.075$	1	OSC →KIX ➔HKG ➔ LEJ→ Berlin	2360.25	10
	2	Zoh → KEL… SHA ➔LEJ→ Greven	5489	20
	3	OAA→NGO➔HKG➔DXB ➔LEJ→Hanau	3964.25	20
$r_{18} = 0.05$	1	OSC →KIX ➔HKG ➔DXB ➔ LEJ→ Berlin	1492.5	1
	2	Zoh → KEL… SHA ➔LEJ→ Greven	5489	20
	3	OAA→NGO➔HKG➔DXB ➔LEJ→Hanau	3068.5	13
$r_{18} = 0.025$	1	OSC →KIX ➔HKG ➔ LEJ→ Berlin	1662	3
	2	Zoh → KEL… SHA ➔LEJ→ Greven	5489	20
	3	OAA→NGO➔HKG➔DXB ➔LEJ→Hanau	2282.75	6
$r_{18} = 0$	1		0	0
	2	Zoh → KEL… SHA ➔LEJ→ Greven	5489	20
	3	OAA→KIX➔SHA ➔LEJ→Hanau	4181	24

→ truck - - - rail ➔ air … sea

shipment 1 and 3 are abandoned because it needs to consider the resilient cost, too. When Hong Kong Airport (HKG) totally can't work, the constant value products (shipment 1) are abandoned totally so that the company can rescue more holiday gifts (shipment 2) with the less cost spending.

The renting activities for HKG hub failure scenario are listed in Table 4.18. Most of trucks are rented from carrier 1 because of the lower renting cost. There is an exception in the scenario $r_{18} = 0.075$, it rents one ton trucks capacities from carrier 2. We can infer that when the rented capacities are few, it may rent the trucks from the carrier with shorter renting time to save the time spending instead of saving cost. For the air and sea transport, we find that most of aircraft containers are rented from non-partners because the contractual partner doesn't accommodate the capacities for the requisite routes. The same situation also happens to the sea transportation. Thus, the selection for the air and sea carriers is limited by the airlines and shipping lines which set up from contractual partners.

Table 4.18 Renting capacities for HKG hub failure

Capacity remaining proportion (Severe level)	**Link**	**mode**	**carrier**	**rent amounts (ton)**
$\boldsymbol{r_{18} = 0.75}$	(OAA, KIX)	truck	carrier 1	3
$\boldsymbol{r_{18} = 0.2}$	(OAA, KIX)	truck	carrier 1	3
$\boldsymbol{r_{18} = 0.15}$	(OAA, NGO)	rail	Japanese National Railways	26
$\boldsymbol{r_{18} = 0.1}$	(LEJ, Hanau)	truck	carrier 1	3
	(OAA, NGO)	rail	Japanese National Railways	27
	(KHH, SHA)	ship	Evergreen	20

$r_{18} = 0.075$	(OAA, KIX)	truck	carrier 2	1
	(KEL, SHA)	ship	carrier 1 (Evergreen)	20
$r_{18} = 0.05$	(KEL, SHA)	ship	carrier 1 (Evergreen)	20
$r_{18} = 0.025$	(KEL, SHA)	ship	carrier 1 (Evergreen)	20
$r_{18} = 0$	(OAA, KIX)	truck	carrier 1	2
	(KIX, SHA)	aircraft	carrier 2 (non-partner)	24
	(KEL, SHA)	ship	carrier 1 (Evergreen)	20

The changing allocation of own trucks (Table 4.19) happens at the service center in Japan primarily because the location of the disruption is in Japan. When the disruption becomes more serious, it spends the recovery cost on the Japan service centers rather than on the Germany service centers. Thus, we know that the model will recover the more critical parts first. In general, the trucks re-allocations are changed depending on the route choice.

In Table 4.20, we count the amount of own trucks re-allocation and renting capacities for failed HKG hub. In the slight disruption, it does the trucks re-allocations and rents the trucks. Sometimes considering to arrival time, the Japan rail is chosen to reduce the shipping time. When the capacities remain 0.1, it starts to rent the ship containers and when the HKG hub totally can’t work, 24 tons capacities for aircraft containers will be rented. In general, the amounts go up gradually. It means when the situation becomes more serious, the recovery activities will increase.

Table 4.19 own trucks re-allocation at nodes for HKG hub failure

Scenario (Severe level)	node	rent amounts (ton)
$r_{18} = 0.75$	OAA	12
	OSC	8
	LEJ	3
$r_{18} = 0.2$	OAA	12
	OSC	15
	LEJ	3
$r_{18} = 0.15$	OSC	7
	LEJ	4
$r_{18} = 0.1$	Zoh	17
	OSC	16
	LEJ	2
$r_{18} = 0.075$	Zoh	18
	OAA	15
$r_{18} = 0.05$	Zoh	18
	OAA	8
$r_{18} = 0.025$	Zoh	18
	OAA	2
$r_{18} = 0$	Zoh	18
	OAA	12

Table 4.20 The amounts of own trucks re-allocation and renting capacities for failed HKG hub

Capacity remaining proportion (Severe level)	**The amounts of trucks re-allocation (ton)**	**Renting capacities (ton)**			
		Rail	Truck	Aircraft container	Ship container
$r_{18} = 0.75$	23	0	3	0	0
$r_{18} = 0.2$	30	0	3	0	0
$r_{18} = 0.15$	11	26	0	0	0
$r_{18} = 0.1$	35	27	3	0	20
$r_{18} = 0.075$	33	0	1	0	20
$r_{18} = 0.05$	26	0	0	0	20
$r_{18} = 0.025$	20	0	0	0	20
$r_{18} = 0$	30	0	2	24	20

In order to proof the effectiveness of our model, we compare our first objective value with the value without resilient strategies which is obtained from the revised model. We delete the decision variables including re-allocating trucks and renting capacities from our resilient model and change the objective functions to be maximizing total throughputs and minimizing the travel time in the revised model. The comparing results are list in Table 4.21 and show in Figure 4.4. We find the increased percentage of cargo time value enhances increasingly when the disruption gets more serious.

Furthermore, the recovery cost raises by the situation getting serious, but when the capacities remain 5% of HKG hub, the cargo time value starts to decline and recovery cost reduces. It can be interpreted that the model considers the two of objective functions and decide to give up some cargos to reduce the recovery cost. When the Hong Kong Airport totally doesn’t work, the express company needs to pay a lot of money to recover the cargo time value from 0 to 516000 thousand dollars. Thus, it is worth noting that if we want to recover from very severe disruption, the express company needs to pay a lot or it may implement the proactive resilient strategies to prevent its disruption.

Table 4.21 Cargo time value and recovery time for HKG hub failure

Capacity remaining proportion (Severe level)	**without resilient strategies**	**with resilient strategies**		
	cargo time value (thousand dollars)	cargo time value (thousand dollars)	increased percentages	recovery cost (dollars)
$r_{18} = 0.75$	500000	543000	8.6%	13479.5
$r_{18} = 0.2$	500000	543000	8.6%	14179.5
$r_{18} = 0.15$	500000	551000	10.2%	148900
$r_{18} = 0.1$	408000	562000	37.75%	207746
$r_{18} = 0.075$	275000	490000	78.2%	19727.5
$r_{18} = 0.05$	178000	418000	134.83%	2700
$r_{18} = 0.025$	81000	357000	340.74%	2000
$r_{18} = 0$	0	516000		1476381

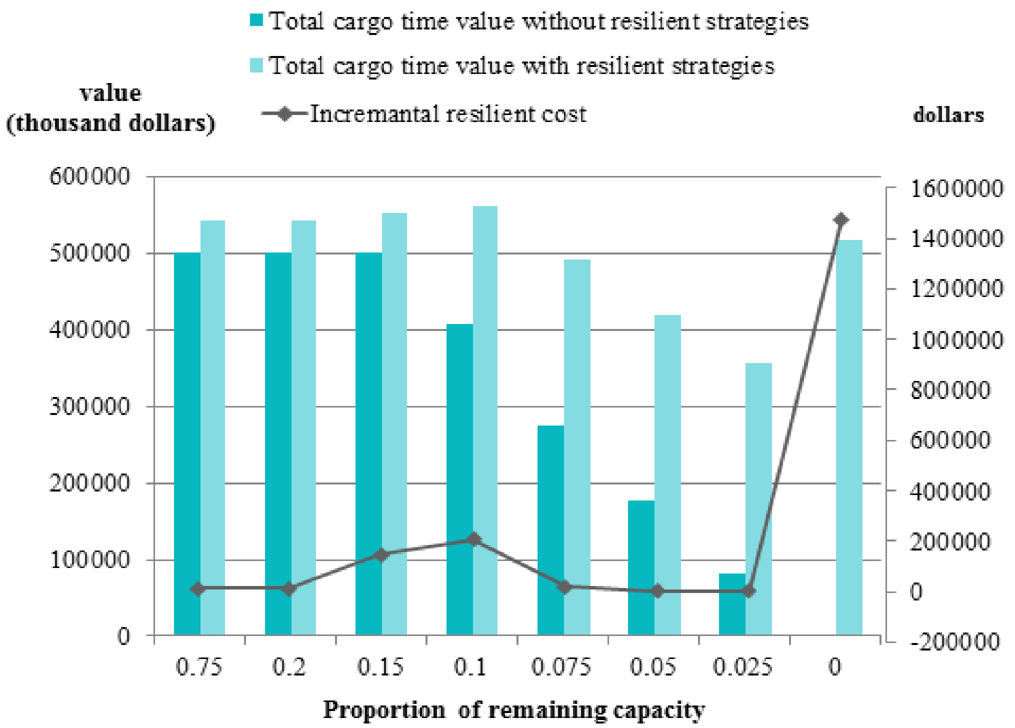


Figure 4.4 Cargo time value and recovery cost for HKG hub failure

Scenario 2 : Japan Earthquake

In the Japan earthquake scenario, we assume the combination of link, node and mode failed situation. The resulting new alternative paths are shown in Table 4.22. Because Narita International Airport (NRT) is closed and the links from Tokyo International Airport (HND) to HKG and SHA leave few capacities, the cargos are transported from service centers in Japan to Kansai International Airport (KIX) and Central Japan International Airport (NGO). The constant value commodities and holiday gifts will go through Hong Kong International Airport (HKG), Dubai International Airport (DXB) and Leipzig/Halle Airport (LEJ). The technologic products (short life-cycle commodities) are transported from Shanghai Pudong Airport (SHA) to Leipzig/Halle Airport (LEJ) directly. Otherwise, due to the road system and rail are broken in Japan, only part of cargos can be delivered.

Comparing with the results from the model without resilient strategies, our model recovers the cargo flows of 14 ton technologic products (short life-cycle commodities) from Nerima (TYN) to Greven (Grv). On the other hand, it is worth noting that the results in our model may not choose the paths with shortest travel time, for example shipment 1 and 2, but it must choose the paths that allow the shipments be delivered before the cargo time value declines and the paths which will not have additional expenditure.

Table 4.22 The alternative routes for Japan Earthquake in the two situations

→ truck - - - rail ➔ air … sea

The results from different model	b	path	travel time (min.)	cargos quantities
with resilient strategies	1 2 3	OSC → KIX ➔HKG ➔DXB➔LEJ→ Bel TYN → KIX ➔ SHA ➔ LEJ → Grv NGC → NGO➔ HKG➔ DXB➔LEJ →Han	2412.75 3481 3601.75	10 14 18
without resilient strategies	1 2 3	OSC→ KIX➔HKG➔ LEJ→ Bel NGC→ NGO➔ HKG ➔LEJ→ Han	2360.25 0 3299.25	10 0 18

The renting activities for Japan earthquake scenario are listed in Table 4.23. We find most of renting capacities are used to transport the cargos of shipment 2 including the trucks rented from Nerima (TYN) to Kansai International Airport (KIX) and the aircraft containers rented from Kansai International Airport (KIX) to Shanghai Pudong Airport (SHA). But there is an exception which is the trucks rented from Nagoya Central (NGC) service center to Central Japan International Airport (NGO). It is because the trucks get broken in this scenario.

No matter the shipment is from Nerima service canter (TYN) to Kansai International Airport (KIX) or from Nagoya Central service center (NGC) to Central Japan International Airport (NGO), it rents the trucks from carrier 1 because the renting cost is cheaper than carrier 2. Until the capacities of carrier 1 are exhausted, the capacities of carrier 2 are rented. It shows that the time spending on dispatching the trucks (RT_i^{me}) by different carriers is not the significant factor which impacts the renting decisions.

The reason why aircraft containers are rented from non-partner is that the partner carrier doesn't set up the route from Kansai International Airport (KIX) to Shanghai Pudong Airport (SHA).

Table 4.23 Renting capacities for Japan Earthquake

Link	**mode**	**carrier**	**rent amounts (ton)**
(TYN, KIX)	truck	carrier 1	10
	truck	carrier 2	1
(NGC, NGO)	truck	carrier 1	3
	truck	carrier 2	1
(KIX, SHA)	aircraft	carrier 2 (non-partner)	14

The changing allocation of own trucks happens at Nagoya central service center

(NGC). Five trucks (5 ton.) are re-allocated to transport the cargos from Nagoya central service center (NGC) to Central Japan International Airport (NGO).

Scenario 3 : Icelandic volcano eruptions

In the Icelandic volcano eruptions scenario, we assume that all the air links from the other airports to Europe airports are all failed. The resulting new alternative paths are shown in Table 4.24. It is noted that intermodal transportation, which is integrated with air and rail, becomes the best way to transport the cargos from Asia to Europe. They are transported from Hong Kong International Airport (HKG) or Shanghai Pudong Airport (SHA) to Moscow by air, and then transported to Parchim International Airport (SZW) or Leipzig/Halle Airport (LEJ) by rail.

We find that shipment 2 (technologic products with high value) and Shipment 3 (holiday gifts) are transported to the destination before the cargo time value declines. In order to maintain more cargo time value, the model lets the technologic products and holiday gifts be transported by the routes with shorter travel time. Besides, comparing to the results of the model without resilient strategies, our model recovers the amount of delivered cargos from 0 to 48 ton.

The results from different model	b	path	travel time (min.)	cargos quantities
with resilient strategies	1	OSC → KIX→HKG→MOW - - - SZW→ Bel	5554.45	20
	2	TYN - - -NRT→ SHA →MOW - - -SZW→ Grv	5756.7	20
	3	NGC → NGO →SHA →MOW - - -LEJ→Han	4231.7	8
without resilient strategies	1			0
	2			0
	3			0

→ truck - - - rail → air … sea

Table 4.24 The alternative routes for Icelandic volcano eruptions

The renting activities for Icelandic volcano eruptions scenario are listed in Table 4.25. It rents plenty amount of aircraft containers and rail capacities. Most of aircraft containers are rented from non-partners because the contracted partner doesn't set up these routes.

Table 4.25 Renting capacities for Icelandic volcano eruptions

Link	mode	carrier	rent amounts (ton)
(NRT,SHA)	aircraft	carrier 2 (non-partner)	20
(NGO, SHA)	aircraft	carrier 2 (non-partner)	8
(HKG, MOW)	aircraft	carrier 2 (non-partner)	20
(SHA, MOW)	aircraft	carrier 2 (non-partner)	8
(TYN, NRT)	rail	Japanese National Railways	20
(MOW, LEJ)	rail		8
(MOW, SZW)	rail		40

The changing allocation of own trucks happens in the Osaka Central service center (OSC) and at Parchim International Airport (SZW). Ten trucks (10 ton.) are re-allocated to Osaka Central service center (OSC) to transport the cargos from OSC to Kansai International Airport (KIX). One truck (1 ton.) is re-allocated to Parchim International Airport (SZW) to service the route from SZW to Greven (Grv).

The comparison between all the scenarios

In the following Table 4.26, we know that different scenarios have different renting activities. It is worth noting that it rents large quantities of the rail and aircraft containers in the Icelandic volcano eruption.

Table 4.26 The amounts of own trucks re-allocation and renting capacities for all scenarios

Scenario	The amounts of trucks re-allocation (ton)	Renting capacities (ton)			
		Rail	Truck	Aircraft container	Ship container
The failure in HKG hub $r_{18} = 0.1$	35	27	3	0	20
Japan Earthquake	5	0	15	14	0
Icelandic volcano eruptions	11	68	0	76	0

To confirm the effectiveness of our model in the different scenarios, the total cargo time value with the resilient strategies and without the resilient strategies are shown in Figure 4.5 and Table 4.27. The results show that our model which considers the several recovery activities can lead to significant improvement in the total cargo time value. It indicates that the recovery activities play the important role in the aftermath of a disruption. It worth noting that the resilient cost spending on volcano eruption is much higher than the other scenarios. It is the most severe disruption to the express company. The company may need to focus on the proactive resilient strategies in advanced.

Table 4.27 Total cargo time value and incremental recovery cost for different scenarios

Scenario	without resilient strategies	with resilient strategies		
	cargo time value (thousand dollars)	cargo time value (thousand dollars)	increased percentages	recovery cost (dollars)
Japan Earthquake	172000	382000	122%	1344937
Icelandic volcano eruptions	0	392000		6190646
The failure in HKG hub $r_{18} = 0$	0	516000		1476381

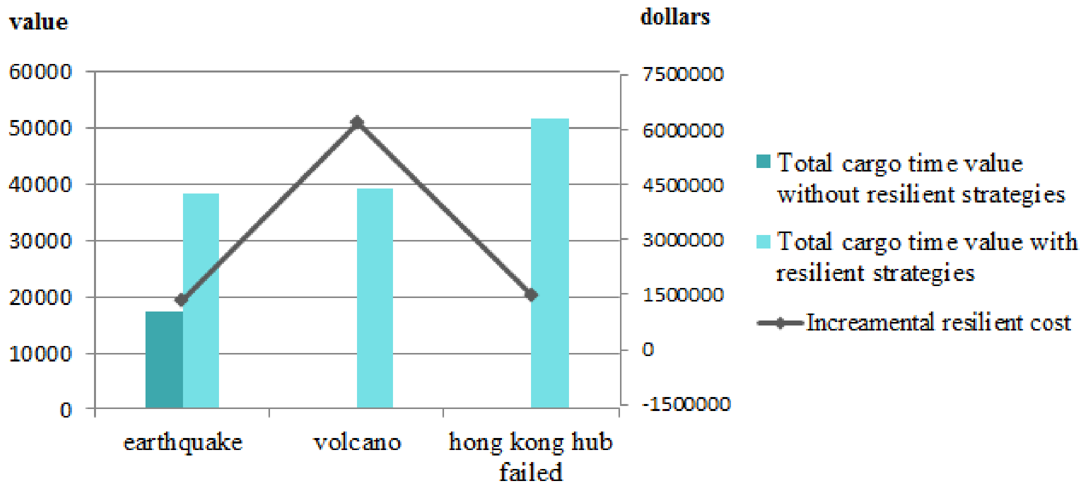


Figure 4.5 Total cargo time value and incremental recovery cost for different scenarios

4.4 Sensitivity Analysis

A sensitivity analysis is carried out to find the influential parameters to our objectives. The parameters we perform in sensitivity analysis are divided into three categories, capacity, time and cost. Capacities parameters include available rented capacities from other carriers (AK), own flights capacities (WA) and own truck capacities (KL); Time parameters include transportation time (T), time spending on re-allocating own trucks (ET), time spending on renting capacities (RT); cost parameters include rent cost(RC) and cost of re-allocating trucks (VC).

In sensitivity analysis, we choose scenario 4 in small network to be the analyzed case. To perform the changes, we present each value as a ratio (Y_1, Y_2) between the new performance value and the original value. The original values are the results of original scenario 4. Y_1 and Y_2 are defined as follows.

$$Y_1 = \frac{Objective\ 1^{new}}{Objective\ 1^{original}}$$

$$Y_2 = \frac{Objective\ 2^{new}}{Objective\ 2^{original}}$$

Objective 1 is total cargo time value and objective 2 is incremental resilient cost.

1 .Capacity parameters

Call for the resilient strategies in chapter 3.1.1, we mentioned that reserved capacity is one of possible proactive strategies to reduce the disruption impact on transportation. Thus, we analyze the effects of changing capacities parameters in our model including available rented capacities from other carriers (AK), own flights capacities (WA) and own truck capacities (KL) to find how much impact they have.

Figure 4.6, 4.7 and 4.8 depict the variation of Y_1 and Y_2 in AK, WA and WL. We see that the less available rented capacities (AK) the company has, the less cargo time value (Y_1) it can reach and less resilient cost (Y_2) it needs to pay. Because available rented capacities (AK) limits the recovery activities.

In Figure 4.7, when the own flights capacities (WA) becomes smaller, the incremental resilient cost (Y_2) is increasing and the impact on Y_2 is more significant. The reason is that it needs to rent more capacities from others to maintain the cargo time value.

The variation of Y_2 in own truck capacities (KL) is similar with own flights capacities (WA) in Figure 4.8. The difference is that KL doesn't decrease progressively with the less degree. It is close to a linear relationship between resilient cost (Y_2) and increased own truck capacities (KL).

The fluctuation of Y_1 in AK, WA and KL are slight comparing to Y_2 so we analyze it in Figure 4.9.

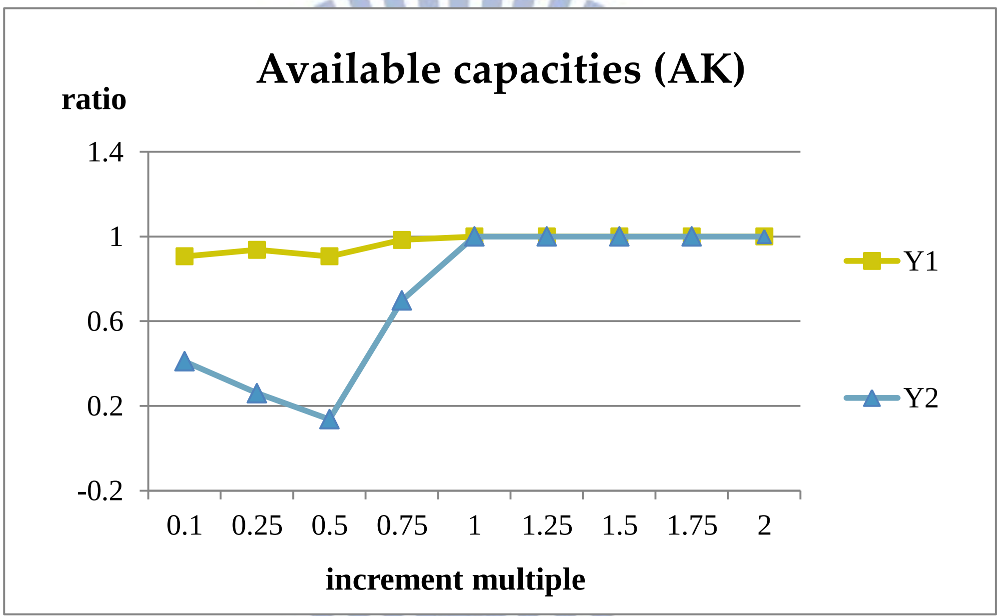


Figure 4.6 Variation of Y_1 and Y_2 in AK

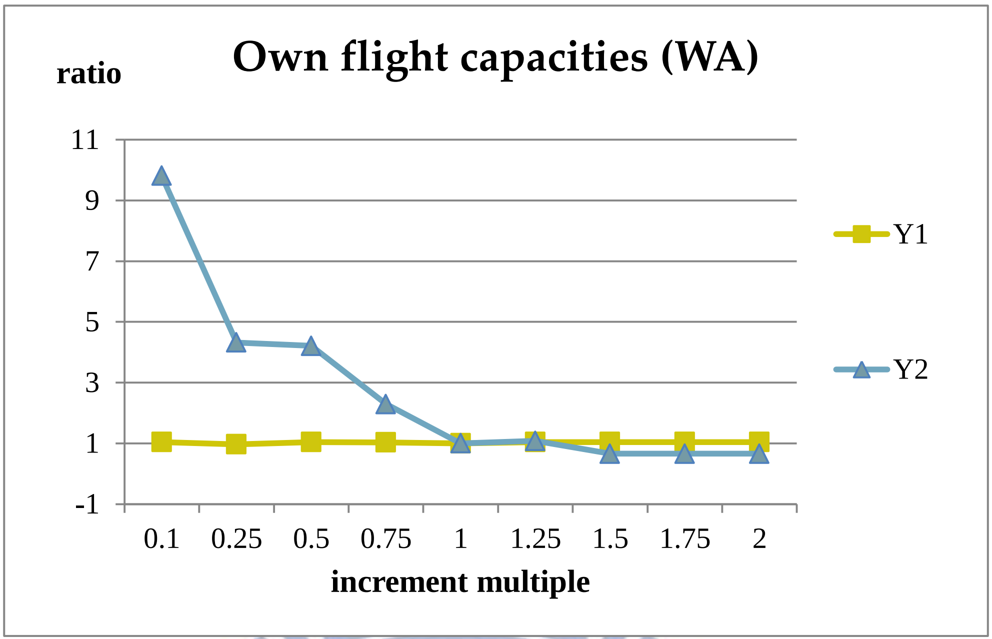


Figure 4.7 Variation of Y_1 and Y_2 in WA

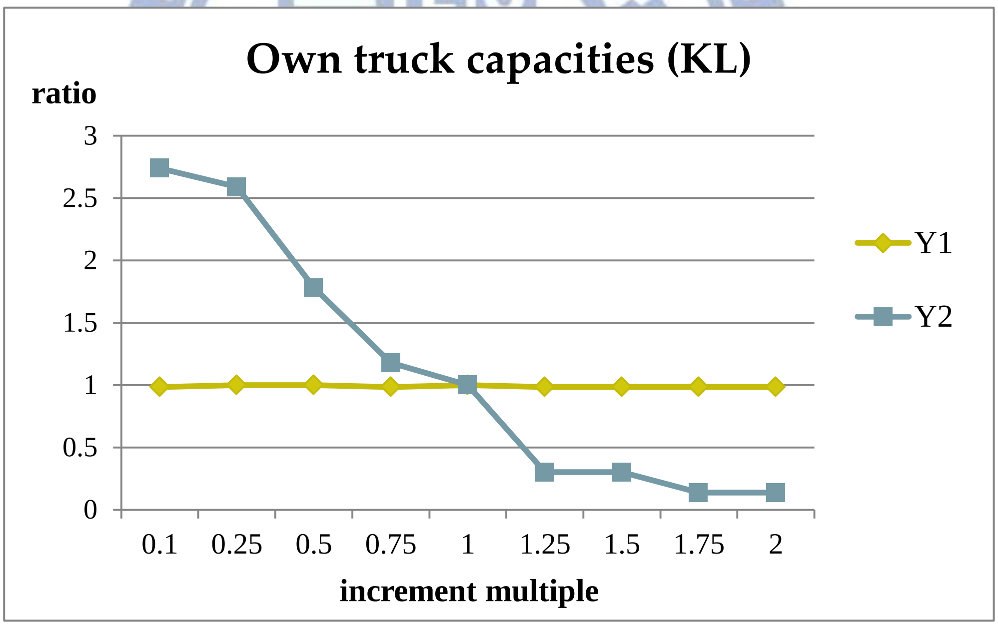


Figure 4.8 Variation of Y_1 and Y_2 in KL

When we compare Y_1 and Y_2 separately (Figure 4.9 and 4.10), we see that Y_1 (the ratio of cargo time value) is more sensitive in available rented capacities (AK) and own flights capacities (WA). It means the parameters, AK and WA, have more impact on the cargo time value and throughputs. Otherwise, the variation of Y_1 in KL is relatively stable.

In Figure 4.10, we find there are two kinds of curves. One is going down and the other is raising. When the own capacities of company including WA and KL decrease, Y_2 (the ratio of incremental resilient cost) will increase progressively. But when the rented capacities (AK) decrease, Y_2 (the ratio of incremental resilient cost) will decrease. It can be interpreted as following. When the own capacities are few, the company is going to rent more capacities from others. However, when there are few available renting capacities, the company may not recover the cargo flows.

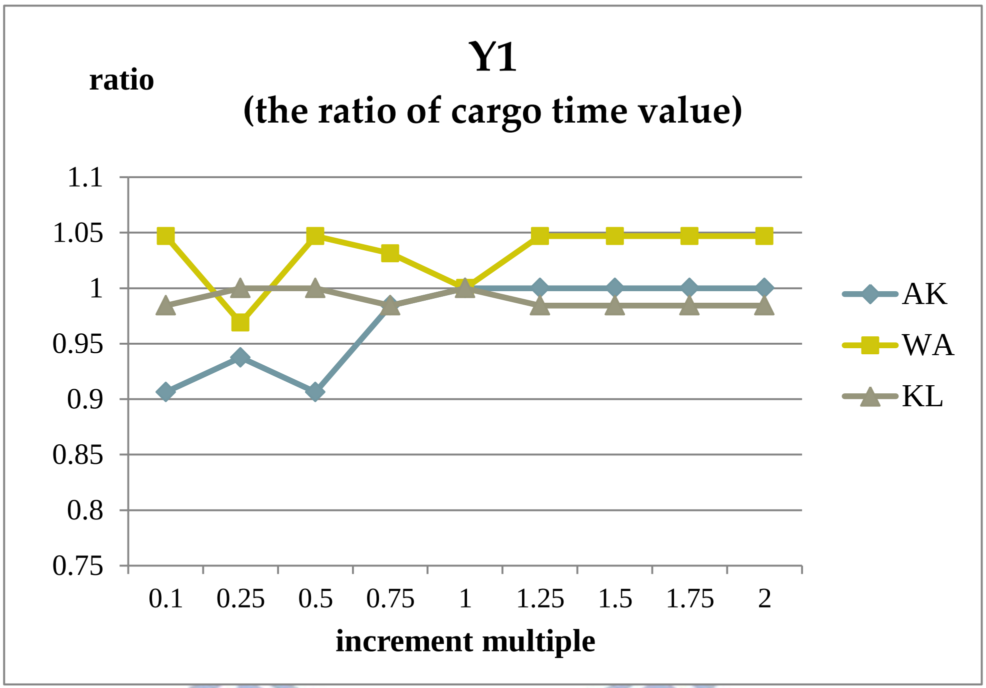


Figure 4.9 Variation of cargo time value in capacity parameters

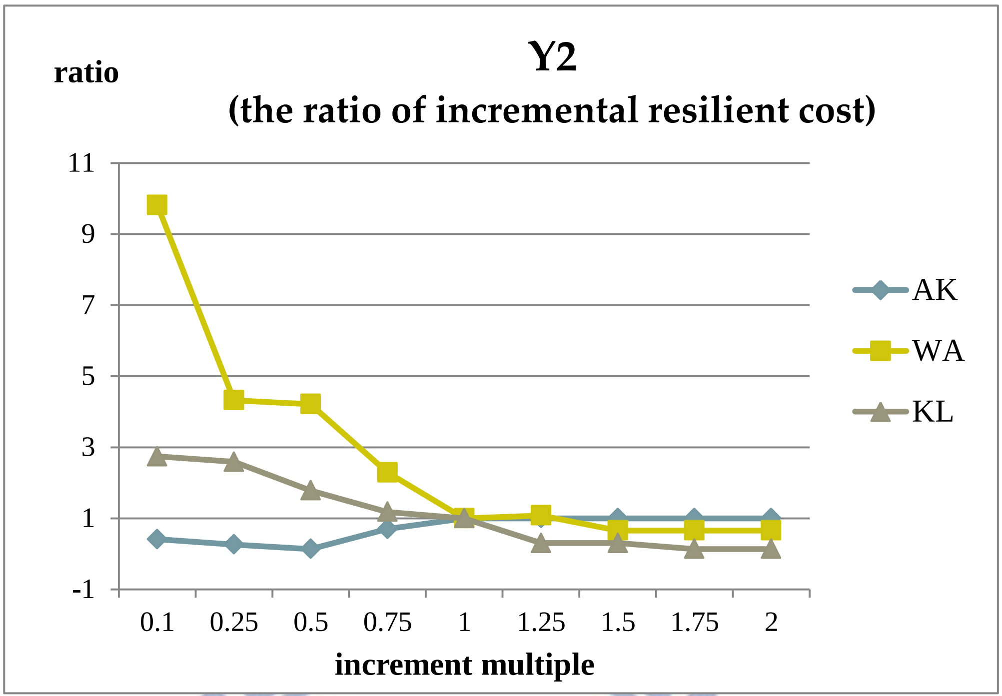


Figure 4.10 Variation of incremental resilient cost in capacity parameters

2. Time parameters

Figure 4.11, 4.12 and 4.13 illustrate the effects of changing transportation time (T), re-allocation time (ET) and renting time (RT). The changing of transportation time (T) is more significant when the transportation time is larger than twice. Y_1 (the ratio of cargo time value) and Y_2(the ratio of incremental resilient cost) are declining first and then increase. It can be interpreted that a longer transportation time will force the total cargo time value reducing. Some of cargos are not delivered on time. Thus, the resilient cost will reduce first. But when the transportation time is over a threshold, it begins to spend a lot of money to prevent the decline of cargo time value and cost is high.

Otherwise, ET and RT have less impact to objective values than T. When renting time (RT) is over 2.75 multiple, Y_1 and Y_2 decrease.

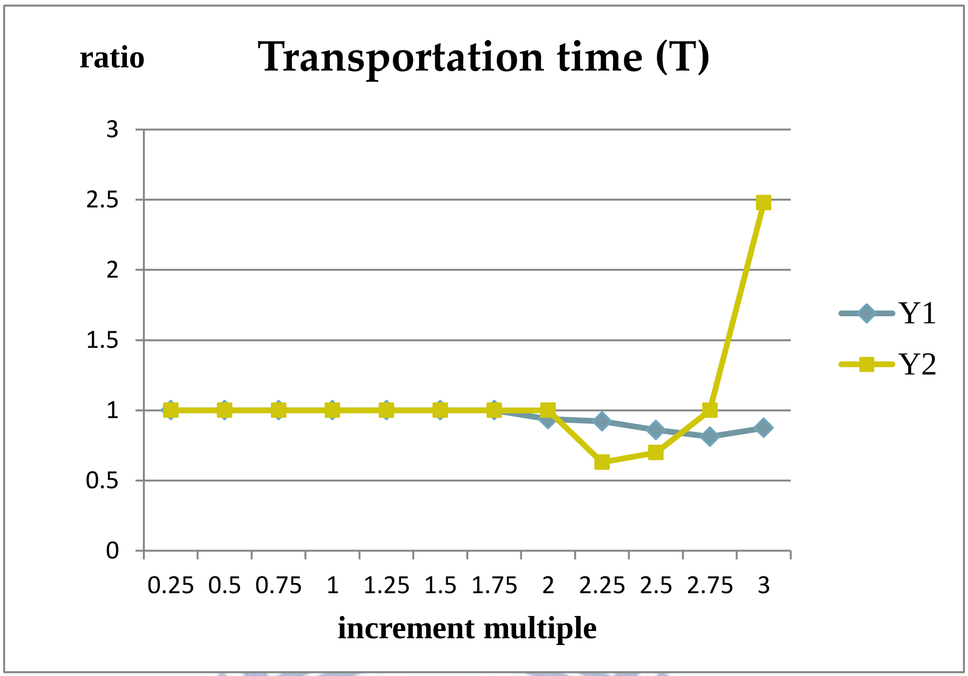


Figure 4.11 Variation of Y_1 and Y_2 in T

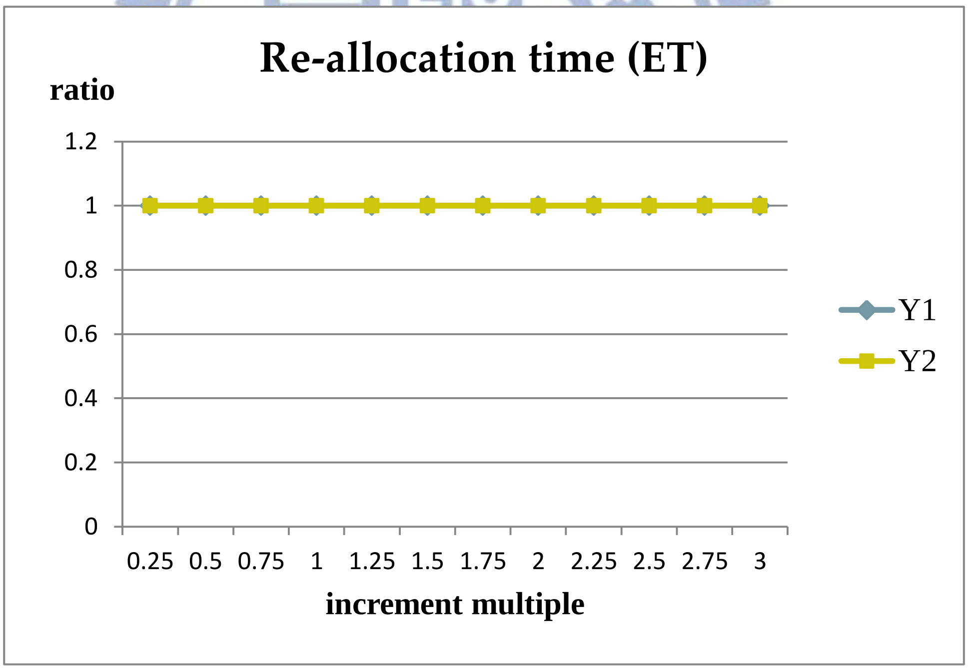


Figure 4.12 Variation of Y_1 and Y_2 in ET

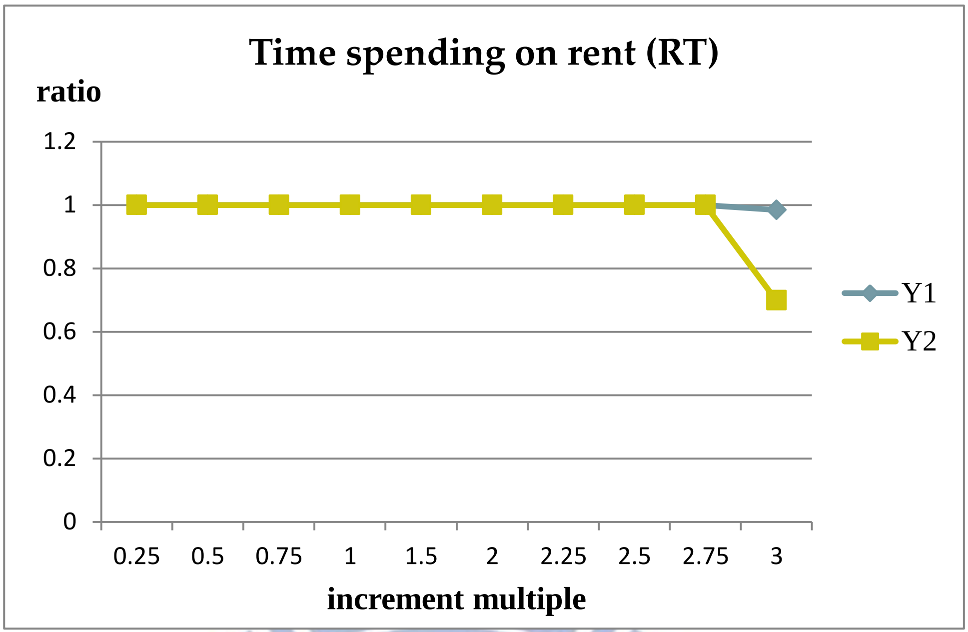


Figure 4.13 variation of Y_1 and Y_2 in RT

When we compare Y_1 and Y_2 separately (Figure 4.14), we see that Y_1 (the ratio of cargo time value) is declining as transportation time (T) expands generally. Comparing to transportation time (T), Y_1 (the ratio of cargo time value) is less sensitive in time spending on renting capacities (RT) and truck re-allocation (ET). In Figure 4.15, the variation of Y_2 in the time parameters is greater when the increment multiple of T is far from 1.

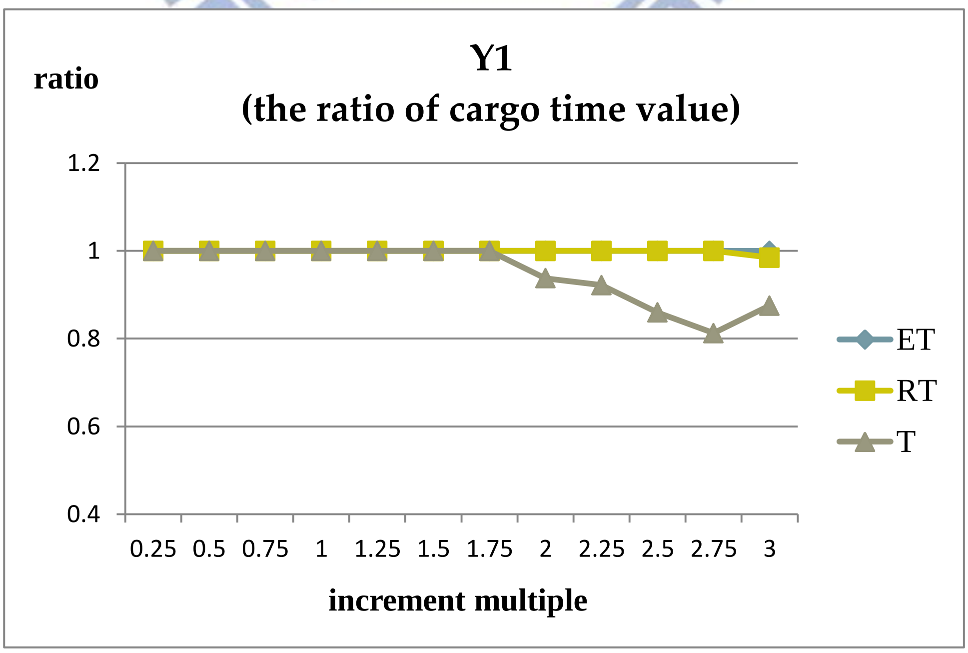


Figure 4.14 variation of cargo time value in time parameters

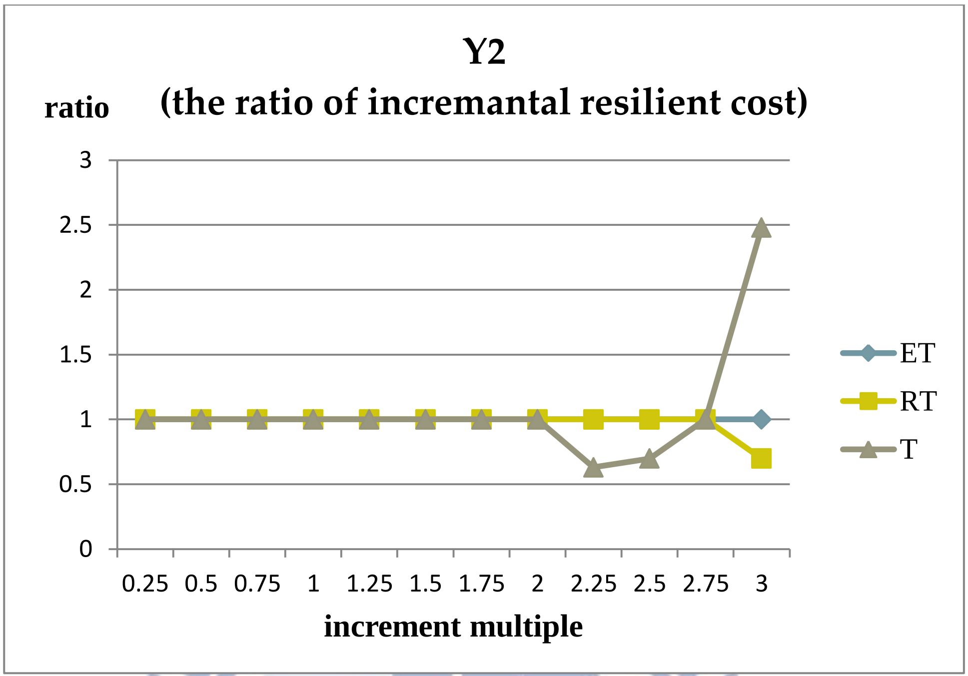


Figure 4.15 variation of incremental resilient cost in time parameters

3. Cost parameters

Obviously, the incremental resilient cost is affected by renting cost. Figure 4.16 and 4.17 demonstrate the results when the renting cost and re-allocation cost change with increment multiple. In Figure 4.16, it shows that Y_2 is increasing in RC but Y_1 doesn't change. In Figure 4.17, Y_2 is also increasing in VC but Y_1 is decreasing slightly when VC is below 0.5 multiple. We can interpret that the renting cost and re-allocation cost directly impact the total incremental resilient cost, which is intuitive. They don't impact total cargo time value and the choice of recovery activities. The curve of Y_2 in RC is linear but it is not linear in VC. This is because there is the fluctuation existing in the balance between two objectives.

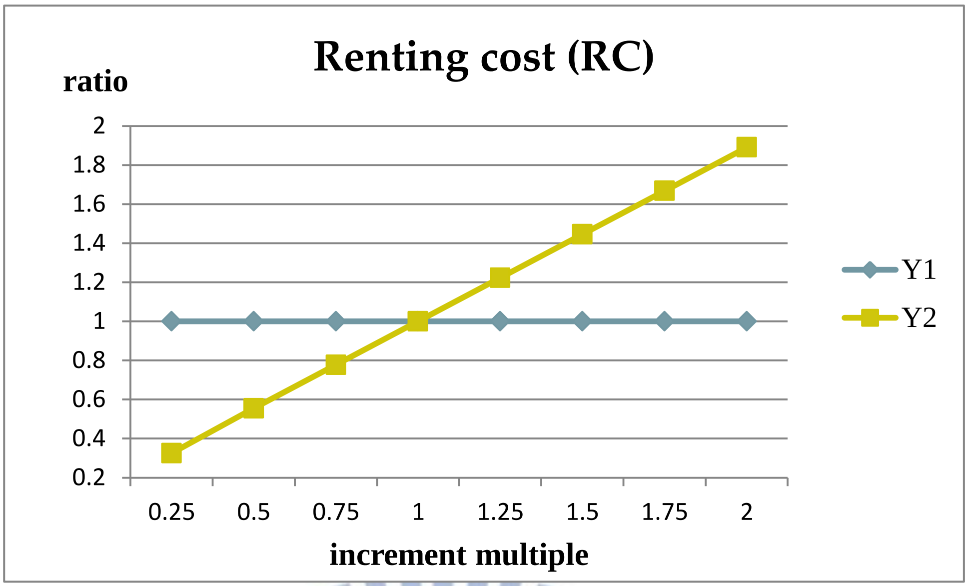


Figure 4.16 Variation of Y_1 and Y_2 in RC

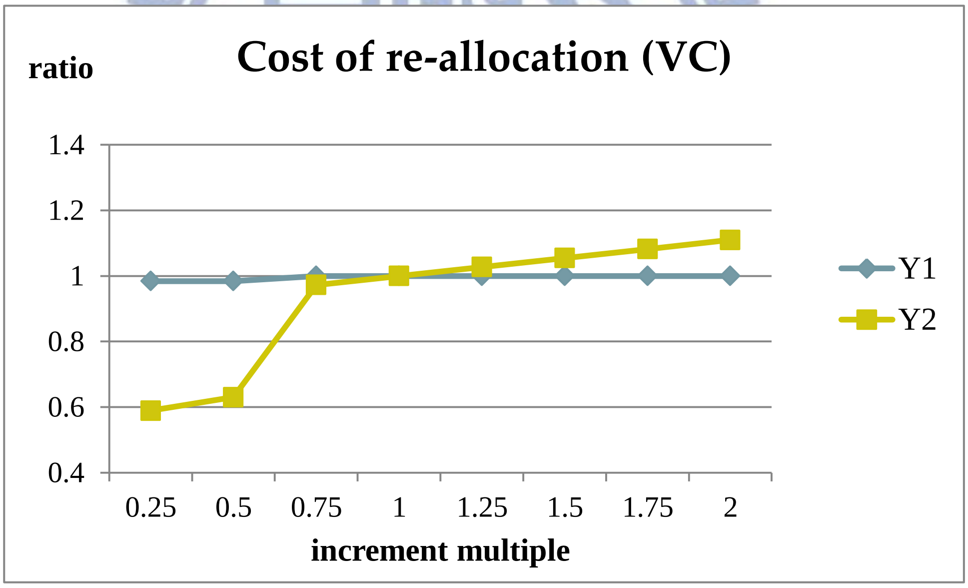


Figure 4.17 Variation of Y_1 and Y_2 in VC

When we compare Y_1 and Y_2 separately (Figure 4.18 and 4.19), we see that Y_1 (the ratio of cargo time value) is no change in RC and a little change in VC. Y_2 is increasing as RC and VC increase. We find that incremental resilient cost is more sensitive in renting cost (RC) than in re-allocation cost (VC) because the renting cost is higher than re-allocation cost.

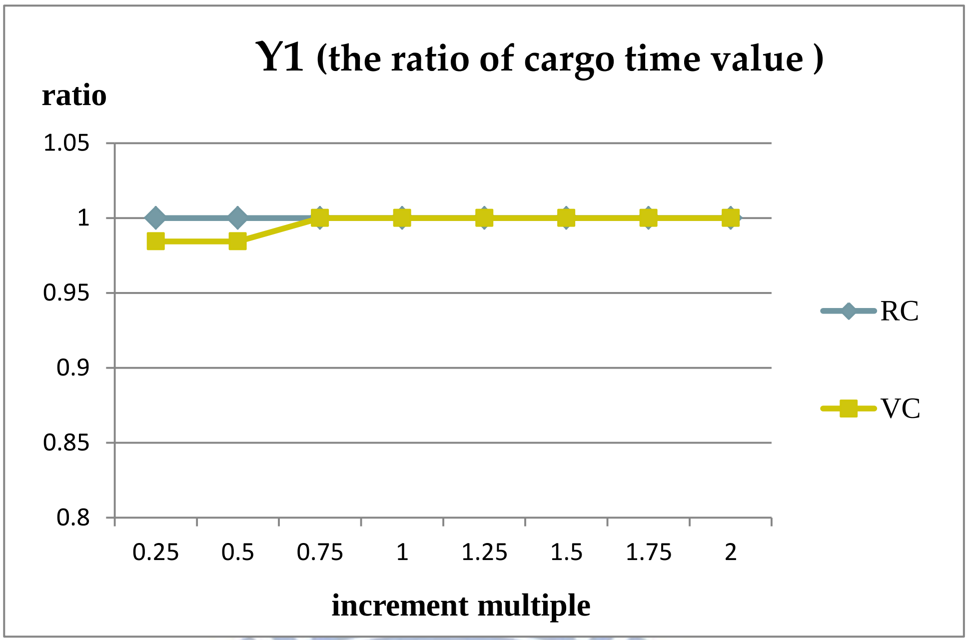


Figure 4.18 Variation of cargo time value in cost parameters

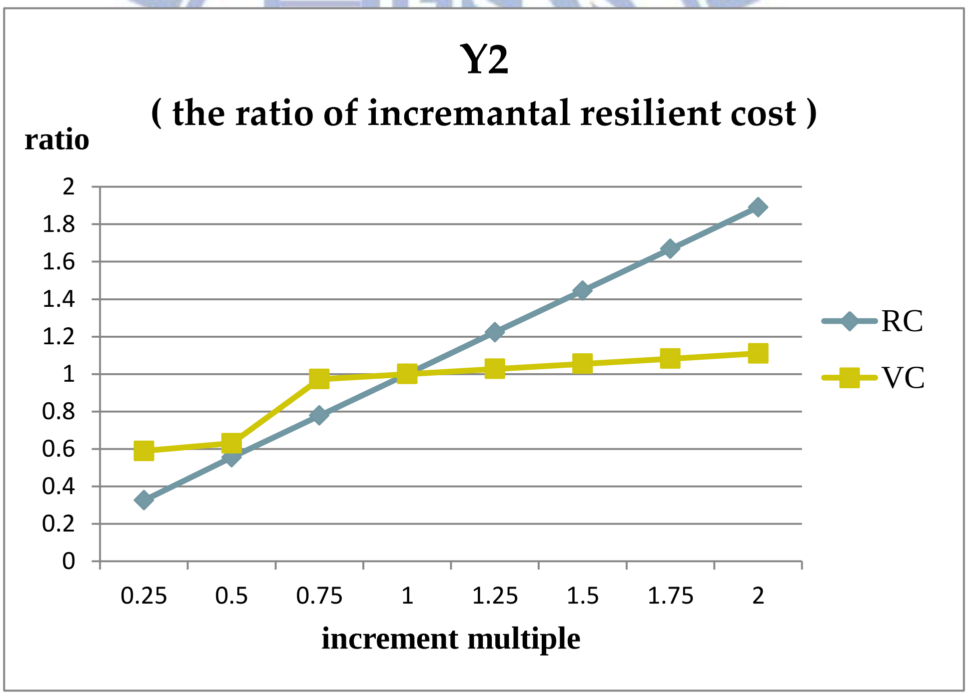


Figure 4.19 Variation of incremental resilient cost in time parameters

4.5 Managerial Implication

From the above scenarios and sensitivity analysis, we can give some advices to the express company.

4.5.1 The simple recovery process

From the small network case, we find that the recovery activities are taken in following sequence:

1) Change to the alternative paths

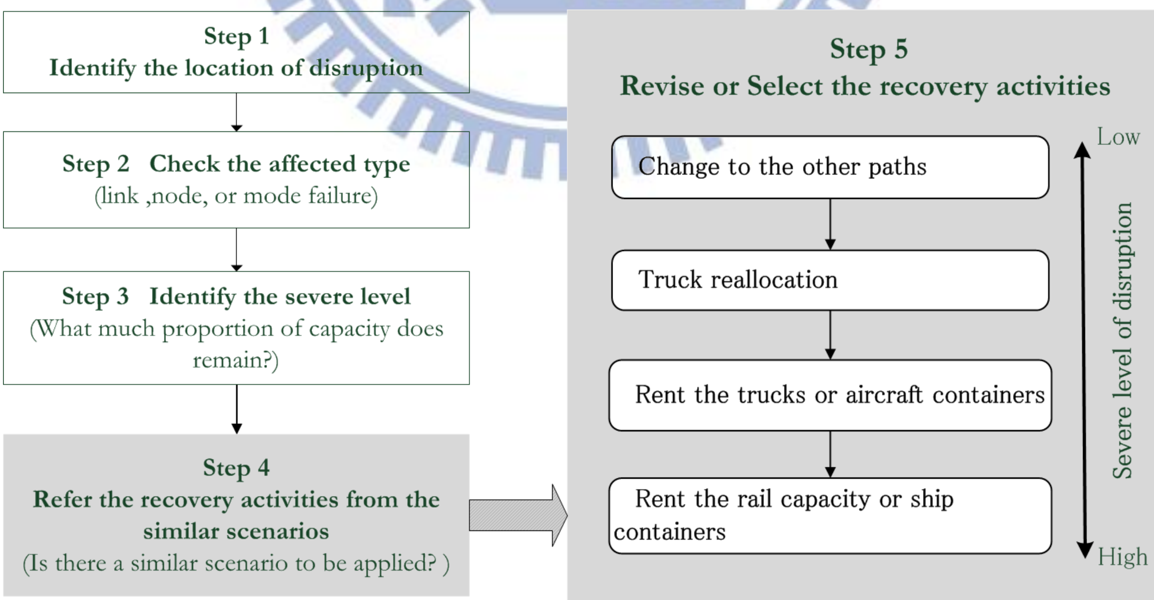
2) Re-allocate own trucks

3) Rent trucks or flight containers

4) Rent the different modes (train or ship)

First, the path will change and then the own trucks will be re-allocated. Only when above changes can still not satisfy the demand, the model will rent the additional modes. Finally the different modes will be chosen, for example the train or ship.

Figure 4.21 The simple recovery process



Recall that the goal of our research was to find the possible recovery activities which can effectively respond the situation of disruption. We can establish the simple recovery process

(Figure 4.21) according to the aforementioned sequence in the small network case. The process can tell the express company the rough direction in the pre-incident stage. When the disruption occurs, the company identifies the location, affected type and severe level of disruption first. Then, find the similar scenario. They can refer its recovery activities and revise the actions by this process. Should we change to the other paths? Should we re-allocate own trucks? If there is no similar scenario, we also can directly evaluate each recovery activities step by step by experience. With more severe situation, the company needs to consider more recovery activities together. This rough response action only can use in the short term. If company wants to consider the recovery activities in the medium-term or long term, it needs to execute our resilient model to get more precise quantitative solution.

4.5.2. The suggestion for the reactive recovery actions

1. Mode choice

(1) Sea transportation is advantageous in the short distance to be the substitute for air transport during the disaster, for example , Keelung port to Shanghai Seaport.

(2) If rail transportation wants to substitute for the trucks which service between service centers and airports, it depends on the transportation and transshipping time. If sum of them are shorter than the transportation time for trucks, rail may be chosen during the disaster, for example, rail in Japan in our scenario.

(3) In our large-scale network case, rail is a nice substitute for air in the continents of Europe and Asia, for example, Shanghai - Moscow - Europe.

2. Route choice

(1) From the scenario and the sensitivities analysis, we know that objective functions are not sensitive in transportation time in the certain range. Only when it is over a threshold, it affects the objective functions. Thus, instead of choosing the route with shortest shipping time, the express company can choose any routes which allow the cargos be delivered before the cargo time value declines. We infer that it is because of the assumption of our cargo time value function. If there are different type of functions, the rule maybe different.

(2) The sensitivity analysis shows that the low renting cost is more significant than the transportation time to impact the objective functions. Renting time and re-allocating time have smallest impact on them. Thus, the express company may consider the renting cost first then the transportation time in the certain range because the time becomes less sensitive due to our cargo time value function.

3. Carrier selection

(1)In the scenario of Japan earth quake and failed Hong Kong airport, we find most of trucks are rented by carrier 1, because its renting cost is cheaper than carrier 2. But the renting time of carrier 1 is much longer. It shows that the time spending on renting and dispatching the trucks (RT) by different carriers is not the significant factor to impact the carrier selection. From the sensitivity analysis, we also can find the renting cost (RC) has more impact on the objective function than the renting time (RT). Thus, we consider that the key effected factor for carrier selection is renting cost (RC).

(2) In the scenario of failed Hong Kong airport, we find that when the rented capacities are few, it may rent the trucks from carrier 2 to save the time spending instead of saving cost. According to above finding, we suggest that when the rental capacities decrease, the carrier selection can change from low cost carrier to the carrier with short renting time.

4. Cargos arrangement

From scenario analysis, we find technologic products (short-life cycle commodities with high values) are always transported with the entire amounts and on time. The holiday gifts will be considered in the second order. The constant value products are most easily abandoned or transported with long travel time. Thus, sorting the cargos with different type of time value function and transporting them efficiently can help company to reach higher cargo time values.

For the express company, we are going to suggest them to consolidate their resource to handle the cargos with high value or cargos with highly time sensitive and transport different types of cargos with different routes. The way can make express company reach the great efficiency to get higher customers satisfaction during the disruption.

5. Renting activities vs. Trucks re-allocation

(1) From sensitivity analysis, we find no matter in renting activities or truck re-allocation, the cost parameters effect the second objective function more significantly. So the express company can pay more attention on the cost saving rather than time saving when it makes the decision on the recovery activities.

(2) On the other hand, the second objective (the incremental resilient cost) is more sensitive in the renting cost (RC) than the re-allocating cost (VC). Thus, we can infer that renting activity plays more important role in recovery than the truck re-allocation. To the express company, saving the renting cost (RC) is more efficient than re-allocating cost (VC).

(3) Own truck re-allocating activity is the smaller recovery. It changes with route choice, so company can re-allocate the trucks by experience if the disruption is not complex. But when it is complex, the company has better to recover based on our model's solution.

From the above suggestions, we find the renting cost seems to play the important role on the recovery. Time becomes less sensitive during the disruption. It is because the cargo time value function we assume. Due to the time value function, the cargo only needs to be sent before the cargo time value declines. Thus, in the certain range (not over the time threshold), the model can do the more flexible decision on time and the main affected factor is renting cost in this certain range.

4.5.3. The suggestion for the proactive resilient strategies

Although our model provides the quantitative tool which is used after the disruption, we also can use it in advance to help express company draft proactive strategies. For example, we can give the express company some proactive suggestions based on our large-scale scenario analysis.

1. Prepare the backup hub

From the large-scale results, we find having the backup bub in the network is important. When the critical global hub like Hong Kong Airport in DHL failed, the shipments will be consolidated in the Shanghai Pudong Airport (SHA) instead. If there is no backup hub, the recovery cost should be very high so that the company is prone not to recover. Thus, the express company is necessary to invest in the redundant global transshipping hub before the disruption. It can lead to a better recovery.

2. Develop the mainly alternative route depending on our results

We also can suggest company to develop the alternative route before the disruption happens based on the result of model, for example SHA- LEJ or HKG- DBX-LEJ in our big network scenarios. The company can maintain few flights in the alternative routes in normal times or ensure the availability of rental capacities in the alternative routes. Once the disruption occurs, the company can use these routes quickly.

3. Sign the different type of contracts with carriers

From sensitivity analysis, we know that when the own capacities are few, the company is going to rent more capacities from others. However, when there are few available renting capacities(AK), the company can't recover the cargo flows. Thus, it should focus on the resource acquirement after the disruption. We suggest the express company can sign the different type of contracts with carriers.

(1) Choose specific carriers which have the specific routes to be long term contractual partners (long term partnership)

(2) Sign the emergency contracts with non-long term partners (short term partnership)

In the scenarios of Icelandic volcano and Japan earthquake, most of aircraft containers are rented from non-partners because the contractual partner doesn't accommodate the capacities for the requisite routes. The same situation also happens to the sea transportation. Thus, the selection for the air and sea carriers is limited by the airlines and shipping lines which set up from contractual partners.

According to the above results, the express company can use our model to do several scenarios analysis. These scenarios may have big impact on the company or are with the high probability. Based on the result, the express company can choose specific carriers to be long term contractual partners. For the carriers who are not the long term partners, we put stress on signing the emergency contract with them to ensure the timely acquirement of capacities.

4. Appropriate reserved capacities

From sensitivity analysis, increasing more own capacities only can reduce a little resilient cost and increase a little cargo time value. The benefit of increasing own capacities is getting less. It shows a diminishing curve. Thus, maintaining appropriate reserved capacity is a better choice to company.

Because the proactive recovery decision problem is not in our research scope, we don't know how much capacities the express company should maintain before the disaster. So we give the suggestions to the future study that providing the model which can consider both proactive and reactive resilient decisions.

On the other hand, it is worth noting that by choosing either resilient strategy or activity, express company will have higher cost. There is the question from these companies. Is it worth to spend such great amount money to recover the transportation activities? As far as the long-term business goal is concerned, the added cost is kind of saving the customers' satisfaction and commercial goodwill. By the increasing disruption events, the companies can't be passive role to do nothing anymore. They need to consider the benefits of their customers and create the good enterprise image so it is necessary to spending on the recovery activities. From the other standpoint, we also realize that the cost plays the key role in the express company. Thus, in order to use the less expenditure to reach the great effects, our model considers two objectives simultaneously which is maximizing total cargo time value and minimizing the incremental cost from recovery.

V. Conclusion and Extensions

5.1 Conclusion

1. This paper studies the recovery problem for the natural and man-made disaster. Although this problem was extensively discussed in the literature, no models is tailored for the international express companies to consider the cargo time value and incorporates several resilient strategies, for example renting measure.

2. Instead of arbitrarily making rush decisions during the post-disruption phase, this paper contributes a method for quantifying and optimizing the resilience strategies based on an integrated resource allocation concept, regardless of how the available resources are located with respect to the studied logistics network or how many capacities we should rent from others .

3. The mathematical programming model is employed in the numerical experiments to present the applicability of our model. The results show that different resilient strategies or recovery activities are adopted depending on different failure types and affected locations. In general, the strategies will increase and be more complex when the situation becomes worse.

4. From several scenario analysis and sensitivity analysis, we explore some rules from the results and give some suggestions to the express company. Due the assumption of our cargo time value function, we find that time will become not sensitive to express companies during the disaster. The model can choose any routes which allow the cargos be delivered before the cargo time value declines even if the travel time is not the shortest. The renting cost becomes the more significant factor in the recovery activities, carrier selection and route choice. They are based on our cargo time value function type. If it changes, there is the different rule in the result.

5.2 Extensions to Future Research

1. In the future research, we suggest to obtain the practical and accurate data in the transportation time, renting time and available rental capacities, etc., and acquire more useful solutions to examine the nodes or links in advance.

2. The usefulness of the numerical results can be increased by further developing commercial software for real-time control operations.

3. Although our model can examine the reliability of primary hubs and links within the existing operational networks before the disruptions, we can't decide which proactive strategies the express company should invest in. Thus, in the future, the model may extend to consider both proactive decision and reactive decision for disaster recovery problem. It can let companies do more useful decisions in investment before disruption and in cost spending after disruption.

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