國立交通大學

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碩士論文

敏捷供應鏈之適應性配送模式

An Adaptable Distribution Model for Agile Supply Chains

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摘　　要

在全球化之際，具備敏捷能力來彈性反應目前變遷快速的環境，為企業維持競爭優勢的關鍵。然而，鮮少研究以數量方式探究敏捷性。因此，本研究針對運輸環境不確定性，且依據四大適應性配送原則(低成本配送、快速反應配送、擁擠配送以及第三地配送)建構出敏捷供應鏈之適應性配送模式。

敏捷能力最主要的特性為在不同情境下的反應能力，本研究透過不同情境分析來評估模式的適應性配送，進而觀察運輸系統的反應方式。研究結果顯示在敏捷供應鏈之下，透過該適應性配送模式可彈性地反應出各種情境之應對方式。

關鍵字：敏捷供應鏈、適應性配送、反應能力

An Adaptable Distribution Model for Agile Supply Chain

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ABSTRACT

Being able to respond flexibly to volatile and turbulence environment, agile is crucial for enterprises in gaining a competitive advantage in the global marketplace. However, research about modeling agile supply chains is scanty. This research is devoted to developing an adaptable distribution model for agile supply chain with emphasis on transportation uncertainties, which is based on the principles of adaptable distribution: low cost, time, congestion, and third place distribution. The main characteristic of agility is the ability of responsiveness under different changing conditions. Hence, scenario analyses are conducted to evaluate the impact and the way to reflect through the proposed model and observe how the transportation behaves and responds under different conditions. The results demonstrate the proposed model is suitable and responds appropriately within agile supply chain based on adaptable distribution.

Key words: Agile supply chain, Adaptable distribution, responsiveness

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“G-R-A-D-U-A-T-I-O-N”是一件多麼值得慶祝的事，記錄自己在研究所兩年內的學習，同時更代表了另一段旅程的開始。

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中華民國九十八年六月

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Chapter 1 Introduction

1.1 Motivations and background

In the current challenging business environment, turbulent and volatile markets have become the norm, product life cycles have shortened and globalization has increased uncertainty. As many markets are dynamic and difficult to predict, supply chain management (SCM) is now focus on “shifting from the idea of cost as an order winner to responsiveness as the market winner” (Christopher and Towill, 2002). Notably, most organizations are driven by forecasting rather than demand. Furthermore, recent economic trends have de-emphasised the benefits of vertical integration－economies of scale, access to capital, and large physical infrastructure investment, and instead have improved the benefits of specialization － speed, agility, and rapid growth (Samaranayake, 2005). In response to this shift, companies should take advantage of changing opportunities. However, to achieve competitive advantage in a global marketplace, the ability to respond rapidly to changes, called “agile supply chain management,” has become increasingly important.

An agile supply chain thus should posses the ability to respond appropriately to changes occurring in its business environment (Lin et al., 2006). Agility, then, can be defined as the ability of an organization/supply chain to respond rapidly to changes in market and customer needs, both in terms of volume and variety. A key characteristic of agility is the ability to reflect dynamic market conditions, which are typically characterized by volatility and turbulence, and unpredictable demand. To cope with such instability, several companies have adopted agile supply chain practices in respond to the unique needs of customers and markets. For instance by Baker (2008), Argos, a unique retailer sells general merchandise and products for the home over 700 stores throughout the UK and Republic of Ireland, online, and over the telephone. The company has experienced rapid growth, five distribution centers were opened and one closed, adding a net 1.3 million ft2 (121,000 m2) to the warehousing capacity within a three-year period. Besides the peak season throughput of Argos is about three times above the average level for the year; Avon cosmetics in Europe faces a further challenge in quantities ordered with more case picking now needed from the largely narrow aisle pallet store; And a global drinks company produces a wide range of alcoholic drinks with many global brands in UK. A key challenge for the company is handling of the seasonal peak when about 60% of the annual volume is dispatched within a three-month period. The changing conditions of competition and market turbulence require organizations to become increasingly responsive to customer needs. Hence, the increased urgency of the search for agility exists and the importance of agility be recognized.

Generally, in an agile supply chain, manufactures search globally for cheap, quick, and flexible manufacturing. However, such agile manufacturing operations also create new demands and challenges for the transport logistics and distribution. Notably, distribution is critical to process of supply chain, and links an entire organization with its inbound and outbound suppliers and the market in which it operates (Arif *et al.*, 2009). Additionally, efficient distribution is critical to successful supply chain management as it involves transport multiplicities, in the forms of path, time, place, and quantity across the chain. Transport multiplicity implies that transportation modes are diverse varieties. When international trade increases as global manufacturing expands, various transportation modes are needed. Global distribution typically involves overseas and domestic transportation. Overseas transportation usually comprises air and sea modes, whereas domestic transportation is via rail, trucks, air and river mode. Delivering products worldwide may be complex due to the need to utilize multiple modes and routes. Moreover, both a shorter planning horizon and increasing transportation costs extensively disturb the product distribution management (Mentzer *et al.*, 2004). Goetschalckx *et al.* (2002) further observed that managers are concerned with transportation modes and routes o increase the efficiency of product distribution. Therefore, enterprises must determine the appropriate modes and routes when dealing with transport multiplicity.

Superior service and strengthening customer satisfaction are important goals for physical distribution providers. A distribution system providing reliable service reduces supply chain uncertainty and the amount of inventory required throughout a supply chain (Korneliussen and Grønhaug, 2003). Hence, it is essential for planning and service provider in the transport logistics and physical distribution industry to respond appropriately to evolving dramatically market changes in a timely manner. Thus, in a global marketplace, distribution system must make good use of resources, such as warehousing, freight transportation, inventory control, order processing, intermodalism, market forecasted and customer service, to achieve a rapid changing flow of goods through an agile supply chain. The operating efficiency of a company can depend on how well distribution nodes are interconnected. Particularly as regards in rapid growth, it will become increasingly difficult as flows move forward due to congested distribution or the limited capacity of warehouses, ports, and rail (Maskell, 2001). It has responded by pooling resources to establish an outbound distribution system with higher performance efficiency. Therefore, distribution resource planning (DRP) has a critical role in agile supply chain. Companies require adaptable and flexible distribution to achieve responsiveness in volatile markets. However, few studies have examined the precise role of distribution within agile supply chain. Most studies address the concept of agile supply chain, and applied qualifying methods or statistics analyses. Therefore, this study examines how organizations operate their outbound distribution into modeling with emphasis on uncertain transport environment, in order to provide an appropriate and prompt response within an agile supply chain. Furthermore, the proposed model takes into consideration from operational perspectives, reflecting a dynamic, changing, and unpredictable transportation environment.

1.2 Research objectives

As mentioned, this study focuses on the outbound distribution within agile supply chain for distribution to be agile in the true sense of the world. The goals of agile supply chain are to achieve speed-to-market, adaptability, flexibility, and respond and react rapidly and effectively to customer demand and changing markets while keeping cost at a minimum level. To attain these goals and support market responsiveness, distribution resources, such as inventory, capacity, lead time, transshipment, and international intermodal route selection, must be integrated at the operational level. However, few studies have investigated global distribution approaches for agile supply chains to provide flexible distribution guidance for decision-makers who can then effectively respond to dynamic globalized marketplaces. This study proposes an adaptable distribution model for agile supply chain that reflects agility properties and explores how to incorporate resources to meet particular requirements of an outbound distribution system. Specifically, the purposes and contributions of this study are as follows.

1. This study constructs a flexible and adaptable distribution model within agile supply chain, in order to quantify and measure the benefits of agility using numerical or quantitative methods rather than qualify or conceptual management methods. Several authors (Christopher, 2000; Maskell, 2001; Huang *et al.*, 2002; Khan *et al.*, 2009; Huang *et al.*, 2008) have compared agile supply chains with lean manufacturing or conventional supply chains. Most studies focus to delineate the management of agility or are linked to

manufacturing only. However, outbound distribution is as critical as manufacturing is. There has been little research performed to develop a quantitative model that simultaneously considers outbound distribution as a tool or strategy supporting agile supply chains. Explore adaptable distribution in response to market turbulent and volatile with particular emphasis on transportation environment uncertainties is important.

2. This study explores how transportation resources behave or respond to different conditions within an agile supply chain. The dominant characteristic of agility is examined by assuming that diverse transportation modes and paths are the main ways to achieve agile distribution in changing environments. Moreover, the results of the proposed model vary theoretically over time in responding to different situations. Furthermore, the responsiveness framework in the proposed model is based on adaptable distribution, which is composed of low cost, time, congestion, and third place distribution principles to respond under classical agile environments, involving out of stock and mode capacity limitations, urgent orders, and specific node or link lost their functions.

3. In this study, the adaptable distribution within an agile supply chain problem is analyzed from the operational perspective, that is, by considering the dominant characteristic or resources related to an agile distribution system. Integrating and coordinating resources ensure efficient and effective supply chain management with sustainable competitive competencies. The proposed model

incorporates different resources in a distribution system rather than individual resources, such as randomly generated demand, stochastic transportation lead time, transportation, inventory and handling costs, capacity, exchange rates in different countries, and factors that are hard to quantify as flow congestions or encountered pirates, as the ability to respond to rapidly changing environments that change over time. Therefore, this study models the uncertainties existing in agile distribution and simultaneously supports decision-making within agile supply chain.

1.3 Research scope and approach

This study aims at developing an adaptable distribution model within agile supply chain for finished product, especially in the fast moving consumer electronics with short life cycle. These need for agility most apparently as new products are coming very fast and increasing at an astonishing level. According to the specific issues emphasized on transport environment uncertainties in outbound distribution, the products in the proposed model belong to finished goods at distribution centers preliminarily. The planning frame of this study focuses on operational perspectives of a globalized marketplace in views of short term. The research scope is shown as Figure 1.1.

In global distribution, the research scope represents both overseas and domestic transports. For domestic transport, the product can be delivered by single mode or intermodal, such as rail, truck, air, and river, from DCs through other DCs to demand areas or directly to demand areas, including wholesalers, retailers, and end customers; for overseas transport, the flows must be dispatched by rail or truck from DCs to internal air/sea ports in the beginning. Thus transport to the optimal abroad airport or seaport, and deliver directly to demand areas or through DCs. Once the best air/sea ports reaches the capacity limit or due to the policies restriction, the distribution can be substitute by the second air/sea ports, adjacent to the best or main port or other feasible ports, as the dotted lines shown in Figure 1.1.

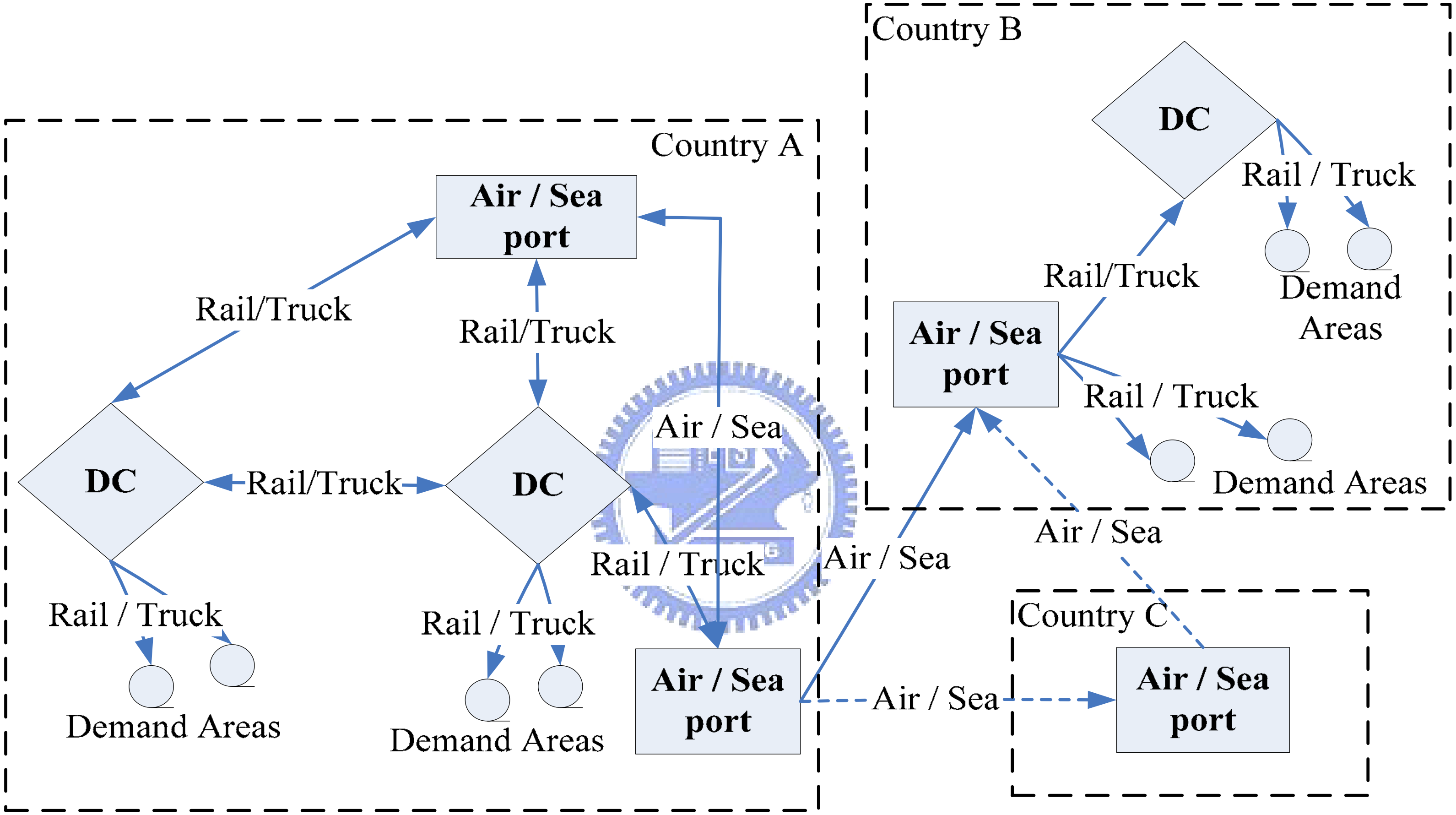

Figure 1.1 The outbound distribution network in a global market

In this study, the decision makers are assumed to be "third-party logistics (3PL)", the glue of companies, and they need to plan and manage the distribution operations. Considering the inherent nature of agile supply chain, the proposed model involves the changing conditions of each period with minimizing total enterprises operating cost. It is obvious that the problem is formulated in this study as a multi-modal, multi-paths and multi-period problem, using software Lingo to decide the optimal route selection, dispatching quantities, and intermodal transport for agile supply chain. The model features the adaptable transportation as main objectives with minimizing the total enterprises operating cost during the distribution planning stage.

1.4 Thesis framework

The framework and organization of this study is show in Figure 1.2. It depicts the content of the model and how to solve this problem. Chapter 1 illustrates the overview of this study in terms of motivation and background, objectives, scope and method, framework, and research flow. Chapter 2 reviews literatures in agile supply chain, distinguishing from the traditional supply chain, and relevant topic of uncertain transportation environment. Chapter 3 presents an adaptable distribution model for agile supply chain with emphasis on transport environment uncertainty. The proposed model considers outbound distribution from operational perspectives, including intermodalism, capacity, inventory, lead time, modes and routes selection constraint, reflecting to an adaptability distribution involves the following four principles: (1) speedy distribution, (2) low cost distribution, (3) congestion distribution, and (4) third place distribution, which are described respectively as follow:

Principle 1: Speedy distribution

Speedy distribution means that products are promptly shipped between places. Under binding time limitations, products need to be delivered as soon as possible through the fastest mode which is available between origin and destination. Usually, not only domestic but also overseas distribution would adopt airline transport to fulfill customers' requirements.

Principle 2: Low cost distribution

Low cost distribution implies products are shipped using the cheapest method. If relaxed time constraint is allowed, products can be shipped by low cost modes. Kiesmüller *et al.* (2005) developed a model for quantifying the value of using an additional slow mode instead of only using the existing fast mode. Regarding Canada-Mexico shipments as an example, the route utilizing water modes costs 20 percent less than the route crossing via truck mode; however, the latter is two days faster (Bookbinder and Fox, 1998).

Principle 3: Congestion distribution

Congestion distribution indicates products are transported through unsaturated channels to avoid congesting transportation capacity. Congestion has placed significant burdens on the transportation infrastructure in the face of increased global trade (Namboothiri and Erera, 2008). Once the best airport or seaport reaches the situation of capacity saturation, both speedy distribution and low cost distribution cannot be adopted by decision makers. Consequently, products need to be delivered through second best place, adjacent to the best (main) port. For example, products are transferred via Shanghai Pudong airport instead of Shanghai Hongqiao airport as the latter does not have enough capacity.

Principle 4: Third place distribution

Third place distribution means products are transferred via a third place (besides rational OD pair) owing to external policy considerations. For example, since direct cross-strait flights are prohibited between Taiwan and China, products are usually transferred through Hong Kong in actual practice. Another example is that products manufactured in China sometimes require export certification before domestic sale. Consequently, products are first be exported to the nearest offshore location (e.g., Hong Kong) and then re-imported to China.

A mixed integer nonlinear programming (MINLP) model is formulated to evaluate the adaptable and flexible distribution within a agile supply chain, and also determined the optimal route, intermodal transport, and product flows. Chapter 4 is focus on computational experiment and scenario analyses, solving the model through samples testing, LINGO software. Additionally, the analyses and discussions can be acquired through the results. In the last, chapter 5 makes conclusions and suggestion in the future research. Furthermore, the research process and step are shown in Figure 1.2.

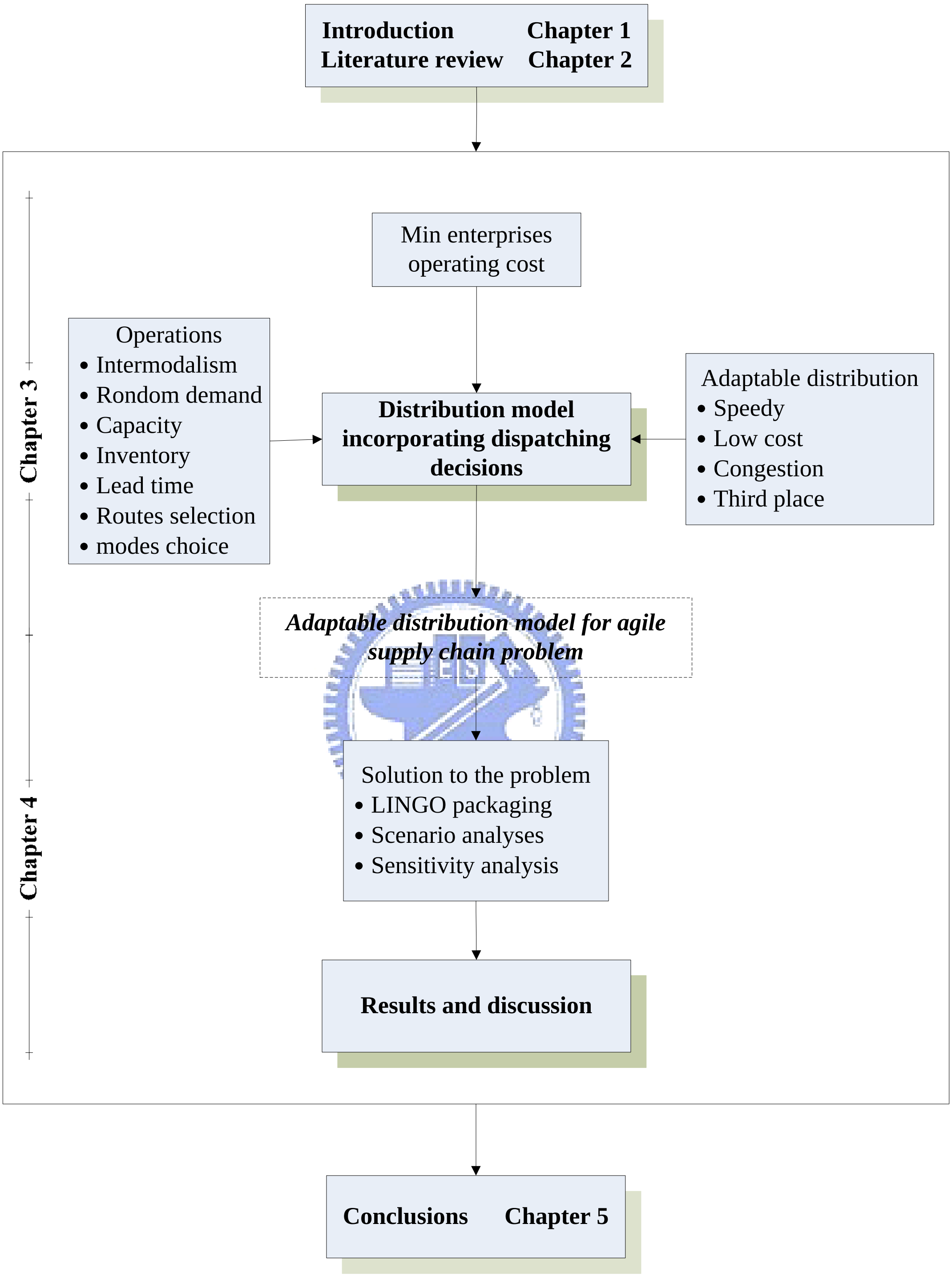

Figure 1.2 The framework of the study

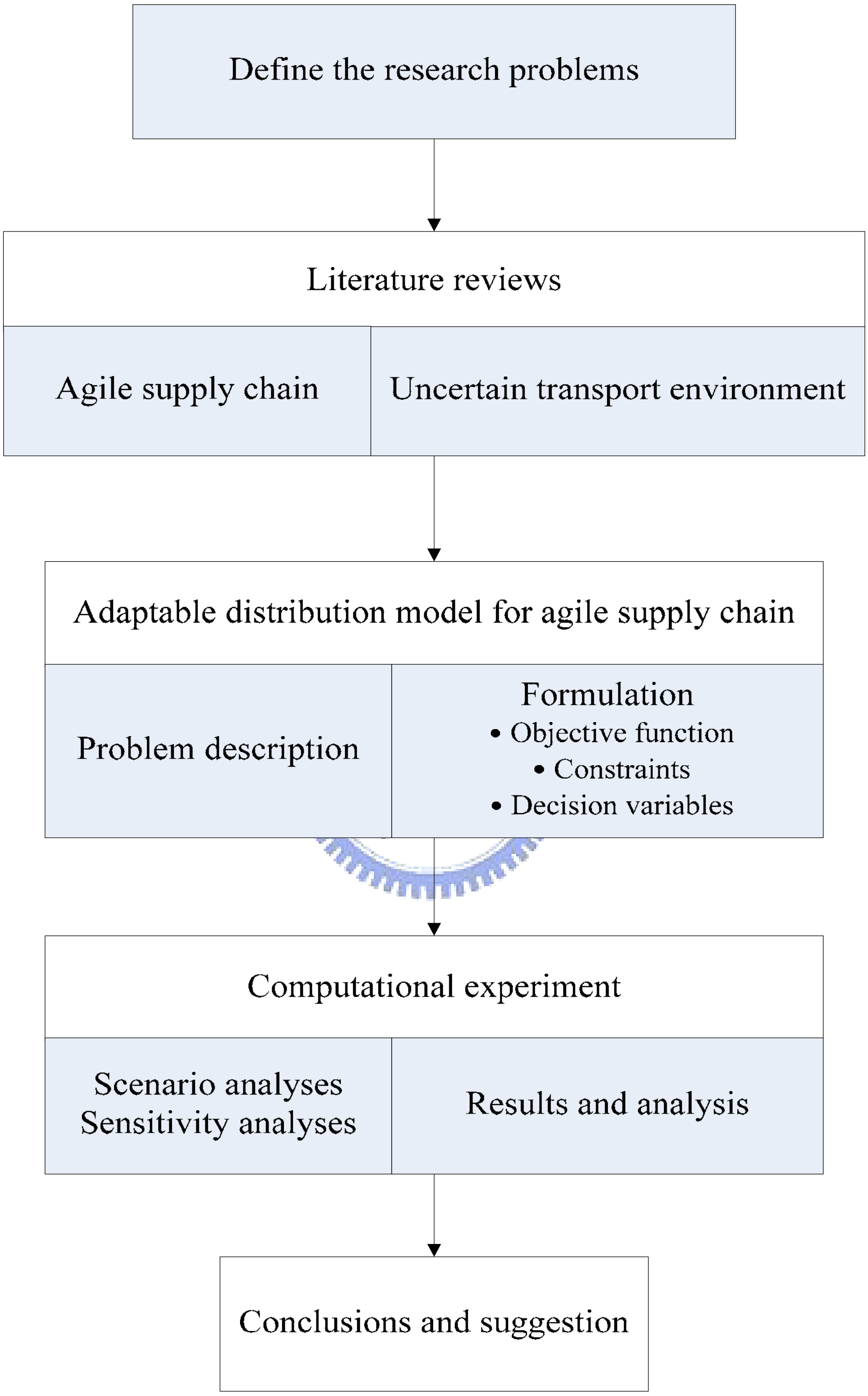

Figure 1.3 The research process flow chart

Chapter 2 Literature review

This chapter reviews the literature on related issues including: 2.1 Agile supply chain concept; 2.2 Uncertain transport environment; and 2.3 Summary.

2.1 Agile supply chain concept

Since the introduction of the term “supply chain management” (SCM) in 1982, it has received a lot of interests both in the literature and practice. According to Stevens (1989), a supply chain is a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via a feed-forward flow of materials and feedback flow of information. Therefore, an agile supply chain as implied by the name, combining the agility component into supply chain management together, in order to respond the dynamic business markets.

The definition of agility is a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets (Christopher, 2000). Sharp *et al*. (1999) identified that agility might be defined as the ability of a supply chain to rapidly respond to changes in market and customer demands. Furthermore, Maskell (2001) addressed that agility is the ability to thrive and prosper in an environment of constant and unpredictable change. Indeed, the origin of agility concept lies in flexible manufacturing systems (FMS), or called agile manufacturing. FMS to achieve quick response and agile manufacturing at low cost, and effective Supply Chain Management (SCM) mechanisms to deliver products quickly with low inventories can all be regarded as responses to these new competitive pressures (Erenguc *et al.*, 1999).

Initially, the route to manufacturing flexibility was through automation to enable rapid changes and a greater responsiveness to changes in product mix or volume. Here are some of the most common axioms of agile manufacturing:

1. Everything is changing very fast and unpredictably.
2. The market requires low volume, high quality, custom and specific products.
3. These products have very short life-cycles and very short development and production lead times are required.
4. Customers want to be treated as individuals – mass production is moribund.

Nevertheless, several authors explored the difference between agile manufacturing and lean manufacturing to emphasis the specialized of agility. Naylor *et al*. (1999) identified two definitions related the agile and lean manufacturing paradigms to supply chain strategies.

> Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a *volatile* market place; Leanness means developing a value stream to eliminate all waste, including time, and to ensure a *level* schedule.

Companies that have adopted lean manufacturing as a business practice are anything but agile in their supply chain. The origins of lean manufacturing can be traced to the Toyota Production System (TPS), with focus on the reduction and elimination of excess, waste and unevenness in the supply chain (Ohno, 1988). The problems arise as Toyota lean philosophy is implanted into situations where demand is volatile. While leanness may be a component of agility in certain circumstances, where demand is predictable and the requirement for variety is low, by itself it will not enable the business to meet the precise needs of the customer more rapidly.

The distinctions of agility and leanness can be diagrammatically represented in the demand volume-product variety/variability matrix in Figure 2.1. The dominant dimensions are variety, variability (or predictability) and volume determine. “Agility” is needed in less predictable environments where demand is volatile and the requirement for variety is high; “Lean” works best in high volume, low variety and predictable environments (Stratton and Yusuf, 2000).

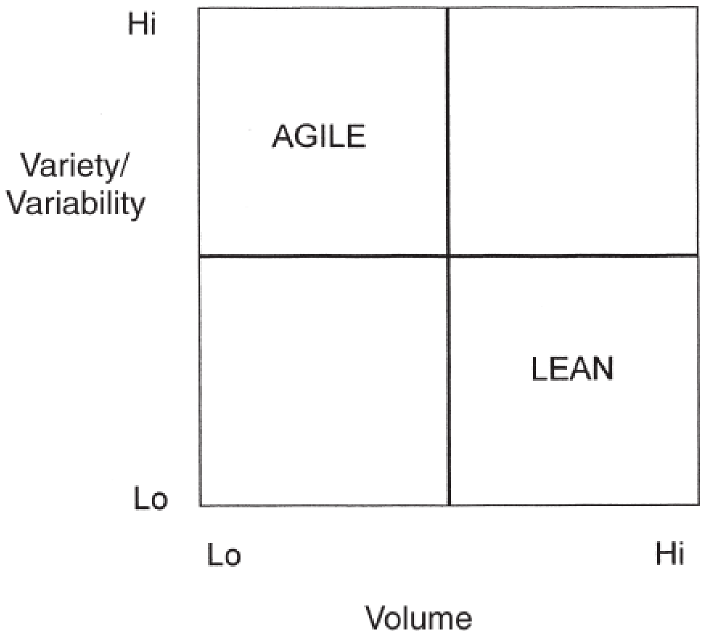

Figure 2.1 Applications of lean and agile

Source: Stratton and Yusuf (2000)

Whereas, with lean the focus is on eliminating waste and achieving low cost delivery of a standard and stable product, the agile paradigm focuses on the need to deliver a variety of products with uncertain demand. Table 2.1 and 2.2 compare the differences of lean and agile supply chain by Mason-Jones *et al.* (2002) and Huang *et al.* (2002) respectively. The former typifies the distinguishing attributes of the associated supply chain. The later is characterized of lean and agile supply chain into sub-categories as purpose, approach to choosing suppliers, inventory strategy, lead time focus, manufacturing focus, and product design strategy, are summarized as shown in Table 2.2.

Table 2.1 Comparison of lean supply: The distinguishing attributes

Distinguishing attributes	Lean supply	Agile supply
Typical product	Commodities	Fashion goods
Market placed demand	Stable	Unstable
Product variety	Low	High
Product life cycle	Long	Short
Mfg task	Low cost	Delivery speed
Delivery penalties	Long term contractual	Loss of order
Purchasing policy	Product specific	Assign capacity
Information enrichment	Desirable	Important

Source: Mason-Jones *et al*. (2002) modified.

Table 2.2 A comparison of lean and agile supply chain

Category	Lean supply chain	Agile supply chain
Purpose	Focus on cost reduction, flexibility and incremental improvements for already available products Employs a continuous improvement process to focus on the elimination of waste or non-value added activities across the chain	Understand customer requirements by interfacing with the market and being adaptable to future changes Aims to produce in any volume and deliver into a wide variety of market niches simultaneously Provides customized products at short lead times (responsiveness), by reducing the cost of variety
Approach to choosing suppliers	Supplier attributes involve low cost and high quality	Supplier attributes involve speed, flexibility, and quality
Inventory strategy	Generates high turns and minimizes inventory throughout the chain	Deploys significant stocks of parts to tide over unpredictable market requirements
Lead time focus	Shorten lead-time as long as it does not increase cost	Invest aggressively in ways to reduce lead times
Manufacturing focus	Maintain high average utilization rate	Deploy excess buffer capacity to ensure that raw material/components are available to manufacture the product according to market requirement
Product design strategy	Maximize performance and minimize cost	Use modular design in order to postpone product differentiation for as long as possible

Source: Huang *et al*. (2002)

However, lean operations depend on level scheduling and the growing need to accommodate variety and demand uncertainty has resulted in the emergence of the concept of agility (Stratton *et al*., 2003). Later, this idea of manufacturing flexibility or lean manufacturing was extended into the wider business context or the whole supply chain and the concept of agility as an organizational orientation was born. According to Lin *et al*. (2006) mentioned, agile supply chain forges legally separate but operationally interdependent companies such as suppliers, designers, manufacturers, distribution services, etc. linked via a feedforward flow of materials and feedback flow of information. The drivers of agility or the business environment is change. Although not new, variation is occurring faster than previously. Therefore, an agile supply chain requires various distinguishing capabilities or fitness, such as responsiveness, competency, flexibility/adaptability, and quickness/speed. Furthermore, the author has modified a conceptual model for agile supply chain base on a review of literature, as shown in Figure 2.2.

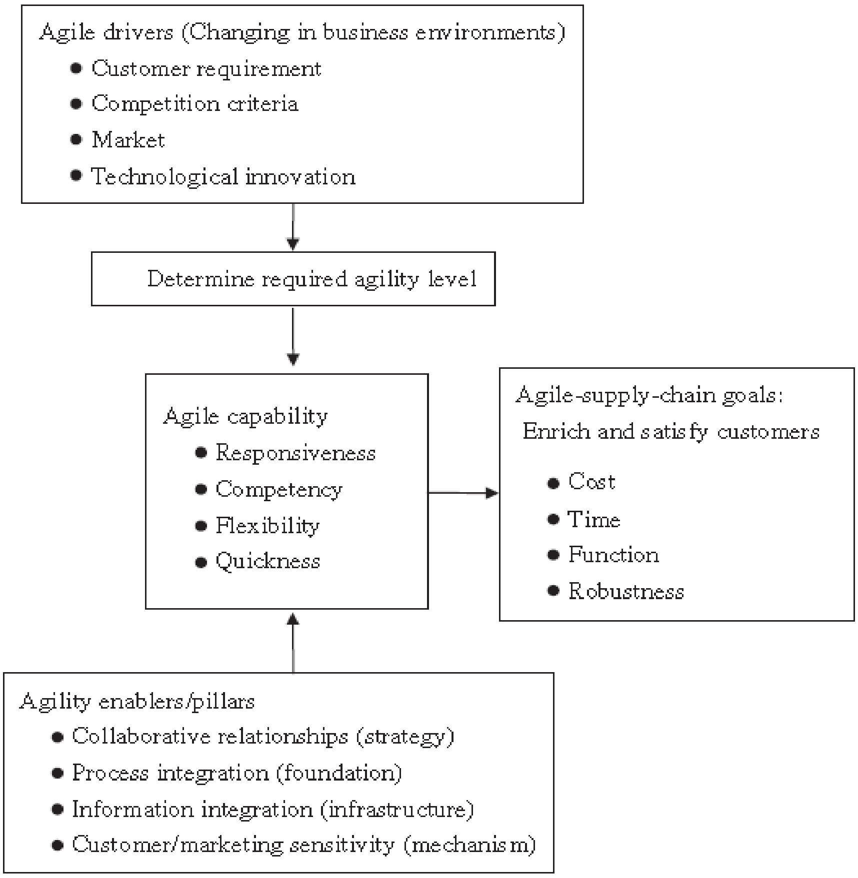

Figure 2.2 Conceptual model of agile supply chain
Source: C.-T. Lin *et al*. (2006)

As supply chains are becoming more customer orientation and also become less static. Agile supply chain has the ability to thrive and prosper in a turbulent environment. Danuta *et al*. (2009) also pointed out that the agility concept is widely adopted to the area of contemporary business. Companies have realized that agility is essential for their survival and competitiveness. Agile supply chain has been advocated as the 21st century supply paradigm, and is seen as a winning strategy for companies wishing to become national and international leaders (Yusuf *et al*., 1999). Table 2.3 summarizes main issues and results in literature on agile supply chain.

Table 2.3 Main issues and results in literature on agile supply chain

Authors	Main issues	Important results
Christopher (2000), Maskell (2001), Huang *et al.* (2002),	Investigate the different between lean and agile manufacturing	Define the dominant characteristic of lean and agile supply chain, including product types, volume, variety and variability etc.
Naylor *et al.* (1999), Perry *et al.* (1999), Baker (2008), Danuta *et al.*(2009), Stratton *et al.* (2003), Swafford *et al.* (2006)	Examine empirical cases about how they operate within agile supply chain	The competencies of companies are critical to responsive and react the volatile and turbulent business environment
Lin *et al.* (2006)	Develop a fuzzy agility index (FAI) based on agility providers using fuzzy logic	The evaluation demonstrates the this method can provide analysts with more reliable information for decision
Giachetti *et al.* (2003)	A measurement framework to analyze measures of structural properties of the enterprise system	The measurement framework empower system designers to better incorporate desirable structural properties to align system design with enterprise strategy
Yusuf *et al.* (2004)	Discuss the nature of an agile supply chain and explore some of its attributes and capabilities	The lean supply chain has higher level of impact on competitive objectives in contrast to the agile supply chain

Source: this study

Summary:

An agile enterprise is a fast moving, adaptable and robust business. It is capable of rapid adaptation in response to unexpected and unpredicted changes and events, market opportunities, and customer requirements (Kidd, 2000). According to SCOR model (Supply Chain Council, 2004), the agile supply chain is divided into three parts, procurement/sourcing flexibility, manufacturing flexibility, and distribution/logistics flexibility. However, this study focuses on the distribution/ logistics flexibility, exploring more detail from operational perspectives. Distribution and logistics flexibility enables a firm to adapt its delivery schedules to unpredictable or rapidly changing customer requirements, thus providing the potential for gaining competitive advantage based on delivery performance (Swafford *et al*., 2006). A business exhibiting distribution flexibility achieves higher levels of efficiency within agile supply chain. Nevertheless, there has very little research on distribution flexibility, most separately exploring the capability rather than combining all into one model. Distribution and logistics is also critical for agile supply chain.

2.2 Uncertain transport environment

With a shorter planning horizon and an overall objective of minimizing enterprises costs, transportation has become a critical component in the distribution process (Tyan *et al*., 2003). Globalization force companies to redesign or manage their supply chain efficiently whereas transportation and logistics are drivers in world trade. Global transportation uncertainties are dramatically rising in light of volatile demand and international logistics. In literature of supply chain management, there are lots of studies that have conducted the role of transportation and logistics operations within a supply chain. Vidal and Goetschalckx (2000) model the effect of uncertainties on global logistics systems at international level, including exchange rate fluctuation, stochastic demand, political instability, variable transportation lead time and market prices with the objective of minimizing supply chain costs that include procurement, production, transportation and fixed plant and inventory costs. Das and Sengupta (2009) studied the global and multinational companies are subject to government regulation in addition to other international uncertainties due to operation in diverse geographic locations. The paper presents an integrated model for simultaneous strategic and operational planning in a global supply chain affected by government regulations. At operational level, the proposed model assesses customer demand and transportation time uncertainties to aid decisions regarding production, the transportation and distribution of products and safety stock issues.

Factors such as exchange rates, volatile demand, government regulations, variable transportation time and cost, and capacity are taking into consideration as transport uncertainties with particular emphasis on transport modes and the transportation channels to use. This view is strengthened by Punakivi and Hinkka (2006), taking the selection criteria of transportation modes from the four Finnish industrial points as the main research problem. Based on the results, high value, short life cycles and worldwide market are typical to use rapid modes of transport. Cullinane and Toy (2000) adapt the Stated Preference (SP) techniques to identify the major influential attributes in freight route/ mode choice, including transit time reliability, speed, cost, and loss/damage.

Jong *et al*. (2004) contain a review of the literature on freight transport models for forecasting, policy simulation and project evaluation at the national and international levels. Haughton (2007) models situation in which random day-to-day demands complicate decisions made by managers of vehicle routing/dispatch operations. The paper proposes a rule by trying to maximize the likelihood that each customer will continue to be served by the driver who is most familiar with that customer.

Li *et al*. (2008) present a coordinated scheduling problem of parallel machine assembly manufacturing and multi-destination transportation in consumer electronics supply chain by dividing into two sub-problem, to respond the shorten time from order receipt to delivery and improve on-time delivery accuracy. The proposed model determines the appropriate allocation of orders to available vehicle capacities and the schedule of assembly manufacturing by two heuristic algorithms to solve the problem.

Motivated by observing the chemical industries, Kiesmüller *et al.* (2005) presented a dual supply model taking into account that the replenishment cycle involves not only the physical distribution of goods, but also the manufacturing of products. This study also investigated a class of order-up-to policies and showed how to compute the optimal policy parameters. The results showed that especially in cases where the manufacturing lead time is long and the difference in cost between fast and slow modes is big and the lead time difference is large, the added value of including the manufacturing lead time for the model is substantial. In industries such as the chemical industry using the models would imply a dramatic shift from road transport to rail or barge transport.

Additionally, Eskigun *et al.* (2005) design an outbound supply chain network considering lead times, location and capacitated of vehicle distribution facilities, and the choice of transportation mode in the automotive industry. A Lagrangian heuristic is conducted to solve the integer linear programming (ILP) problem. Results of the scenario analyses indicate that as the lead-time gains importance, the use of trucks increases significantly to deliver the vehicle directly from plants to demand areas in shorter lead-time. In addition, this study also determines the vehicles delivery directly to demand areas or through a distribution center, based on domestic intermodal transportation and route selection. Chang (2008) extends to international intermodal routing, which consider three important characteristics: (1) multiple objectives; (2) scheduled transportation modes and demanded delivery times; and (3) transportation economies of scale. The study formulates a multi-objective multi-modal multi-commodity flow problem (MMMFP) with time windows and concave costs and develops a heuristic algorithm base on relaxation and decomposition techniques.

As mentioned above, intermodal freight transport has developed into a significant part of transport industry in its own. It reflects the combination of at least two modes of transport in a single transport chain. Several authors have explored about the intermodal transportation related issues. Bookbinder and Fox (1998) obtain the optimal routings for intermodal containerized transport from Canada to Mexico. Each link employs available intermodal services with given its transit time and transportation cost. A shortest path algorithm enables calculation of the route requiring least time and the route of minimum cost. The results show the non-dominated time/cost tradeoff relationship. Macharis and Bontekoning (2004) review related operational research literatures and point out mostly works are focus on single modal transportation problem. They also argue the intermodal freight transportation is emerging as a new transportation research application field.

Woxenius (2007) described six principles for design of transport systems, including direct link, corridor, hub-and-spoke, connected hubs, static routes, and dynamic routes. The theory is then applied to intermodal freight transport by comparing the terminology from the perspectives of researchers, commercial operators and policy-makers. Groothedde *et al.* (2005) take into account the tendency of globalization of industries, small shipments sizes, high frequencies, and the fragmentation of flows. This study models the collaborative, intermodal hub networks with shifting consolidated flows to modes to synchronization between expensive but fast and flexible means of transport and inexpensive, but slow and inflexible means through collaboration. The resulting methodology is explained through presenting the results of the design and implementation of collaborative hub network for the distribution of fast moving consumer goods using a combination of trucking and inland barges. Table 2.4 summarizes main issues and results in literature on uncertain transport environment.

Summary:

Past literatures have demonstrated the importance of logistics and transportation on the efficiency of a supply chain. Moreover, global transportation environment uncertainties are dramatically rising in light of volatile demand and international logistics with time shifting. Regarding to the uncertain factors, such as transport modes choices/intermodal, paths/ routes selection, variable transit cost and time, demand fluctuation, facility capacity, exchange rate between each country, and government regulations, have been investigated as emerging research topics and applications. However, these transport uncertainties are only explored partially or as conceptual issues in recent research, not considered as the main problem on the distribution model.

Table 2.4 Main issues and results in literature on uncertain transport environment

Authors	Main issues	Important results
Goetschalckx (2000)	Modeling the effect of uncertainties on global logistics systems	The proposed model demonstrates the effect of uncertainties is significant that may differ with small changes in some parameters.
Das and Sengupta (2009)	Global companies are subject to government regulations in addition to other international uncertainties due to operation in diverse geographic locations.	The results show that the decision makers must aim at optimal redeployment of available capacity if government regulations lead to changes in the cost of input resources.
Punakivi and Hinkka (2006), Cullinane and Toy (2000), Jong *et al.* (2004)	Taking into consideration of mode choices and route selections as important issues on distribution.	The influential factors include transit time, cost, reliability, and types of dispatched products.
Haughton (2007), Li *et al.* (2008), Kiesmüller *et al.* (2005)	Modeling situations in random demand, scheduling problem of manufacturing and transportation, and replenishment cycle.	The results of the difference in cost and transportation time between fast and slow modes, available vehicle capacities, and demand will affect the total benefit and the route/mode choices.
Eskigun *et al.* (2005), Chang (2008)	Design outbound supply chain networks based on domestic and international intermodal problem.	The models reflect multiple objectives, delivery lead times, transportation modes, locations, capacity, and transportation economies of scale that are considering into intermodal problem.

Authors	Main issues	Important results
Bookbinder and Fox (1998), Macharis and Bontekoning (2004), Woxenius (2007)	Exploring the intermodal problem with optimal routing transport, operational research method, and different route networks.	Intermodal freight transportation is emerging as a new transportation research application field in recent years.
Groothedde *et al*. (2005)	Modeling the collaborative, intermodal networks with shifting flows and modes to synchronization between expensive but fast and flexible of transport and inexpensive, but slow and inflexible means through collaboration.	The resulting methodology is explained through presenting the results of the design and implementation of collaborative hub network for the distribution of fast moving consumer goods using a combination of trucking and inland barges.

Source: this study

2.3 Summary

This study divides literature reviews into two parts: agile supply chain and uncertain transport environment. First, the concept of “supply chain agility” is means the changing conditions of competition and increasing levels of environmental turbulence and requirement for companies to become more responsive to the needs of customers (Khan K *et al.*, 2009). What it really means for a company to be agile, it’s the ability to respond to the marketplace uncertainty while flexibility performance reflects value addition as the firm’s ability to respond. Agile supply chains are capable of rapid adaptation in response to both expected and unpredicted situations and achieving competitive performance in a highly dynamic business environment. In a bid to cope with market instability, the past literatures show that several companies have adopted agile supply chain into their operations. However, most studies are related to agile manufacturing while agile distribution also plays an interconnected role between inbound and outbound suppliers and customers. Agile supply chain distribution enhances organizational performance and makes the operations more efficiency. Developing a flexible and adaptable distribution conducts by using and planning distribution resources, including transportation modes, route selections, transit time, government regulations, and so on.

The second part explores the uncertain transport environment. An agile distribution contains diversity transport environment and is capable to use those resources to respond promptly. Past literatures take into account the influential attributions in relation to the transportation or logistic environment, such decisions factors as modes choice, intermodal transport, path/ route selection, variable transport cost and time, volatile demands, facility capacities, exchange rates, and government regulations. Flexible distribution is critical as it involves lots of uncertainties within agile supply chain. From the viewpoint of being agility, the distribution must reflect the dynamic transport environment and respond appropriately to the changing conditions. Although this issue has been addressed as an oncoming challenge, there is no currently mathematical model for agile distribution with particular emphasis on transport uncertainties. Therefore, this study aims to develop an agile distribution model for handling the dynamic and uncertain transport environment, and determine the flexible optimal solution with different situations.

Chapter 3 An adaptable distribution model

This chapter developed a MINLP model which attempted to minimize the total enterprising cost of delivery products subject to constraints satisfying all kinds of conditions in different time periods, such as random demands in various geographic countries, inventory relationship between supply flows and demand flows along with time periods, lead time limitation of orders, capacity of facilities and modes, limitation of routes selection. The impacts of changing conditions in accordance with time periods are also presented in the proposed model to achieve the “agility” property. Hence, this chapter is divided into three parts, including 3.1 Problem statement; 3.2 Model formulation; and 3.3 Summary.

3.1 Problem statement

The adaptable distribution provides more than one single available transportation mode and path in the view of decision makers within the planning period or cutoff time, the time that companies stop receiving customer orders. In this study, a hypothetically constructed multi-modes, multi-paths, and multi-period intermodal distribution planning problem is dealt with. Therefore, products in the distribution centers (DCs) are delivered directly to demand areas or through air/sea ports via one of two basic modes in each link. As Figure 3.1 shows, the outbound distribution network consists of a third-part logistic (3PL) considering multiple DCs, ports, and demand areas (wholesalers, retailers, and end customers) in different countries of globalized marketplace along with time periods.

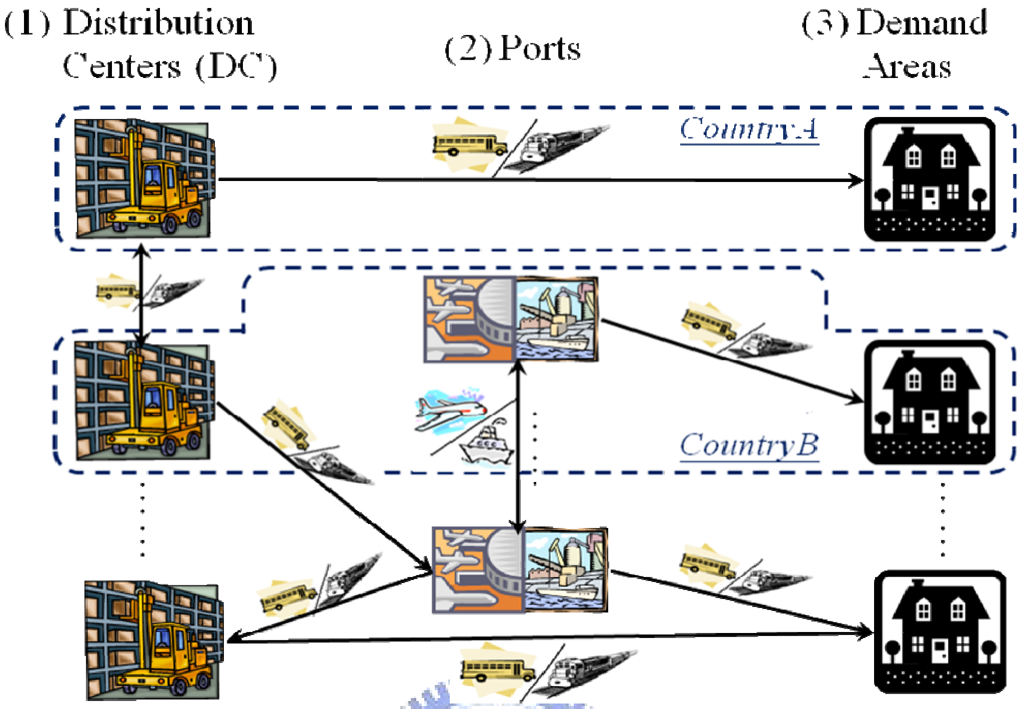

Figure 3.1 The outbound distribution network

In the proposed model, all the available alternatives and basic conditions are giving into the network planning, such as demand, capacity, location, and different costs of each node and link. In order to specify the research scope and facilitate model formulation in the network model of an adaptable distribution within agile supply chain, four assumptions are postulated in the following:

(1) The locations of DCs and air/sea ports are known and existed.

(2) There is no inventory happened at any port, but considering inventory operations at each DC and into transportation time.

(3) Only the single-product condition is involved in the proposed model to facilitate model formulation because different products may

require specific operations in agile supply chain.

(4) The time-varying quantity of product demands is randomly given to meet the unpredictable demands situation.

Moreover, decision makers in agile distribution system under concern aim to make the following decisions or research questions for the adaptable distribution problem for agile supply chain.

(1) How much is the product flow of each link in each planning period?

(2) How should the product be delivered to demand areas directly or through ports or other DCs, via intermodal transportation or single mode in each planning period?

(3) What should the amount of inventory at each DCs to be maintained in each planning period?

3.2 Model formulation

In this section, the adaptable distribution problem for agile supply chain is formulated as a MINLP model that address the decision problems defined in the previous section.

3.2.1 Notations and definitions

First, the sets, parameters and decision variables are defined below.

Sets

$K =$ Set of demand areas, indexed by k.
$W =$ Set of DCs, indexed by w.
$P =$ Set of Ports, indexed by p.
$M =$ Set of transportation modes, indexed by m.
$M(i, j) =$ Set of available transportation modes from node i to node j;
$i \in W \cup P;\ j \in W \cup P \cup K;\ m \in M;\ i \neq j.$
$T =$ Set of time period, indexed by t.

Parameters

With the consideration of being agile, the exogenous variables should reflect the dynamic and changing situations of the transport environment. As a consequence, this study makes the factors, demand is randomly generated and transportation time fits stochastic. Rest of parameters involve exchange rate, to present the global supply chain in different countries, costs of handling, inventory, transportation, capacity , lead time and time value. Details are defined as the following:

D_{jt} = Demand of finished product at node j in t period; $j \in K;\ t \in T$.

E_{it} = Exchange rate of node i in t period; $i \in W \cup P \cup K;\ t \in T$.

HC_{it} = Unit handling cost of finished product at node i in t period; $i \in W \cup P;\ t \in T$.

$CINV_{it}$ = Unit inventory cost at node i in t period; $i \in W \cup P;\ t \in T$.

TC_{ijmt} = Unit transportation cost of finished products shipped from node i to node j, using transportation mode m in t period; $i \in W \cup P$; $j \in W \cup P \cup K;\ m \in M;\ t \in T;\ i \neq j$.

CAP_{jt} = Capacity of node j for finished product in t period; $i \in W \cup P;\ t \in T$.

CAP_{ijmt} = Capacity of mode m for finished product from node i to node j in t period; $i \in W \cup P$; $j \in W \cup P \cup K;\ m \in M;\ t \in T;\ i \neq j$.

LT_{jt} = Lead time of each node j in t period; $j \in K;\ t \in T$.

TTV_{jt} = Time value of node j given in \$/unit of time; $j \in W \cup P \cup K;\ t \in T$.

Besides, this study also considers some factors that are hard to quantify, such as the chance for transportation to meet congestion or encountered pirates. Once the situation exists, it will affect the transportation time or cost of using specific modes during the distribution process. Therefore, this model adds parameters of Z_{ijmt}, which follows the normal distribution, and penalty of transportation cost and time as presented below.

$$Z_{ijmt} = \begin{cases} 1 & \text{if link from node } i \text{ to node } j \text{ using transportation mode } m \text{ in } t \text{ period,} \\ & \text{happen the events, such as reaching the congestion or pirates ;} \\ & i \in W \cup P;\ j \in W \cup P \cup K;\ m \in M;\ t \in T;\ i \neq j. \\ 0 & \text{otherwise} \end{cases}$$

$\overline{TC}_{ijmt}$ = The penalty of transportation cost to incurred from node i to node j, using transportation mode m in t period while Z_{ijmt} equal to 1.

$\overline{TT}_{ijmt}$ = The penalty of transportation average time to incurred from node i to node j, using transportation mode m in t period while Z_{ijmt} equal to 1.

As to transportation lead time, in light of Vidal and Goetschalckx

(2000), is based on the relationship of transportation lead time and inventory. Cateora (1996), for example, states that the correct selection of transportation modes requires viewing distribution as an integrated system. He presents a real case where air transport is cheaper to use than ocean transport because of the higher safety stock kept by the company to respond to the higher absolute variability of lead time that characterizes ocean transport. Therefore, the parameter of transportation lead time is composed of cycle stock, safety stock, shipment inter-arrival time, expected lead time, and the coefficient of variation of lead time. Besides, many authors have also applied the gamma distribution for modeling inventory problems and stochastic lead times (Yeh, 1997; Tyworth *et al.*, 1996; and Segerstedt, 1994).

In this proposed model, the transportation lead time is compared by three different distributions, namely, the exponential distribution for which the standard deviation is equal to the expected lead time, a particular case of the gamma distribution for which the standard deviation is equal to the square root of the expected value, and a general lead time distribution whose coefficient of variation (CV) can be estimated. Details are described and defined as the following:

TT_{ijmt} = Total average time to calculate transportation time value and inventory costs incurred from node i to node j, using transportation mode m in t period; $i \in W \cup P$; $j \in W \cup P \cup K$; $m \in M$; $t \in T; i \neq j$.

These coefficients are equal to the following expressions:

$TR_{ijmt} + (SIT_{ijmt}CSF) + SSF_{imt}TR_{ijmt}$ for exponential lead times;

$TR_{ijmt} + (SIT_{ijmt}CSF) + SSF_{imt}\sqrt{TR_{ijmt}}$ if the lead times can be modeled using a distribution whose expected value is equal to its variance; and

$TR_{ijmt} + (SIT_{ijmt}CSF) + SSF_{imt}\mathrm{CV}_{ijmt}TR_{ijmt}$ if the lead times follow any probabilistic distribution, whose coefficient of variation can be estimated.

CSF = Cycle stock factor in percentage.

CV_{ijmt} = the coefficient of variation of lead time from node i to node j, using transportation mode m in t period; $i \in W \cup P$; $j \in W \cup P \cup K$; $m \in M$; $t \in T; i \neq j$.

SIT_{ijmt} = Shipment inter-arrival time from node i to node j, using transportation mode m in t period; $i \in W \cup P$; $j \in W \cup P \cup K$; $m \in M$; $t \in T; i \neq j$.

SSF_{imt} = Safety stock factor kept at node i in t period; $i \in W \cup P$; $t \in T$.

TR_{ijmt} = Expect lead time from node i to node j, using transportation mode m in t period; $i \in W \cup P$; $j \in W \cup P \cup K$; $m \in M$; $t \in T; i \neq j$.

Decision variables

x_{ijmt} = Amout of finished products shipped from node i to node j, using transportation mode m in t period; $i \in W \cup P$; $\mathrm{j} \in W \cup P \cup K$; $m \in M$; $t \in T$; $i \neq j$.

$$y_{ijmt} = \begin{cases} 1 & \text{if products are shipped from node } i \text{ to node } j\text{, using transportation mode } m \text{ in } t \text{ period;} \\ & i \in W \cup P;\ \mathrm{j} \in W \cup P \cup K;\ m \in M;\ t \in T;\ i \neq j. \\ 0 & \text{otherwise} \end{cases}$$

$qinv_{it}$ = Amount of period inventory for product at node DC i in t period; $i \in W$; $t \in T$; $qinv_{i(t=0)}$ is given in t = 0 period.

3.2.2 The objective function and the constraints

As aforementioned, this study proposes a MINLP model that attempts to minimize the total enterprising cost of delivery products. In such agile environment, firms may consider their distribution can be reflected flexibly and appropriately to the agile business circumstances. Therefore, the model formulation should be emphasized on the transportation uncertain environment within the agile supply chain. The description of the proposed model is summarized as Table 3.1.

Table 3.1 The description of model formulation

Model formulation	Description
Objective functions	Minimize total enterprising cost : (1)
Constraints	● Flow conservations : (2), (3), and (4)
	● Lead time linitations: (5)
	● Capacity limitations : (6) and (7)
	● Transportation mode limitation: (8)
	● Dispatching limitation to destinations: (9)
Decision variables	● Integer variables: (10) and (12)
	● Binary variables: (11)

(*): The constraint number which is stated as follow.

The objective function is attempted to minimize the total enterprising cost, including transportation cost, transportation time value and the penalty, handling cost, and inventory cost. Details are expressed as follows:

Minimize total enterprising cost

= Total transportation cost + Total transportation time value

+ Penalty of transportation cost + Penalty of transportation time value

+ Total handling cost + Total inventory cost

$$
\begin{aligned}
Min \sum_{i\in W\cup P}\sum_{j\in W\cup P\cup K}\sum_{m\in M}\sum_{t\in T}\left(\frac{1}{E_{jt}}\right) TC_{ijmt}\, x_{ijmt}\, y_{ijmt}(1-Z_{ijmt}) \; + \\
\sum_{i\in W\cup P}\sum_{j\in W\cup P\cup K}\sum_{m\in M}\sum_{t\in T}\left(\frac{1}{E_{jt}}\right) TT_{ijmt}\, TTV_{jt}\, x_{ijmt}\, y_{ijmt}(1-Z_{ijmt}) \; + \\
\sum_{i\in W\cup P}\sum_{j\in W\cup P\cup K}\sum_{m\in M}\sum_{t\in T}\left(\frac{1}{E_{jt}}\right) \overline{TC}_{ijmt}\, x_{ijmt}\, y_{ijmt}\, Z_{ijmt} \; + \\
\sum_{i\in W\cup P}\sum_{j\in W\cup P\cup K}\sum_{m\in M}\sum_{t\in T}\left(\frac{1}{E_{jt}}\right) \overline{TT}_{ijmt}\, TTV_{jt}\, x_{ijmt}\, y_{ijmt}\, Z_{ijmt} \; + \\
\sum_{i\in W\cup P}\sum_{j\in W\cup P\cup K}\sum_{m\in M}\sum_{t\in T}\left(\frac{1}{E_{jt}}\right) HC_{it}\, x_{ijmt}\, y_{ijmt} + \sum_{i\in W\cup P}\sum_{t\in T}\left(\frac{1}{E_{jt}}\right) CINV_{it}\, qinv_{it} \qquad (1)
\end{aligned}
$$

$$
\sum_{j\in W\cup P\cup K}\sum_{m\in M} x_{ijmt}\, y_{ijmt} \le qinv_{i(t-1)} \qquad \forall\, i,t\,;\; i\in W;\; t\in T;\; i\neq j. \qquad (2)
$$

Total delivery quantity in each DC per period is limited by available amount of inventory in last period for the supply side by constraint (2).

$$qinv_{i(t-1)} + \sum_{l\in W\cup P}\sum_{m\in M} x_{limt}\, y_{limt} - \sum_{j\in W\cup P\cup K}\sum_{m\in M} x_{ijmt}\, y_{ijmt} = qinv_{it}$$

$$\forall\, i,t\ ;\ i\in W\cup P;\ t\in T;\ i\neq j\neq l. \qquad (3)$$

Constraint (3) is the flow conservations for both DCs and ports. Total amount of product transported from node *l* to node *i* plus the inventory at node *i* in last period minus the flow transported from node *i* to node *j* that must equal to the amount of inventory at node *i* in *t* period.

$$\sum_{i\in W\cup P}\sum_{m\in M} x_{ijmt}\, y_{ijmt} = D_{jt} \qquad \forall\, j,t\ ;\ j\in K;\ t\in T;\ i\neq j. \qquad (4)$$

Constraint (4) states the demand satisfaction. The demand of each demand area must be satisfied in each period.

$$\sum_{i\in W\cup P}\sum_{j\in W\cup P}\sum_{m\in M} TT_{limt} x_{ijmt}\, y_{ijmt}(1-Z_{ijmt}) + \sum_{i\in W\cup P}\sum_{m\in M} TT_{ijmt} x_{ijmt}\, y_{ijmt}(1-Z_{ijmt}) +$$

$$\sum_{i\in W\cup P}\sum_{j\in W\cup P}\sum_{m\in M} \overline{TT}_{limt} x_{ijmt}\, y_{ijmt} Z_{ijmt} + \sum_{i\in W\cup P}\sum_{m\in M} \overline{TT}_{ijmt} x_{ijmt}\, y_{ijmt} Z_{ijmt} \leq LT_{jt}$$

$$\forall\, j,t\ ;\ j\in K;\ t\in T;\ i\neq j. \qquad (5)$$

Constraint (5) means the deliver distribution is subject to the lead time limitation. The planning dispatching route must be shipped within the lead time of each demand area in each planning period.

$$\sum_{i\in W\cup P}\sum_{m\in M} x_{ijmt}\, y_{ijmt} + qinv_{j(t-1)} \leq CAP_{jt}$$

$$\forall\, j,t;\ j\in W;\ t\in T;\ i\neq j. \qquad (6)$$

$$x_{ijmt}\, y_{ijmt} \leq CAP_{ijmt} \quad \forall i,j,m,t;\ i\in W\cup P;\ j\in W\cup P\cup K;\ m\in M;\ t\in T;\ i\neq j. \quad (7)$$

Constraint (6) and (7) limit the capacity of nodes and links respectively. The flows come into node j plus the inventory in last period must not exceed the capacity limit of node j, whereas the amounts of product dispatch from node i to node j, using transportation mode m, must not exceed the capacity limit of mode m on each link.

$$\sum_{m\in M} y_{ijmt} \le 1 \qquad \forall i, j, t;\ i\in W\cup P;\ \mathrm{j}\in W\cup P\cup K;\ t\in T;\ i\neq j. \tag{8}$$

Constraint (8) implies that each link is served by less than one transportation mode in each period. It is impossible for each link from node i to node j to use more than one mode at one time.

$$\sum_{i\in W\cup P}\ \sum_{m\in M} y_{ijmt} = 1 \qquad \forall j,t;\ \mathrm{j}\in K;\ t\in T;\ i\neq j. \tag{9}$$

Constraint (9) implies each demand area is served by only one link in each time period. It is impossible for each demand area to be served by more than one link.

$$x_{ijmt} \ge 0 \qquad \forall i, j,m,t;\ i\in W\cup P;\ \mathrm{j}\in W\cup P\cup K;\ m\in M;\ t\in T;\ i\neq j. \tag{10}$$

$$y_{ijmt} \in [0,1] \qquad \forall i, j,m,t;\ i\in W\cup P;\ \mathrm{j}\in W\cup P\cup K;\ m\in M;\ t\in T;\ i\neq j. \tag{11}$$

$$qinv_{it} \ge 0 \qquad \forall i,t;\ i\in W\cup P;\ t\in T. \tag{12}$$

Finally, the decision variables are x_{ijmt} and y_{ijmt}, which is a non-negative integer variable and binary variable respectively. $qinv_{it}$ is determined by decision variables as constraint (3). Constraint (10) and (12) enforce the non-negativity restrictions while constraint (11) is the binary restrictions on the decision variables.

3.3 Summary

Past studies have mostly constructed statistic or conceptual management model for agile supply chain. However, this study endeavors to develop an adaptable distribution model for agile supply chain with particular emphasis on transport environment uncertainties. Hence, this chapter builds a MINLP model with minimizing total operational enterprising cost, considering some operational factors related to dispatch circumstances as transportation modes, routes selection, customer demand, capacity of DCs and modes, inventory, transportation lead time, exchange rate between different countries, and the uncertain events. In order to reflect the changing and uncertain environment, the proposed model makes part of the exogenous variables as randomly generated demand, stochastic transportation lead time stochastic, and the chance of uncertain events as meeting congestion or encountered pirates that follow normal distribution.

In this study, the diversity transportation modes and paths, which become an intermodal distribution chain, are the main flexible way to respond appropriately to the turbulent and volatile transportation environment. Therefore, the decision variables in this study are two: x_{ijmt} and y_{ijmt}, the former variable is the amount of products shipping from node i to node j and using transportation mode m in t period; while the later variable is binary of products shipping from node i to node j and using transportation mode m in t period equal to 1, or otherwise to 0.

An adaptable distribution model for agile supply chain hypothetically constructs a multi-modes, multi-paths, and multi-period intermodal distribution planning problem to deal with in the viewpoint of third-party logistics. One of the special characteristics in the model is to formulate some risk factors in agile distribution, specific link lost its functions such as the chance to meet the congestion during the delivery process, fitting much closer to realistic situation. Besides, the proposed model also takes time period into consideration, so the solutions of decision variables should change along with time, and the parameters also vary according to different timing situations. Furthermore, the results of this adaptable distribution model for agile supply chain are shown as the following Chapter 4.

Chapter 4 Computational experiments and analyses

This chapter illustrates four scenario studies to validate and test the applicability and the solvability of aforementioned model on chapter 3. For the adaptable distribution problem, determining the flexible routes and modes selections are analytically intractable. Hence, scenario analyses are conducted to evaluate the impact and performance of the proposed model and to observe how the transportation behaves and responds under different conditions. Additionally, a LINGO 9.0 program is incorporated to solve the MINLP model. In this point to complete the research objectives for adaptable distribution within agile supply chain, this chapter therefore is divided into three parts, including 4.1 Scenario analyses; 4.2 Sensitivity analyses; and 4.3 Discussions.

4.1 Scenario analyses

As stated previously, agility has been taken as the main approach to respond quickly and appropriately to changing and unpredictable situations within a limited time. The proposed model identifies the ways of responding to different condition, such as warehouses is out of stock and mode reaches capacity limitations, urgent orders, and specific node or link lost their functions. The goal is to determine how the transportation behaves in scenarios common to agile supply chains. Therefore, to cope with the market instability, this section constructs four hypothetically scenario-based adaptable distributions for agile supply chain in the proposed model.

In computational experiments, the basic scenario scope is assumed in accordance with the research scope (see as Figure 1.1), consists of a third-party logistics (3PL) with multiple DCs in different countries of a global business, and finished products are delivered via different transportations modes. To determine the impact of different factors in agile distribution, the scenario scope has three DCs (defined as from node 1 to node 3), four sea/air ports (defined as from node 4 to node 7), and four demand areas (defined as from node 8 to node 11) in three different countries. The capacity of each DC and port are assumed equal. Finished products are stored temporarily at DCs and can be delivered directly to each demand area or through other DCs and ports. Moreover, The DCs and ports are interconnected to each node. The adaptable distribution for agile supply chain considers three short periods, whereas the first period (T=0) is the initial status of each DC. Each DC consists of an inventory cost and handling cost, while each port has a handling cost. Each link has least two modes and the network becomes an intermodal transportation network. Moreover, when the DCs, ports, and demand areas are in the same country, the exchange rate should be the same. Figure 4.1 displays the scenarios-based pattern of logistics behavior.

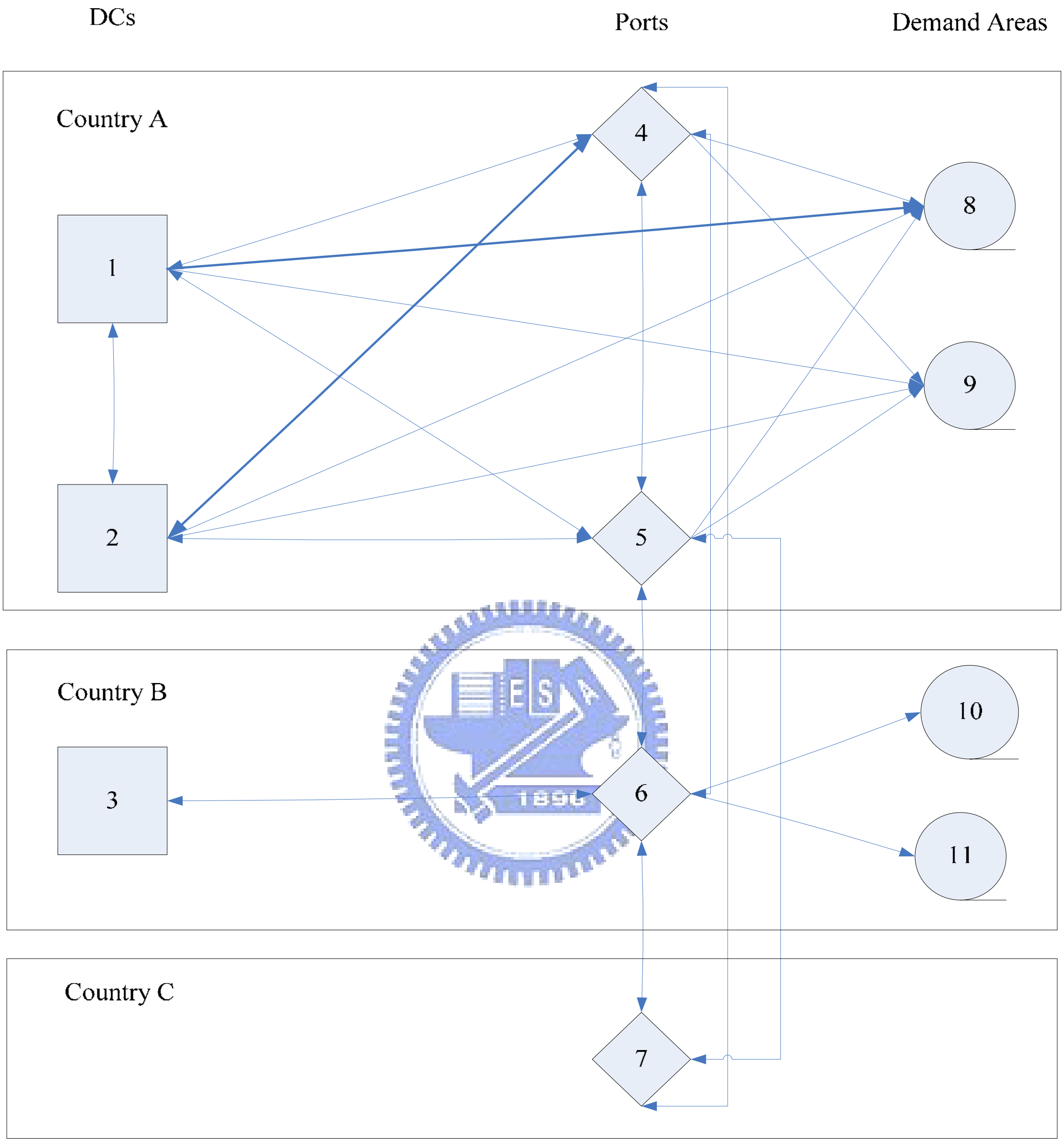

Figure 4.1 The scenarios-based scope

The proposed model for agile supply chain comprises adaptable distribution, which has the following four basic principles: (1) speedy distribution, (2) low cost distribution, (3) congestion distribution, and (4) third place distribution, that are defined and described in section 1.4 Thesis framework. Hence, the response mechanisms of these four scenarios are based on the four principles for achieve agility and validate functions of the proposed model in an agile distribution system. To illustrate the impacts and responses under different changing conditions, the corresponding four scenarios are conducted and summarized as table 4.1 respectively.

Table 4.1 The description of four scenarios

Scenarios	Description (all the available alternatives are given in each scenario)
Scenarios I	Common situations: out of stock and mode capacity limitation
Scenarios II	Demand fluctuations: urgent order
Scenarios III	Special situations: specific link lost its function, such as reaching the flow congestion or encountering pirates
Scenarios IV	Special situations: specific node lost its function, such as ports or DCs strike

Scenario I: (out of stock and mode capacity limitation)

The first scenario is very common situation in which one DC is out of stock and has sufficient inventory to serve demand areas in the same B country. Figures 4.2 and 4.3 show the adaptable distribution route procedures and results for the first scenario in the first (T=1) and second

(T=2) time period, respectively.

For the first time period (T=1), shown as Fig. 4.2, the dispatching routes correspond to the four principles of adaptable distribution. The demand areas in country A are theoretically served directly by the closest and cheapest DCs, which meets the low cost and speedy distribution principles. As to the other demand areas in country B, which are served by the DC in country A (node 2) through ports (node 5 and 6) as the closest DC (node 3) lacks a sufficient number of products. Additionally, the delivery in period 1 replenishes the inventory of the DC (node 3) such that distribution in next period is smooth, meeting the capacity distribution principle.

For the second time period (T=2), shown as Fig. 4.3, the capacity of transportation truck mode from DC (node 1) to demand area (node 8) reaches the congestion, therefore, the dispatching changes the transportation mode from truck to rail, which also follows the capacity distribution principle. Rest of other demand areas are served directly by the closest DCs. Furthermore, the planned delivery routes correspond to the adaptable distribution model build an intermodal transportation network, presented as the agile approach to reflect scenario I conditions.

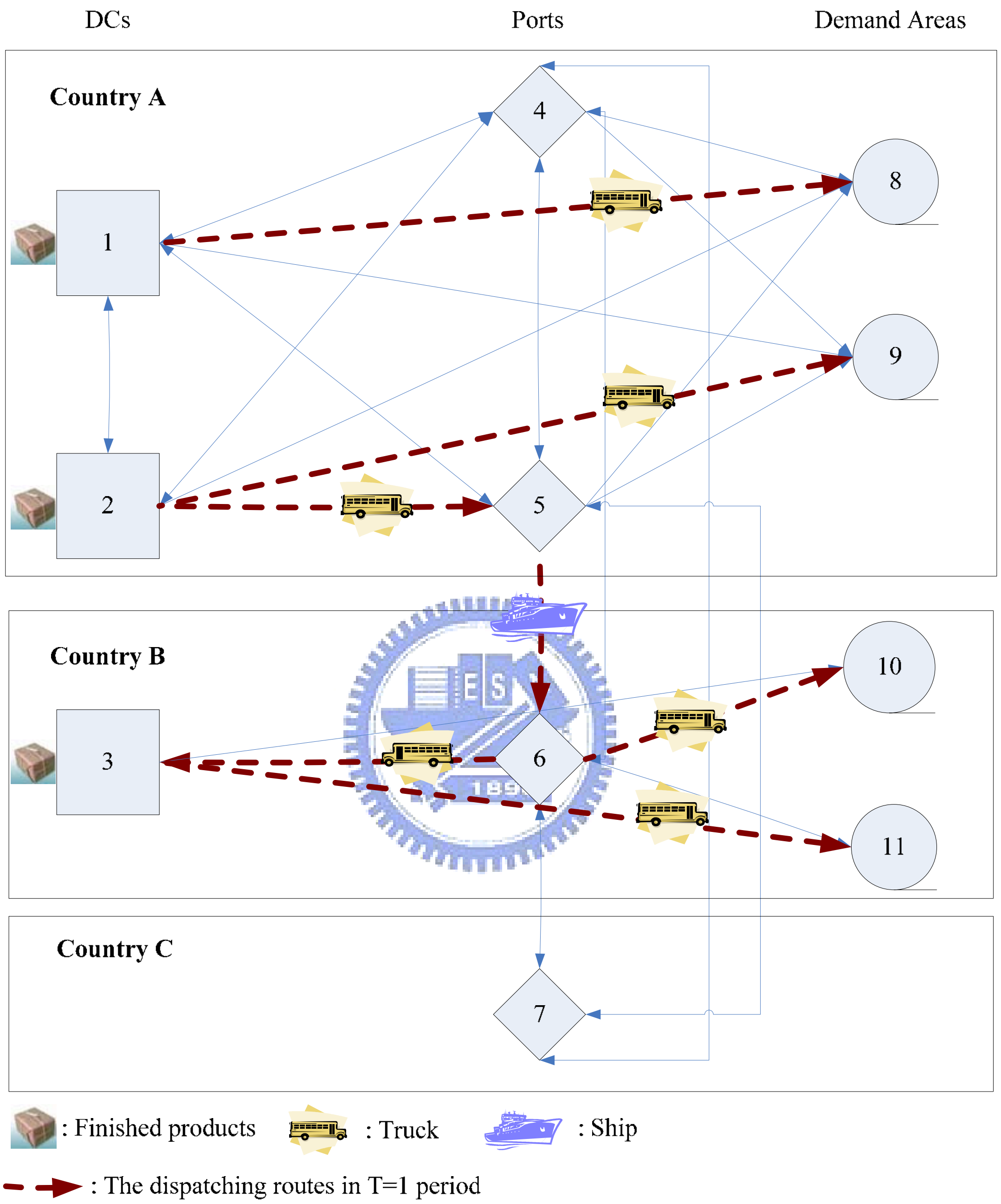

Figure 4.2 The dispatch routes in scenario I for the first period (T=1)

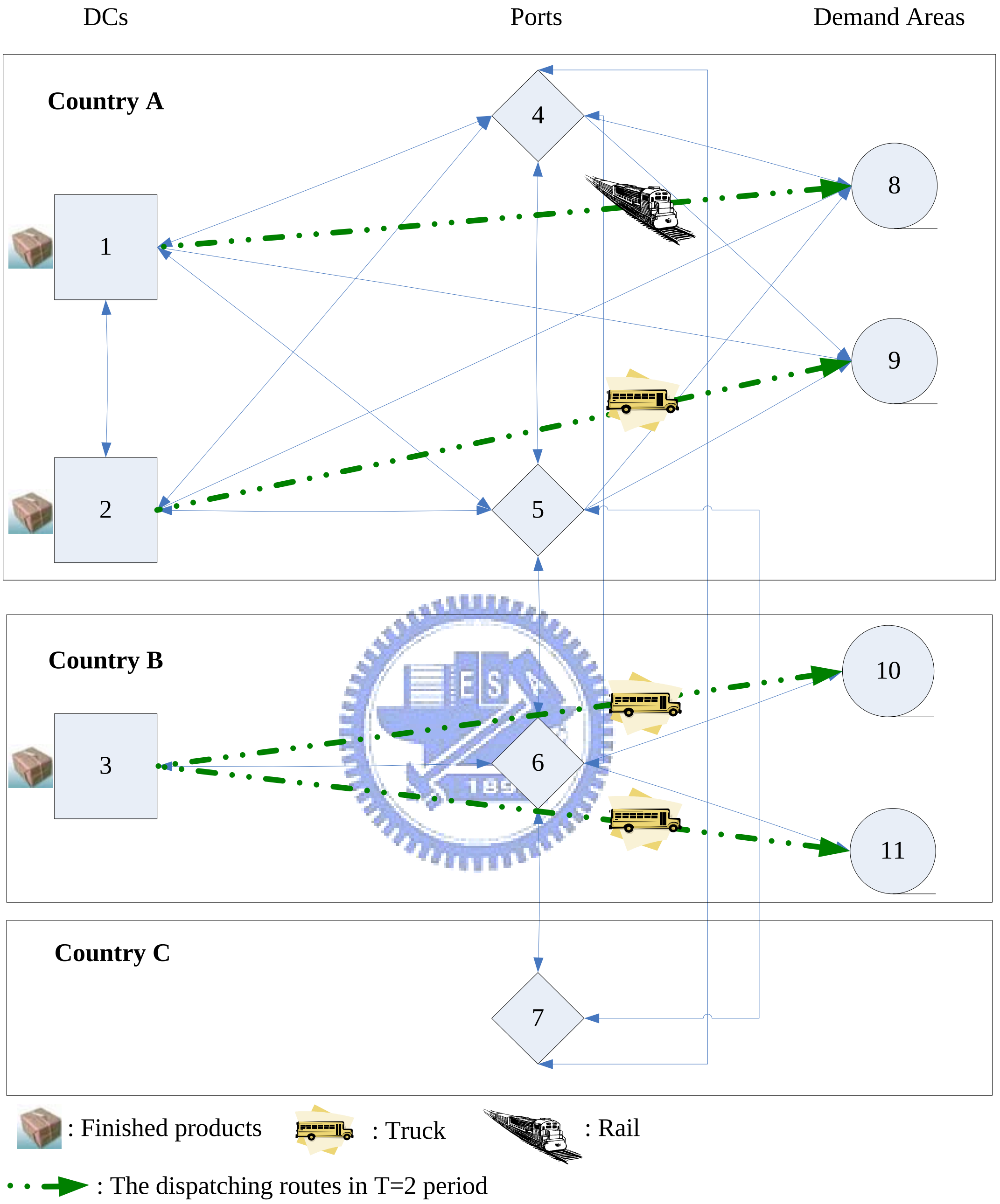

Figure 4.3 The dispatch routes in scenario I, III, and IV for the second period (T=2)

Scenario II: (urgent orders)

The second scenario is an extension of the first scenario; that is, an urgent order occurs at demand area (node10) for the second period (T=2), while products are shipped following the planned routes and transportation modes of the first period (T=1). Under this condition, the demand area (node10) cannot be served directly by the closest DC, as the closest DC lacks sufficient inventory for this urgent order. The dispatch routes in this scenario is showed as Figure 4.4 through the proposed adaptable distribution model, connected to the dispatch routes and modes for the second period (T=2) based on the results of scenario I of the first period (T=1).

For the second time period (T=2), the inventory in DC (node 2) is limited by planning results for the first time period (T=2) in scenario I, so that DC (node 2) has sufficient inventory to serve the urgent order. The results of dispatching for urgent order demand area (node10) in country B is eventually served by the closest DC (node 3) , including the initial inventory and insufficient products related to the surplus sudden demand through ports (node 5 and 6) which is supplied by DC (node 1) in country A. As to the capacity of transportation truck mode from DC (node 1) to demand area (node 8) remain the same congestion condition, the dispatching changes the transportation mode from truck to rail. Rest of other demand areas are served directly by the closest DCs. Therefore, the way of responding to this scenario is according to the adaptable distribution in principle.

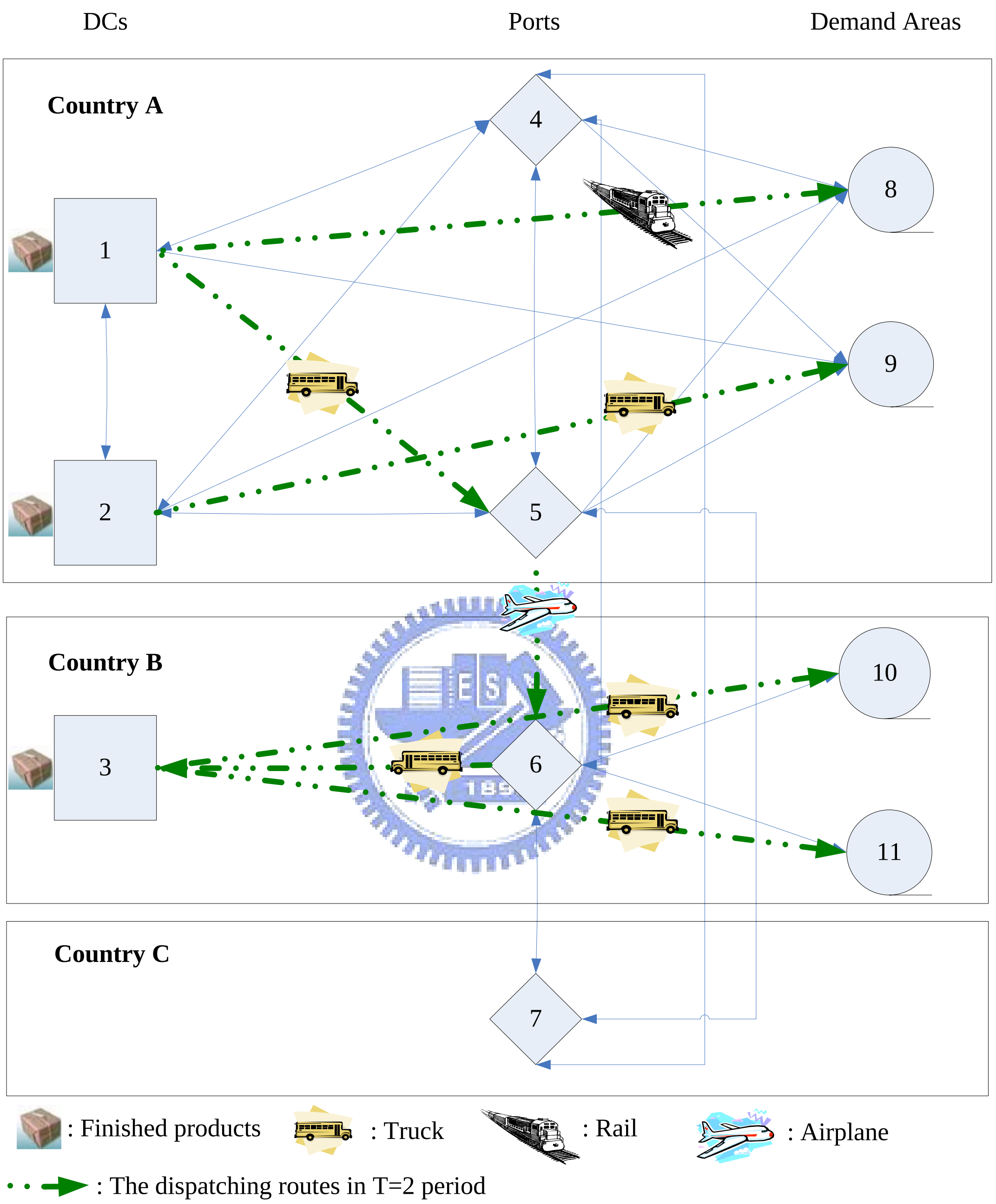

Figure 4.4 The dispatch routes in scenario II for the second period (T=2) based on scenario I of the first period (T=1)

Scenario III: (specific link lost its function)

The third scenario describes the conditions in which one link has lost its functions or contains high risks, including delivery time delays, flow congestion, damage caused by encountering pirates, or routes closed due to political or policy restrictions. This scenario is generally extends the conditions of Scenario I; that is, a delivery is planned when a DC is out of stock. Additionally, the link from port (node 5) to port (node 6) is limited by political restrictions. Nevertheless, through the proposed model, the adaptable distribution route procedures in this scenario can be shown as Figure 4.5 and 4.3, depicting the results of scenario III for the first (T=1) and second (T=2) time period, respectively.

For the first time period (T=1), shown as Fig. 4.5, the dispatching routes correspond to the four principles of adaptable distribution. The demand areas in country A remain the same dispatching routes as scenario I whereas demand areas in country B, which are served by DC in country A (node 2), shift originally from node 5 to 6 to transferred via the third port (node 7) in country C. According to adaptable distribution, scenario III reflects the third place distribution principle as the main agility approach to respond quickly for the changing environment. As to the second time period (T=2), the results are the same as scenario I, shown as Fig. 4.3, which is described above in details.

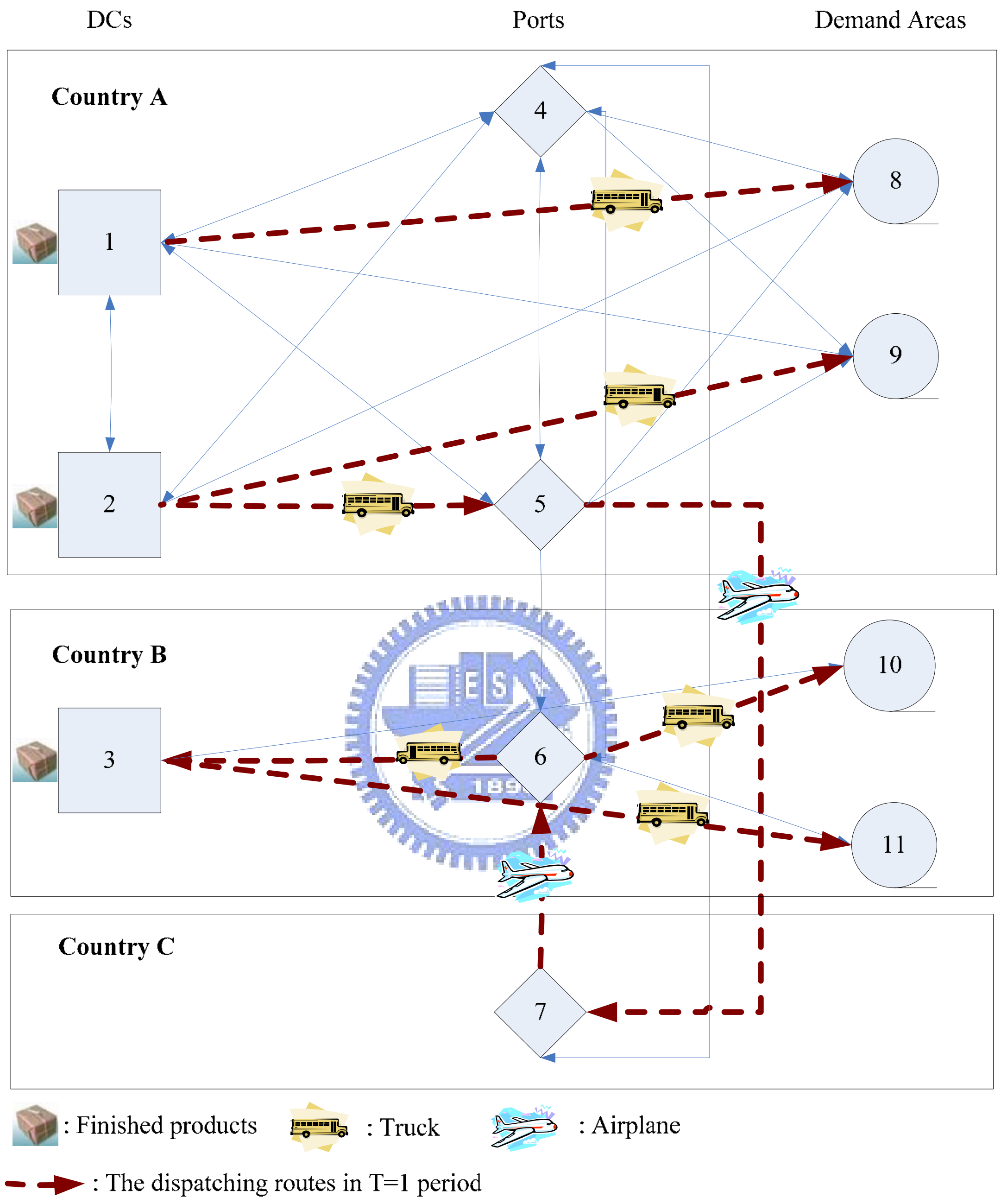

Figure 4.5 The dispatch routes in scenario III for the first period (T=1)

Scenario IV: (specific node lost its function)

The fourth scenario describes the condition in which one node (node 5) has lost its basic functions due to employees of a port or DC strike, a port suddenly closed, or a warehouse is shutdown. This scenario also extends the conditions of Scenario I; that is, a delivery is planned when a DC is out of stock, Additionally, employees at a specific port (node 5) strike. Nevertheless, through the proposed model, the adaptable distribution route procedures for this scenario can be shown as Figure 4.6 and 4.3, depicting the results in scenario IV for the first (T=1) and second (T=2) time period, respectively.

For the first time period (T=1), shown as Fig. 4.5, the dispatching routes correspond to the four principles of adaptable distribution. The demand areas in country A remain the same dispatching routes as scenario I whereas demand areas in country B, which are served by DC in country A (node 2) through port (node 5 and 6), changes from port (node 5) to port (node 4) due to port (node 5) has lost its functions. According to adaptable distribution, scenario IV reflects those low cost, time, and capacity distribution principles as the agility approach to respond appropriately for a port without any normal operation. As to the second time period (T=2), the results are the same as scenario I, shown as Fig. 4.3, which is described above in details. Furthermore, discussions of scenario analyses are presented in section 4.3.

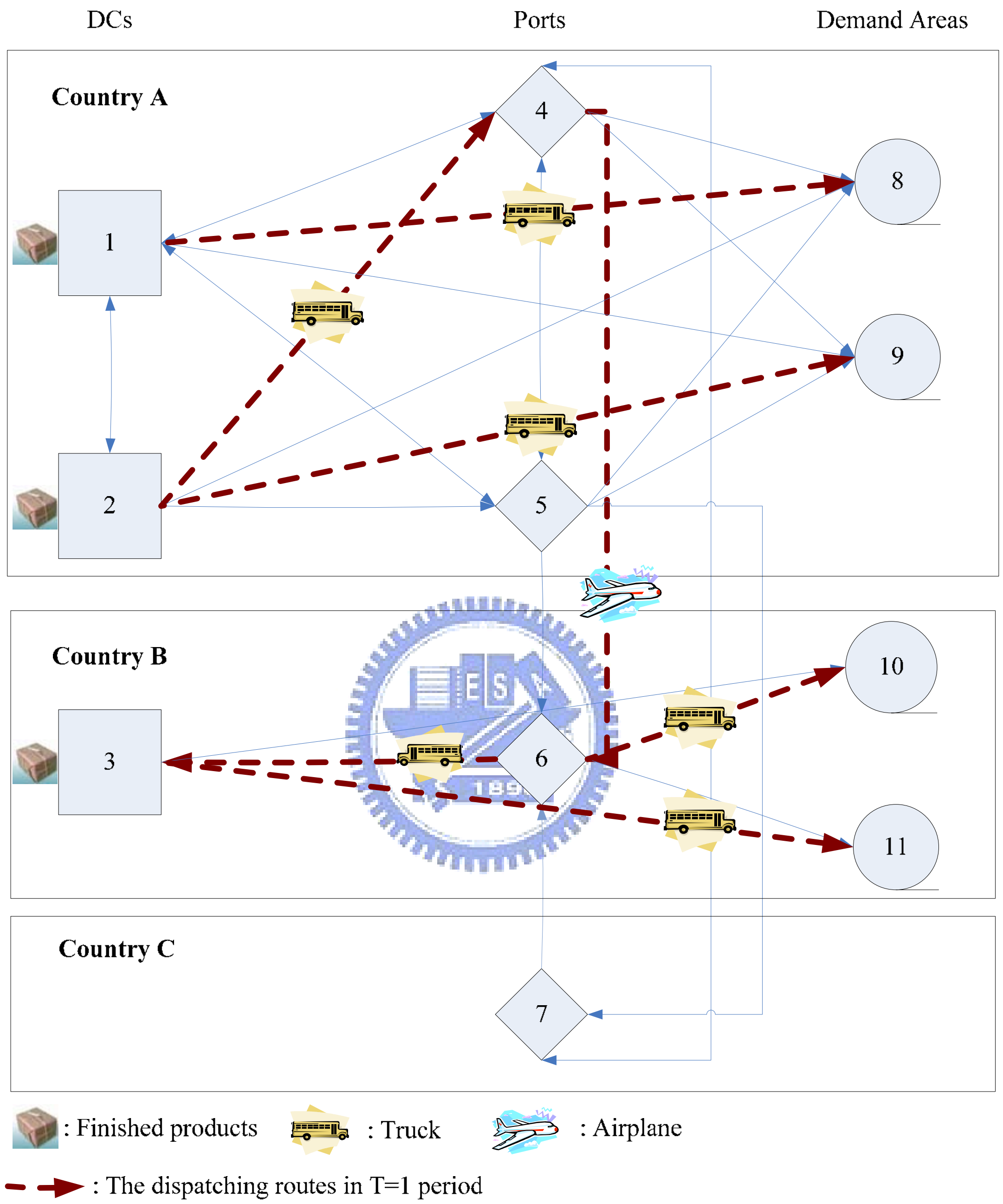

Figure 4.6 The dispatch routes in scenario IV for the first period (T=1)

4.2 Sensitivity analyses

To this point after the scenario analyses above, the total enterprising operation cost is the major objective in the proposed model, which is compose of transportation cost, transportation time value, exchange rate, handling cost, and inventory cost. However, to explore the influences of different parameters setting on the results of the research problem is a critical issue within agile supply chain. Figure 4.7 presents the results of sensitivity analyses for parameters based on scenario I, involving transportation cost, transportation time, exchange rate, handling cost, and inventory cost.

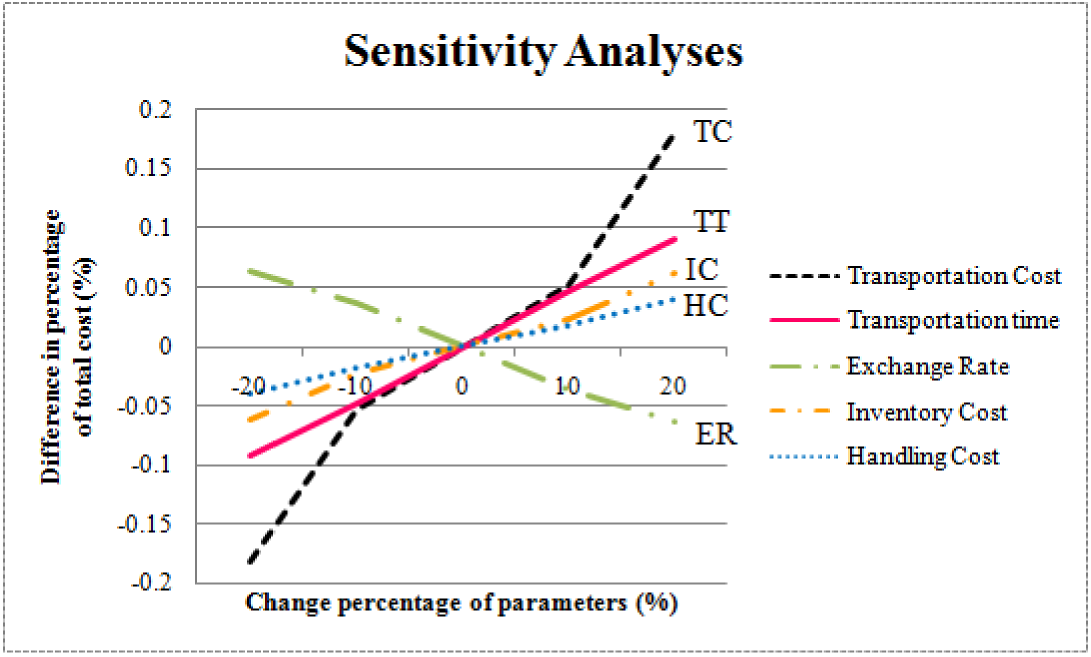

Figure 4.7 The results of sensitivity analyses

Investigating from the output of sensitivity model with respect to input resource costs in order to clearly analyze the impacts of changes on operational level decisions that may make an influence on the performances or outputs in the proposed model. While transportation cost and time always take the major percentage of total enterprising costing, the results also show both these two attributes have significant changes on the costs in agile distribution network. For instance, 10% and 20% increases in transportation cost prompt the objective value (cost) of scenario I increase 5% and 18% respectively in the proposed model, whereas the total cost increase 4.7% and 9.7% with 10% and 20% increase respectively in transportation time. Hence, comparing the aforementioned two parameters, that is, the major influences on the objective costs, the transportation cost is more sensitive or flexible impact on the results than transportation time is.

As to the exchange rate, the only parameter which has the opposite influence on the results exist the potential impact on the total enterprising costs. Although the change of exchange rate is quite small between countries in the short term, it will affect other parameters such like transportation cost, time vale, inventory cost, and handling cost due to globalization. From Figure 4.7 shows that the objective costs decrease 3.6% and 6.4% with increase 10% and 20% on parameter settings of exchange rate. This result demonstrates that exchange rate can’t be ignorable especially in the long term of global environment due to the impact on other related parameter in monetary units. Therefore, as exchange rate is one of the uncertainties in the agile distribution network, it is also the influential parameter that may change on the results or decisions from both operational and strategic level.

Rests of other parameters include inventory cost and handling cost, that is, theoretically occupy only parts percentage of objective values. The results of sensitivity analyses show there is no severe change in total cost due to the changes in inventory cost and handling cost. Besides, the performances of outputs or the route selections basically remain the same under the conditions of scenario I. For example, 10% and 20% increases in inventory cost prompt the objective value (cost) increase partially 2% and 6% respectively, while the total cost only increase 1.7% and 4% with 10% and 20% increase respectively in handling cost, which has much less influence than inventory cost. As expected, inventory and handling cost are only related to the local country and they would not make significant changes than transportation cost, transportation time do. Based on findings from the sensitivity analyses, it may be considered suitable for the research problem in the proposed model and furthermore discussions are explored in the next section.

4.3 Discussions

The concept of agility has been well recognized, especially in the rapidly changing global marketplace, as a competitive approach to respond quickly and appropriately to volatile and turbulent environments. While most definitions of agility that described clearly in section 2.1 cover the essential characteristics of speed/time, flexibility of the system, and the ability to response embedded within those definitions, Ganguly *et al*. (2009) and Yusuf *et al*. (1999) argued that responsiveness is the core definition of agility. Therefore, the primary effort of this study is to articulate the agile distribution through the proposed model and the ability to respond under market changes due to existing literatures on agility presents it as a general concept and linked to manufacturing only (Maskell, 2001). Based on computational experiments and results, some important findings are discussed and summarized as follows.

1. Scenario analyses indicate that, under out-of-stock conditions/mode capacity limitations, urgent orders, and when a specific node or link loses its functions, the proposed adaptable distribution model for an agile supply chain can respond appropriately and adapt to all available alternatives under different situations in these four scenarios by diverse transportation resources. As scenario I (out of stock conditions/mode capacity limitations), the main way to respond is via other warehouse or transportation mode, which occurs frequently in real situations (Deniz *et al*., 2006). Scenario II, which has an urgent order, reflecting the adaptable distribution based on scenario I in the first time period. A similar concept was discussed in

Baker (2008). As to scenario III, and IV (specific node or link lost their functions), that exist highly risks are also responded by adaptable distribution through the proposed model. Similar situations are apparent elsewhere (Das and Sengupta, 2009). Therefore, the results of the four scenarios are responded via diverse transportation resources, the decisions take routes and transportation modes as the main agile or responsive way to reflect through the proposed adaptable distribution model. Moreover, scenarios demonstrate that the proposed adaptable distribution model is suitable and meets the agility requirement within agile supply chains.

2. The responses and results for the four scenarios are base on adaptable distribution principles, which are composed of speedy, low cost, congestion, and third place distribution. The adaptable distribution takes into account all the essential characteristics of agility, including speedy distribution principle (Kumar *et al*., 1995; Cho *et al*., 1996); low cost distribution principle (Yusuf *et al*., 1999; Dove, 1999; Menor *et al*., 2001; Kiesmüller *et al*., 2005); Congestion distribution principle (Sambamurthy *et al*., 2003; Namboothiri and Erera, 2008); and third place distribution principle (Mathiyakalan *et al*., 2005; Raschke and David, 2005). Hence, adaptable distribution principles are reflected by scenario results via the proposed model for agile supply chains.

3. Sensitivity analyses results show that the parameters of transportation cost and time have greater impacts on the objectives than rests of other parameters do, which are based on real situations. Additionally,

only one parameter, exchange rate, has an opposite influence on scenario results, indicating that the influences of the objective values is higher than expected for a small change in the exchange rate.

Chapter 5 Conclusions

This chapter summarizes the important findings as well as some managerial implications with respect to the adaptable distribution model for agile supply chain. Furthermore, future research issues that extends from this research and might have some interesting results also point out.

5.1 Research Summary

Due to globalization, the ability of a company to adapt to unexpected changes is critical to achieving and maintaining a competitive advantage. That is identified as the concept of agility, the ability of responsiveness to turbulent and volatile environment appropriately. This study is devoted to developing an adaptable distribution model for agile supply chains based on the characteristic of agility, responsiveness under changing conditions. Several conclusions can be drawn and summarize as follows.

1. One important contribution of this study is that it formulates an agile distribution system, quantifies and measures the concept of agility through the proposed model rather than using conceptual or statistic methods. In the adaptable distribution model, transportation multiplicities are taken into considerations as decision variables; that is, route selection and transportation modes are used as agile approaches and the main way to response. Therefore, the proposed model is a MINLP model and meets agile property because via different paths and combining various transportation modes in a network with minimized total enterprising operation costs embedded.

2. The typical environment of agility is reflecting by the parameters in the proposed model, such as randomly generated demand, stochastic transportation lead time, exchange rates for the global supply chain, capacity limitations and costs of handling, inventory, and transportation from the operational perspectives.

3. The adaptable distribution model is based on low cost, time, congestion, and third place distribution principle, which are the main characteristic embedded in the agility concept. This study provides a framework of adaptable distribution via a mathematical model that can be applied to explore the impacts of changing situation on the behavior of a transportation system. Additionally, the adaptable distribution principles are trigger by changes in agile supply chains to help decision-makers solve and respond to different situation that have considerable uncertainties in a global supply chain. Hence, the agile approach of the proposed model, which is based on adaptable distribution principles, can respond flexibly and appropriately to any situations.

4. Scenario analyses results demonstrate that the proposed adaptable distribution model is agile in responding to the four different scenarios in accordance with adaptable principles aforementioned. The four scenarios, out of stock and mode capacity limitations, urgent orders, and specific node or link lost their functions, are based on real-world problems. Analytical results validate the functions of the proposed model and demonstrate that decision-makers must attempt to respond optimally under predictable and unpredictable

conditions. Furthermore, the parameters of transportation cost and time, which are identified as crucial factors in most studies, have greater impacts on objective enterprising cost than other parameters do by sensitivity analyses.

5. Enterprises can construct an agile supply chain using the proposed model. Assessing enterprise agility is key to effectively managing business process and achieving greater competitive competencies.

5.2 Extensions for future research

The extensions from the study results for future research are discussed as follows.

1. In this study, the proposed distribution model for agile supply chains is a MINLP model with respect to multi-stage time period, which focuses on responding to changing environments rather than environment filled with a high degree of uncertainties. Future research should endeavor the model to dynamic programming or time-space model with meeting the agile property, and consider the various situations outsides and over time. Furthermore, the model may expand scope to multi-products and an entire supply chain, including suppliers, manufacturers, and distributors, to investigate the entire supply chain within the agile supply chain, as this study focused on the outbound distribution system with emphasis on transportation uncertainties.
2. All case studies in this study are practical “what if” scenarios due to the lack of empirical data. Future studies can apply the proposed model to real or empirical data to make the whole research more complete.

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