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階層式全球物流網路規劃與營運規劃之模式

Hierarchical Network Planning and Operational Planning Model for Global Logistics

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摘要

隨著全球化競爭與經濟發展趨勢，企業為了提升市場競爭力，其市場規模由國內擴展至國外，企業必然積極尋求海外資源之運用，拓展全球市場，故為整合各地有效資源，以全球為腹地，使資源發揮規模經濟與截長補短之功效，並藉由全球資源的運用與配合，來達到整體成效之發揮，使企業全球化成為一個明顯之趨勢。

自從國際快遞公司率先使用「軸輻式運輸網路系統」（Hub-and-Spoke Network System）後，大幅地降低了運輸成本、機隊數目，並提高乘載率，使其他快遞業者逐漸跟進，造成軸輻式網路成為貨物運輸系統的主要網路型態。因此國際快遞業面對目前成長迅速且競爭激烈的全球市場，如何在全球佈局情況下，妥善規劃設計階層式運輸網路，以達到縮短運送時間，提高服務水準；同時在相關資源配置問題上又能增進作業效率，降低營運成本目標，實為業者永續經營的重要課題。

因此本研究認為，針對各種不同之營業據點，在滿足建構網路成本與相關風險限制下，規劃設計出成本最低、利潤最大與顧客滿意最高之階層式運輸網路架構，並在此階層式網路架構下探討每個設施內部中相關資源配置問題。本研究以國際物流業者為主要研究對象，探討在階層式物流網路下，國際物流業者如何進行中期營運之資源配置戰術規劃，並以相關之數學規劃方法構建其全球網路佈局模式與營運規劃模式。

本研究以台灣、中國與美國為研究案例，研究結果發現，透過階層式網路規劃設計後，可以使原本之網路成本降低，並可求出最佳設置相關設施之位置。再透過營運規劃模式進行內部相關資源配置，可瞭解各設施內部之最佳資源配置數量，最後也期望本研究之相關模式與結論能提供於企業之營運參考。

關鍵字：全球物流、階層式網路、網路規劃、資源配置、數學規劃

HIERARCHICAL NETWORK PLANNING AND OPERATIONAL PLANNING MODEL FOR GLOBAL LOGISTICS

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Abstract

With global competition and economic development trends, the enterprise must actively seek to expand the global market in order to enhance the market competitiveness of its market size by domestic extended to foreign countries. Therefore, effective resource integration around the world by the use of global resources becomes an obvious trend.

Since the international express enterprise uses of the Hub-and-Spoke network system first, they reduces transportation costs and the number of the fleet significantly and improves the rate of carriage. The other express enterprise to follow-up gradually resulting in the Hub-and-Spoke network system becomes the primary network type. International express enterprise is facing a rapidly growing and highly competitive global market. How does international express enterprise to plan and design the hierarchical transportation network in order to achieve shorter delivery time, improve service quality under global overall arrangement, improve operational efficiency, and reduce operating costs in resource allocation problem are important issues.

Therefore we present an integrated global logistics (GL) networks planning and operational planning model in which the network components such as hubs and depots are hierarchically characterized and consider the related resource allocation in facilities. In this research, we choose Taiwan, China and the USA in the case study. Finally, we expect that the proposed methodology is beneficial provided for not only academics but also international express delivery enterprises.

Keywords: Global logistics; Hierarchical networks; Network planning; Resource allocation; Mathematical programming.

誌 謝

這本論文的誕生，絕非單靠自己人之力所能為之，在完成的背後，有著許多看不見的手，給了我極大的推力，賦予我持續不絕的信心與能量，以致最終完成這份博士論文。而在這一路上，也非常感謝許多人的幫助與指引，讓我在獲得博士學位的過程中，學習到許多知識與個人發展。一個階段的結束並非全部，而是另一個階段的開始，記得七年前碩士論文誌謝撰寫時也曾說過，因此在拿到學位當下或許開心，其實相對也是要準備面對未來嚴酷的挑戰。

首先在博士論文撰寫期間，承蒙恩師許教授鉅秉細心指導，許老師也是我碩士指導教授，跟著許老師這十年來，均受到恩師的殷切教誨與鼓勵，感激之心實是無法喻於顏表，至此先跟老師至上最深的謝意與敬意。

而論文口試期間，亦蒙陳教授振明、郭教授人介、張教授宗勝、盧教授宗成、馮教授正民與陳教授穆臻的懇切批評與指正，百忙之中抽空前來協助提供諸多寶貴的意見，使得本博士論文能更加的臻於完善，在此也獻上由衷的謝意。

隨著博士的畢業，在交大也剛好待滿十年（含碩士三年、休學服兵役一年與博士六年），在交大交研所這十年來，蒙所上藍教授武王、徐教授淵靜、黃教授承傳、黃教授台生、汪教授進財及邱教授裕鈞在專業知識的指導，在此致上誠摯的謝意。當所上老師扮演嚴父的同時，也非常感謝所上助理洪姐、柳姐與何姐這十年來相關行政與課程業務之幫忙，讓整個求學過程都很順利。此外也感謝在各求學階段中之學長、學姐、學弟、學妹、同學與朋友的關心及指教，謝謝你們在我各階段求學中遇到不盡如意之事，都能在身邊陪伴與鼓勵，在此特表謝意。

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林 永 祥　　　謹誌

2012 年 7 月　台北北門

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

The chapter consists of four sections. Section 1.1 addressed the background, the motivation, principal concept and issues on analyzing hierarchical network planning and operational planning in this study. The research objectives, scope, issues, procedure and framework were introduced in Section 1.2, 1.3, and 1.4, respectively.

1.1 Research Background and Motivation

Networks configurations are one of the critical issues in the area of global logistics (GL), and vital to the implementation of GL operational strategies. With the rapid maturity of the globalization concept, there is growing recognition on the issue that networks configurations should be addressed previous to the operations of GL operational strategies. Correspondingly, the performance of GL strategies and their functional integration should rely greatly on elaborate networks configurations to accomplish the goals of global logistics management. In addition, it can be seen that numerous international express delivery enterprises, e.g., DHL, UPS, FedEx, TNT, have increasingly perceived the significance of constructing hierarchical GL networks, via the integration and classification of the corresponding facilities, such as international hubs and depots, to enhance their competitiveness in global operations.

In spite of the importance of GL networks design, the planning of a GL hierarchical framework for the integration of transnational facilities still remains as a critical issue for the following reasons. First, from a practical point of view, it is difficult to efficiently coordinate the activities of all the transnational facilities, such as depot-depot, depot-hub and hub-hub shipment and transportation activities in a given GL framework due to the variety of their functional relationships in both the spatial and temporal domains. To a certain extent, this difficulty is rooted in the fact that a GL operational networks tends to be hierarchical, containing different nodes located in different layers of the network, where each node has its own operational goals and respective problems. In addition, there exist a limited number of appropriate models suitable for planning the corresponding GL hierarchical networks with the goal of system optimization in global logistics operations. Accordingly, the methodology development for systematically planning GL hierarchical networks is urgently needed.

The prominence of dynamic resource allocation (DRA) strategies highlights the need for time-based hierarchical global logistical distribution operations strategies, which has aroused growing concerns and research interests recently due to the variation of most customer demands. According to the practical procedures of global logistics distribution, estimating customer demand distribution and allocating related resource via suitable model are regarded as two key elements for efficient global air express service. Furthermore, globalized enterprises, e.g., DHL, FedEX, UPS, and TNT, have increasingly undertaken measures, including the integration of corresponding air express cargo in demand side and resource allocation in supply side in order to content with the global market. Herein, the two sequential tasks of demand-based data estimating and resource-based allocating should be well coordinated so as to enhance the effectiveness and efficiency of such random-based and time-based hierarchical global logistical distribution operations. The above cases consider estimating demand data which can be provided with stochastic property and determining related resource allocation which has dynamic characteristic.

Despite the urgent need of DRA for hierarchical global logistical distribution operations, there are a limited number of related studies in previous literature. Previous studies of resource allocation problem (RAP) mainly aim at the optimization of corresponding production management, resource distribution, and project budgeting etc. for other relevance purpose of business operations. Related issues include using mathematical models to determine the type, size, and number of quantity of related resource. To a certain extent, minimization of private business operational costs and maximization of resource usages are the major concern in previous literature.

1.2 Research Objectives

The purpose of this study is to suggest a novel assessment framework for considering spatial factor of hierarchical network facility and temporal factor of demand scenario, for integrating and allocating related resources under hierarchical network facility, for combining hierarchical cluster and Bayesian method in demand side and mathematical programming in supply side. Accordingly, there are three primary objectives in this research:

1. Construct a framework for considering hierarchical characteristic based on the needs of different demand scenario. The conceptual framework can help planners understand the relationship among hub, distribution center, and warehouse depot, and clarify issues and implications related to global logistics enterprise. Furthermore, hierarchical characteristic, considered at the commencement of planning, is a new idea for assessing improvement in global logistics enterprise operations.
2. Propose an approach for integrating and allocating related resource under hierarchical network facility. The approach proposed in this research was aimed to link up the effects of spatial factors in supply side and reveal individual differences of temporal factors in demand side. The decision support model for resource allocation problem can help planners decide and determine number of manpower and mode in each facility.
3. Propose an approach for combining related methodologies in this research. Two types of methodologies were employed in supply side and demand side respectively. One was the hierarchical cluster methodology which was adopted to construct a hierarchical structure and Bayesian methodology which was assumed to generate different demand distributions in demand side. The second was mathematical methodologies including multi-objective programming and dynamic programming in supply side. They were adopted to decide and determine the number of each facility and related resources.

1.3 Research Scope and Issues

Global logistics planning model is one of the many ways to demonstrate global logistics enterprise operation. Different operation environment cases could be represented with different considering factors, interactive relationships, and related costs. However, location choices to a hierarchical network facility are countless and complicated if all details are concerned; it would be technically impossible to analyze location choice in such a detail. A compromise way is to classify location based on either prior knowledge or on statistical information such as hierarchical cluster extracted from data, which is called a hierarchical skeleton. A hierarchical network facility describes a typical correlation condition of logistics network occurrence such as hub, distribution center, and warehouse depot. For this reason, the hierarchical network facility is based on location choice and network design issues.

At the same time, global logistics planning model were divided into strategical system model and tactical system model respectively. The first issue of this research desired to address was whether those facility location significantly related or the hierarchical network configuration in strategical system. In the second issue of this research, tactical system craved for realization the related resource allocation under the hierarchical network facility. The research scope and issues are displayed in Figure1-1.

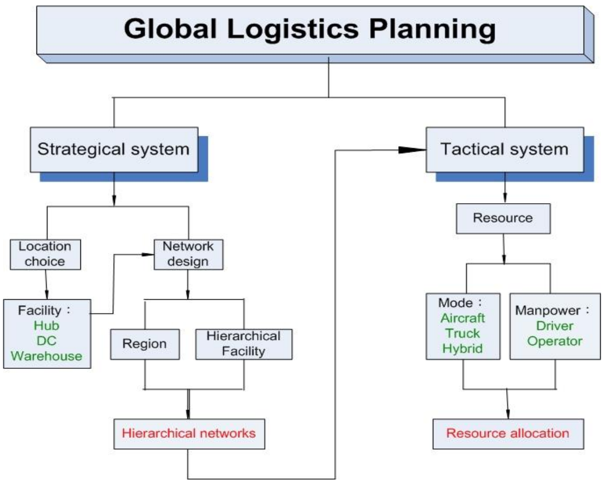

FIGURE 1-1 Research scope

1.4 Research Procedure

Given the objectives, the research procedure and framework was illustrated in Figure 1-2. Prior to recognizing characteristic of global logistics, framework of global logistics is built up as the basis to configure appropriate hierarchical network facility, to allocate suitable related resources, and to combine the related methodology. Meanwhile, the connections among hierarchical network configuration, resource allocation, and countermeasure development were discussed to help define the research scope and issues.

Four stages are then conducted based on the coverage of data. The first one was a generalized two-step approach for exploring global logistics operation characteristics from literature and industry interview. Therefore, the background and the motivation are determined prior to the global logistics objectives. Hierarchical network facility configuration is defined and the conceptual framework is constructed based on the reviewed research including the general logistics network design, hierarchical network configuration, resource allocation problem and resource allocation model and heuristics. Consequently, chapter 1 and chapter 2 are included in this stage.

Based on this, the second stage is undertaken for constructing the strategical system model and tactics system model, models usually shown on global logistics data especially on global logistics real data. The third stage is to integrate strategical system model and tactics system model to global logistics planning model in sequence. If the hierarchical network planning model or operational planning model for hierarchical network is not to find out the optimal solution or has some logic fault, then the feedback motion will go back to the stage 1 to resurvey the identification scope and issues. After the model constructing, the preliminary testing and empirical study of this research are provided from global logistics enterprise database. For this reason, chapter 3 and chapter 4 were presented in second and third stage.

Finally, the fourth stage was conducted to examine hierarchical network facility model and resource allocation model under hierarchical network facility by sensitivity analysis and effect evaluation. If the effect evaluation is not good enough or has some logic fault, then the feedback motion will go back to the stage 2 to reexamine the model construction. Empirical studies were also presented in the chapter 4 due to research integrity. The related issues and conclusions and recommendations were discussed and drawn in Chapter 5.

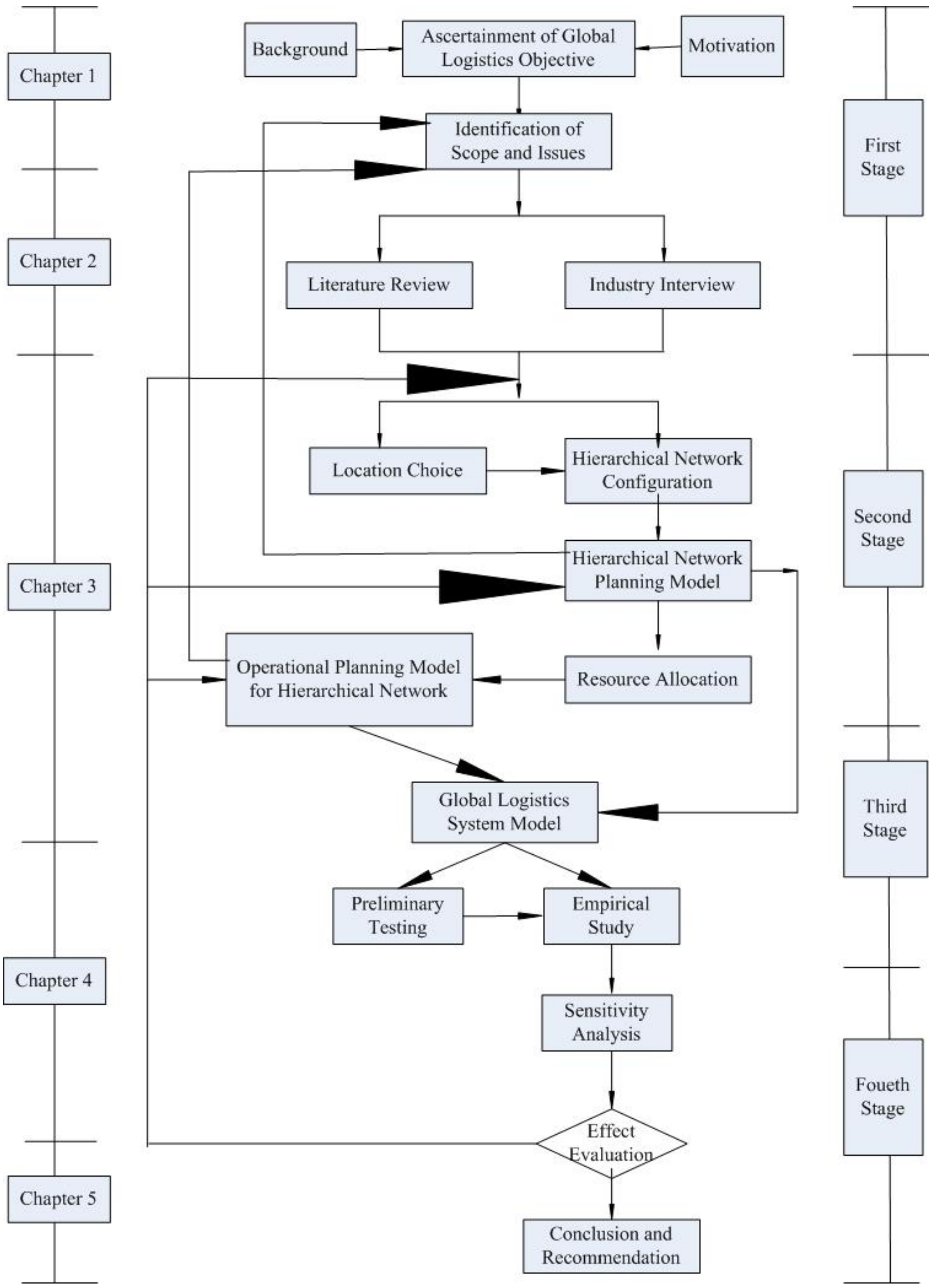

FIGURE 1-2 Research framework

CHAPTER 2 LITERATURE REVIEW

2.1 General Logistics Network Design and Location Problem

Nevertheless, how to incorporate hierarchical characteristics of logistics facilities into GL networks design appears rarely found in previous literature. At this point, several pioneering studies are illustrated below for further discussion.

The significance of issues on general logistics networks configurations has been noticed previously (Miller et al., 1996; Crainic, 2000; Melkote et al., 2001; Drezner et al., 2003; Jayaraman et al., 2003). The development and implementation of a mixed integer programming type model designed to determine the best transport mode and rail network location strategy in Miller et al. (1996). In Crainic (2000), service network design is used to designate the main tactical issues for railways and less-than-truckload motor carriers. Their purpose is to present a state-of-the-art review of service network design modeling efforts and mathematical programming developments for network design. More recently, Melkote et al. (2001) introduce a combined facility location/network design problem in which facilities have constraining capacities on the amount of demand they can serve and present a mixed integer programming formulation of the problem and several classes of valid inequalities were derived, followed by Jayaraman et al. (2003) which proposed the PLOT (Production, Logistics, Outbound, Transportation) distribution network design system that is characterized by the functions of multiple distribution channel members, and their corresponding locations. Later, Drezner et al., (2003) introduce a new network design problem which determines links and facility locations, using several heuristic solution tools such as a descent algorithm, simulated annealing, tabu search, and a genetic algorithm.

Research on facility location models has mainly dealt with assigning facilities to serve their nearest demand areas, in order to minimize aggregate operational costs (Hakimi, 1964;

Cornuejols et al., 1977; Neebe and Rao, 1983; Klincewicz and Luss, 1986; Mirchandani and Francis, 1990; Daskin, 1995; Pirkul and Jayaraman, 1996; Bramel and Simchi-Levi, 1997). To achieve this goal, appropriate decisions in terms of the number and location of facilities as well as the demand area potentially served by each facility, should be made using the facility allocation logic rules. Herein, the properties of the spatially interactive travel behavior have been increasingly incorporated in formulating facility location problems to make these models more suitable for practical applications (Wilson, 1969; Coelho and Wilson, 1976; Leonardi, 1978; Beaumont, 1980; Erlenkotter and Leonardi, 1985; Jacobsen, 1986; Holmberg, 1996). One typical example is use of the spatial gravity model, which characterizes the strength of spatial interaction between each pair of nodes in an activity-corresponding network. In Leonardi_sstudy (1983), random utility theories are used to formulate the resulting models as nonlinear integer programming models with the entropy-maximizing objective. It addition, a variety of techniques, including dynamic programming models (Campbell, 1990; Drezner and Wesolowsky, 1991; Bean et al., 1992; Webster and Gupta, 1995) and heuristic algorithms (Friesz et al., 1988; Miller et al., 1992), have been utilized to increase the efficiency in searching for a final solution. One distinctive feature of these advanced methods is that demand-related attributes, e.g., demand patterns and demand growth rates, are treated in either the dynamic or the stochastic extent rather than in the static domain as in traditional approaches (Drezner and Wesolowsky, 1980; Daganzo, 1987, 1988; Erlenkotter, 1989; Ghosh and Craig, 1991; Hakimi and Kou, 1991).

Therefore, distribution network design problems involve both kinds of analysis. More precisely, these problems consist of determining the best way to transfer goods from the supply to the demand points by choosing the structure of the network (layers, different kinds of facilities operating at different layers, their number and their location), while minimizing the overall costs. Distribution network design problems involve strategic decisions which influence tactical and operational decisions. In particular, they involve facility location, transportation and inventory decisions, which affect the cost of the distribution system and the quality of the customer service level. So, they are core problems for each company.

As emerged from the above discussion, distribution network design problems involve a lot of integrated decisions, which are difficult to consider all together. Generally, some simplifying assumptions have been adopted in the literature, and only some aspects related to the complex network decisions have been modeled. For instance, in the past some authors dealt with distribution network design problems as pure location problems, without trying to address and integrate the different types of strategic decisions.

Webb and, more recently, Salhi and Rand recognized the error introduced into location problems by ignoring the interdependence between routing and location decisions. Since then, some papers focused on the relationships between facilities and transportation costs, stressing that location of distribution facilities and routing of vehicles from facilities are interdependent decisions. In particular, in recent years, some location routing problems (LRP) arising in the context of distribution network design problems have been investigated. In these problems, the facility location and the vehicle routing aspects are solved simultaneously. Given a set of candidate depot sites and customer requirements, in its simplest form LRP consists of determining the location of the depots and the routes of the vehicles for serving the customers, in such a way that some constraints, generally related to depot and vehicle capacity, route lengths and durations, and all the customer requirements are satisfied, while minimizing an objective function involving routing costs, vehicle fixed costs, depot fixed costs and depot operating costs. In, the distribution network design problems have been classified according to the number of layers in the distribution network, and to the type of routes between layers. In particular, Laporte introduced the terminology route of type R (for replenishment), if the route connects a pair of nodes of two different layers (for instance, a depot is connected to a customer), and route of type T (for tour), if it is a tour connecting a node in a layer with more nodes belonging to other layers (for instance, a depot is connected via a tour to a certain number of customers served by the same vehicle). Laporte observed that a distribution network design problem can be formulated as a location routing problem if and only if routes of type T are allowed, and location decisions arise at least at one layer.

In the last two decades, many LRP models have been proposed in the literature to formulate and solve distribution network design problems. Most of them are related to a simple network with two layers (depots and customers), where routes of type T are allowed. Each model is characterized by the number of depots to locate (single depot or multi-depot), by the presence of capacity constraints (depot capacity and vehicle capacity) and other route constraints, and by the form of the objective function.

Since Weber presented the findings of his studies in 1900, many researchers have centred their efforts on studying the problems of hub location. In the area of transport, many of their studies have been concerned with defining the optimum location for manufacturing plants, distribution centres, and hubs. Hander and Mirchandani (1979) offer a classification of the problems associated with location and deal with some of the solutions in depth. Hurter and Martinich (1989) study the problem of locating a new manufacturing plant bearing in mind different production theories.

In order to solve the problem of hub location, it is necessary to study the problem of route design. The traditional means of handling the task of determining the best location for a hub consists of assigning nodes to already existing hubs. In addition, when trying to optimize distribution routes, it is generally accepted that the hubs pre-exist, and the most common strategy is to study each existing origin/destination pair and then determine the best route, depending on the available hubs. Several authors have studied and compared the strategies of direct transport and transport via different terminals.

Blumenfeld et al. (1985) study the optimum transport strategy, considering both the direct transport of goods and also the sending of those goods via a terminal. Hall (1987) studies the strategy of direct goods transport as against the transport of goods via a terminal in a single terminal network with a lot of origins and a few destinations. Later, the same author (Hall, 1989) studies the problem in networks with several terminals.

Leung et al. (1990) study the problem of point-to-point transport within a distribution network. A comprehensive study and review of these models can be seen in Barcos (2002). In order to solve the problem of locating p hubs in an N-node network, Campbell (1994) proposed a linear model; later, Skorin-Kapov et al. (1997) presented a compact formulation of this problem. Aykin (1995) proposes an algorithm to solve the problem of locating p hubs in an N-node network. O'Kelly and Bryan (1998) developed a model called FlowLoc, which consists of introducing changes to the function which was the subject of the model proposed by Skorin-Kapov et al. (1997). Through these changes they show that the cost of transport between hubs goes down when the flow between hubs increases.

2.2 Hierarchical Network Issues

Hub-and-spoke networks reduce the number of under-utilized point-to-point direct loads (Chestler, 1985). As a result, load factors are increased and total operating costs are reduced (Akyilmaz, 1994; Bryan and O'Kelly, 1999). This network configuration is widely adopted by carriers. The pure hub-and-spoke network requires that all loads must either start or end at a hub sort (Bryan and O'Kelly, 1999; Eckstein and Sheffi, 1987; Leung et al., 1990; Lin, 2001a). A complete door-to-door delivery cycle in the network consists of local service and line-haul operations. Each center is the point of collection and delivery for its exclusive service area. Centers dispatch a fleet of package cars (delivery trucks) delivering shipments to consignees, and subsequently collect new shipments from the shippers. This process is local service. When new shipments arrive at the centers, the local service is completed while the line-haul operations begin.

Centers for the air ground intermodal carriers unload shipments from package cars and reload them onto and subsequently dispatch a single tractor trailer/package car to the primary airports. The airports act as an aggregate point of collection for pickup and delivery for their satellite centers, which are also a point of modal exchange. Centers (airports) for the ground-exclusive (air ground intermodal) carriers run a local sort, where new shipments are unloaded from package cars (tractor trailers/package cars), consolidated into a small number of full loads and reloaded onto a fleet of long-haul tractor trailers (aircraft) for the hubs. In practice, long-haul tractor trailers are called feeders. At the hub sort, the inbound shipments are unloaded from tractor trailers (aircraft), consolidated and reloaded onto a fleet of outgoing tractor trailers (aircraft) for the centers (airport) for local delivery (satellite centers). When unable to build full loads for the individual centers (airports), hubs make loads for other hubs for additional consolidation.

On the day of delivery, centers (airports) receive their delivery volumes (aggregate volume for the satellite centers). They run a preload sort, at which the loads are unloaded from the feeders (aircraft), sorted and reloaded onto each package car (tractor trailer/package car) for local delivery (each satellite center). An additional unloading, sorting and reloading onto a fleet of package cars for local delivery is necessary by each center of the air ground intermodal carrier.

This completes the line-haul operations and triggers any round of local service. Thus, hubs and centers (hubs and airports) constitute a hub-and-spoke network for ground-exclusive (air ground intermodal) carriers. Spoke routes radiating from the hubs connect centers (airports), while interhub routes connect a pair of hubs.

In addition, a few hierarchical network design studies using diverse algorithm can also be found (Current, 1986; Sancho, 1996; Lin et al., 2004). In Current et al. (1986), a hierarchical network design problem (HNDP) is formulated to identify the shortest paths among the involved facilities in the proposed two-level hierarchical network. The hierarchical network includes a primary path from a predetermined starting node to a predetermined terminus node. In addition, each node not involve in the primary path must be connected to a given node of the primary path by means of a secondary path. More recently, Sancho (1996) developed a dynamic programming model to find a suboptimal solution for the hierarchical network design problem (HNDP) with multiple primary paths. Based on the concept of hierarchical network, a number of researchers tend to apply the issues to routing problems and network design problem with time windows (Lin et al., 2004; Marin-Tordera et al., 2005;). Based on the concept of a time-constrain hierarchical hub-and-spoke network design, it involves determining the fleet size and schedules on the primary and secondary routes to minimize the total operating cost, while satisfying the desired level of service has been addressed in Lin (2004).

Furthermore, a number of researchers attempt to incorporate multi-depot, hub-location and vehicle routing issues into a comprehensive network planning framework (Jang et al., 2002; Wasner et al., 2004). Based on a proposed conceptual framework of a distribution network, Ambrosino et al. (2005) integrated the problems of facility location and the corresponding vehicle routing and inventory decisions, formulated with a single objective function. Cakravastia et al. (2002) aimed to develop an analytical model of the supplier selection process in designing a supply chain network with the goal of minimizing the level of customer dissatisfaction, which is evaluated by price and delivery lead time two performance criteria. In addition, the network design problems (NDP) have been classified in two different forms: one is the discrete form dealing with the adding new links or roadway segments to an existing road network which is called as the DNDP, and the other one is a continuous form dealing with the optimal capacity expansion of existing links which is called as the CNDP. For example, the discrete network design problem (DNDP) and the continuous network design problem (CNDP) are formulated in Gao et al. (2005) and Ciou (2005), respectively. In whichever form DNDP or CNDP, the objective of NDP is to optimize a given system performance measure so as to minimize total system travel cost, while accounting for the route choice behaviors of network users.

Although there are certain advances in the previous literature related to general networks design, the conceptualization of hierarchical GL network configurations is rarely found. Accordingly, we propose a novel hierarchical GL network planning methodology which integrates the technologies of cluster analysis and integer programming to address the GL network design problem for international express delivery enterprises. Here, the factors of GL resources, facility size, and service area of each node are considered for node classification. Then, the integer programming methodology is applied to the resulting network design problem, where the corresponding facilities including hubs, distribution centers and warehouses are hierarchically structured. In formulating the proposed model, we also consider the multiple GL channel members and related factors, e.g., customs accessibility, transnational transportation and inventory costs, potential benefits, special susceptible area distribution restrictions, and long-term regional market demand conditions.

2.3 Resource Allocation Issues

RAP is the process of allocating resources among the various projects or business units for maximization profit or minimization cost. The process of the RAP desires to search an optimal allocation of a limited amount of resource for optimizing their objective subject to the given resource constraint. An early example is the study by Hou and Chang (2004), which utilizes a linear programming method to formulate the optimization problem of product allocation for allocating a limited number of products among plants that the incurred cost is minimized. However, their model may be limited to the determination of cost-effective production. Similarly, Ernst et al. (2001) formulated the processor and job shop management system as simply a scheduling problem in an attempt to accomplish the goal of either minimum delivery time or maximum equipment utilization. Nevertheless, the issue of lead time is not considered in their study. In contrast, some Scholars deal only with the problem of a portfolio optimization to achieve the objectives of minimizing risk for a target rate of return and maximizing return for given level of risk.

More recently, the use of sophisticated hybrid methods for multiple objectives has drawn increasing attention in early research. Baldwin and Pilswoth (1992) proposed a synthesized mathematical programming method for discussing the fuzzy environment including both fuzzy approach and dynamic programming models simultaneously. In addition, Hussein and Abo-Sinna (1993) proposed a synthesized fuzzy dynamic approach to the multi-objective resource allocation problem for allocating workers to the certain jobs. Nevertheless, the scope of this research is still limited to only certain areas of global logistics.

In, addition, in fact, recent advances in information and communication technologies have significantly altered the consuming behavior of end-customers, and aroused their desire for quick response from the vendor enterprise. Facing such induced issues as distribution channel reconstructing and quick response to the delivery of customer order demands, the specialized city logistics companies have been urgently requested with the capability of allocating limited resources, efficiently and effectively, in the process of city logistics distribution operations. Therefore, Sheu (2006) developed a dynamic customer group-based logistics resource allocation methodology for the use of demand-responsive city logistics distribution operations. Accordingly, dynamic allocation of logistics resources defines the feasibility of an efficient demand-responsive city logistics distribution system by enhancing the resource utility as well as by shortening the pre-route work process time in quick response to changes in customer demands.

Despite the importance of dynamic logistics resource allocation in demand-responsive city logistics distribution operations, studies in terms of incorporating such a mechanism into the comprehensive scheme of demand-responsive city logistics distribution operations are rather limited in previous literature. In contrast, most previous research appears to focus mainly on the en-route freight transportation problems, e.g., vehicle routing problems (VRP), and the corresponding fleet management problems (Altinkemer and Gavish, 1990; Bramel and Simchi-Levi, 1995; Gendreau et al., 1996; Powell, 1987; Powell and Carvalho, 1997; Powell et al., 2002; Mahmassani et al., 2000; Secomandi, 2000). Among these, two typical VRP-induced problems, including the inventory routing problems (IRP) and multi-commodity fleet management problems are illustrated below for discussion.

Essentially, IRP, which is also termed as the vendor-managed distribution system in recent literature (Beltrami and Bodin, 1974; Burns et al., 1985; Federgruen et al., 1986; Blumenfeld et al., 1987; Dror and Ball, 1987; Larson, 1988; Webb and Larson, 1995; Herer and Levy, 1997; Larsen, 2001; Ghiani et al., 2003), can be regarded as an enrichment of vehicle routing problems (VRP) to consider customers inventory factors, such as storage capacity, consumption characteristics and the consequences of stockouts in determining logistics distribution strategies. Such an idea of incorporating both supply-oriented routing and demand-oriented inventory considerations in a logistics distribution system was first proposed by Beltrami and Bodin (1974), followed by some literature which aimed to minimize either the fleet size required for goods delivery in the strategic domain (Larson, 1988; Webb and Larson, 1995) or the corresponding distribution costs in the operational domain (Burns et al., 1985; Federgruen et al., 1986; Blumenfeld et al., 1987; Dror and Ball, 1987; Herer and Levy, 1997). As noted in Dror and Ball (1987), one distinctive feature of IRP models is the ability to ensure that none of the customers run out of the commodity at any time in the planning horizon of logistics distribution, and accordingly, it seems that IRP may be more practical for the operations of demand-responsive logistics distribution, relative to classical VRP approaches.

The RAP appears in many different versions in accordance with various applications. The optimization goal can contain single- or multiple-objectives, when the latter is considered, a weighted objective or the Pareto criterion is usually adopted for determining the optimal solution. Linear RAP (LRAP) optimizes a linear objective while nonlinear RAP (NRAP) deals with nonlinear objective function. The limited resource to be allocated can be either discrete or continuous. A comprehensive survey related to RAP can be found in.

There also exist different methods for tackling the RAP due to its various formulations. Linear programming approaches have been used to formulate the cost-effectiveness analysis for the health care resource allocation. Basso and Peccati proposed a dynamic programming (DP) algorithm with an efficient pruning procedure for solving the LRAP, which maximizes the linear profit. As for the NRAP, a fuzzy DP technique proposed by

Lai and Li incorporates fuzzy evaluation and fuzzy optimization with the traditional DP for obtaining the maximum return. Morales et al. also presented three parallel DP algorithms using pipeline, dominancy, and resource parallelism to conquer the curse of dimensionality. Bretthauer and Shetty devised a branch and bound algorithm for solving NRAP. They further improve the algorithm by incorporating the pegging method for solving the problem more efficiently. Besides mathematical programming approaches, an alternative is using meta-heuristic algorithms.

Dynamic programming (DP) is an optimization approach that transforms a complex problem into a sequence of simpler problems; its essential characteristic is the multistage nature of the optimization procedure. More so than other optimization techniques, DP provides a general framework for analyzing many problem types. Within this framework a variety of optimization techniques can be employed to solve particular aspects of a more general formulation. Resource allocation problem RAP is the process of allocating resources among the various projects or business units. Resource may be a person, asset, material, or capital which can be used to accomplish a goal. A project may be a set of related tasks which have a specific goal. A goal my be objective or target, usually driven by specific future financial needs. The best or optimal solution may mean maximizing profits, minimizing costs, or achieving the best possible quality. An almost infinite variety of problems can be tackled this way, but here are some typical examples as follow. Finance and investment: Working capital management involves allocating cash to different purposes (accounts receivable, inventory, etc.) across multiple time periods, to maximize interest earnings. Capital budgeting: involves allocating funds to projects that initially consume cash but later generate cash, to maximize a firm’s return on capital. Portfolio optimization: creating efficient portfolios involves allocating funds to stocks or bonds to maximize return for a given level of risk, or to minimize risk for a target rate of return. Job shop scheduling: involves allocating time for work orders on different types of production equipment, to minimize delivery time or maximize equipment utilization and many other applications that can be formulated as resource allocation problem.

CHAPTER 3 MODELING

3.1 System specification

This section presents the system specification, which includes the definitions of system components (i.e., nodes), and the conceptual framework of the proposed model.

In the proposed model, we define, as follows, three types of nodes, including: (1) hubs, (2) distribution centers, and (3) warehouse depots, based on their service-competence intensities, where the service-competence intensity (ρ) is aggregated by: (1) yearly transshipment amount (α), and (2) yearly storage capacity (β).

(1) A hub is specified as its service-competence intensity (ρ) is greater than a given threshold δ_1 (i.e., $\rho \geq \delta_1$).

(2) A distribution center refers to a regional logistics facility when its service-competence intensity (ρ) is bounded between respective thresholds δ_1 and δ_2 (i.e., $\delta_2 \leq \rho < \delta_1$).

(3) A warehouse depot represents a local logistics facility as its service-competence intensity (ρ) is smaller than a respective threshold δ_2 (i.e., $\rho < \delta_2$).

Correspondingly, each type of node has its unique transshipment amount and storage capacity specified in the framework.

In order to formulate the aforementioned hierarchical GL networks problem, a comprehensive conceptual model is proposed, as shown in Fig. 3-1, which involves three main operational phases, including: (1) hierarchical clustering demand spots, (2) deciding the number and type of nodes, and (3) determining the location of nodes to carry out the proposed hierarchical GL networks design. In phase 1, the original demand spots are given and grouped, followed by the hierarchical clustering. Accordingly, the number and location of type nodes in each demand group are determined in phase 2 and phase 3 by integer programming respectively. Finally, we also consider the multiple GL channel members and related factors, e.g., investment costs and risks, logistics operational costs, potential benefits, transnational logistics restrictions, and regional demand variations in formulating the proposed multi-objective function to alleviate the decision bias for configuring the hierarchical GL networks and locating the corresponding facilities. The corresponding models executed in these phases are detailed in the following section.

To facilitate model formulation, four assumptions are postulated below.

(1) Only has hub, distribution center and warehouse depot three types of nodes are considered in the proposed model.

(2) The demand quantity associated with each given original demand spots is known.

(3) The range of service-competence intensity associated with each type of nodes of the proposed hierarchical GL networks is known.

(4) The proposed hierarchy is simply composed of three layers involving hubs, distribution centers, and warehouse depots, respectively, where the facilities of a given layer are served merely by the facilities of the direct upper layer. For instance, the hub layer only serves the distribution center layer, and similarly, the distribution center layer provides service only to the layer of warehouse depots.

(5) Facility capacities associated with each layer members of the proposed integrated logistics system are known and given.

(6) Only the single-product such as air express cargo condition is considered in the proposed model.

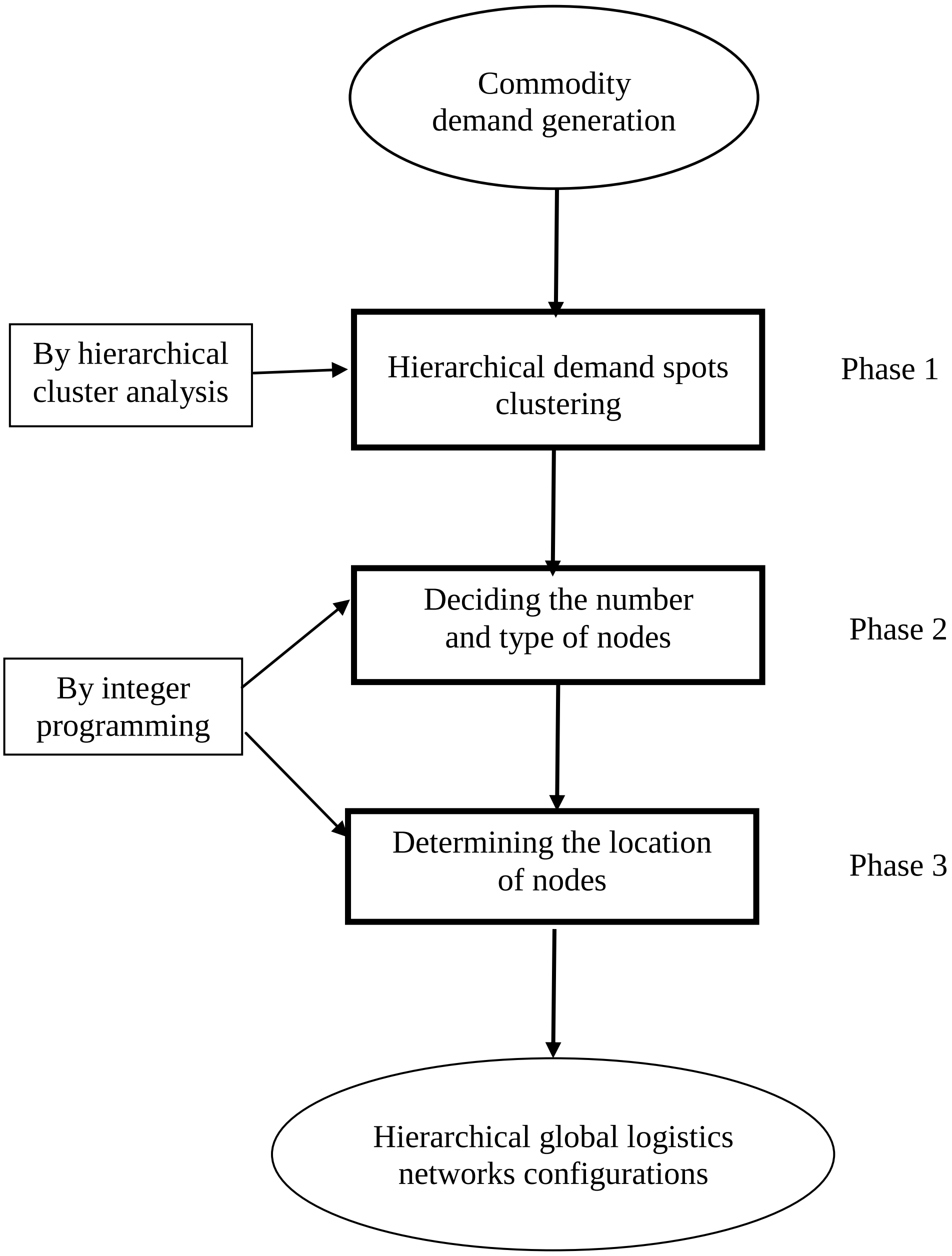

FIGURE 3-1 Hierarchical network conceptual model

3.2 Model development

The scheme of the proposed hierarchical GL networks planning model is shown in Fig. 3-2, consisting of three sequential mechanisms: (1) hierarchical cluster analysis, (2) deciding the number of facilities, (3) determining the facility location. The mechanism of hierarchical cluster analysis aims to classify demand spots into certain hierarchical demand groups, followed by the next two functions conducted to decide appropriate number and locations of facilities to serve these hierarchical demand groups. The resulting 3-layer hierarchical GL networks configurations for international express delivery are illustrated in Fig. 3-3.

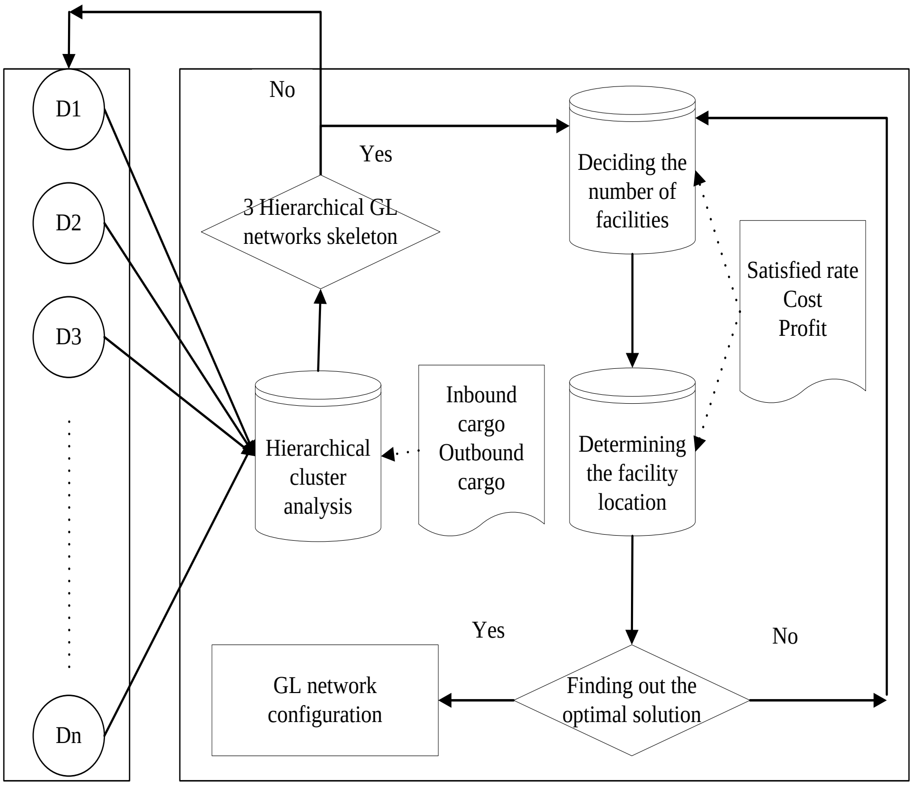

FIGURE 3-2 The scheme of the proposed model

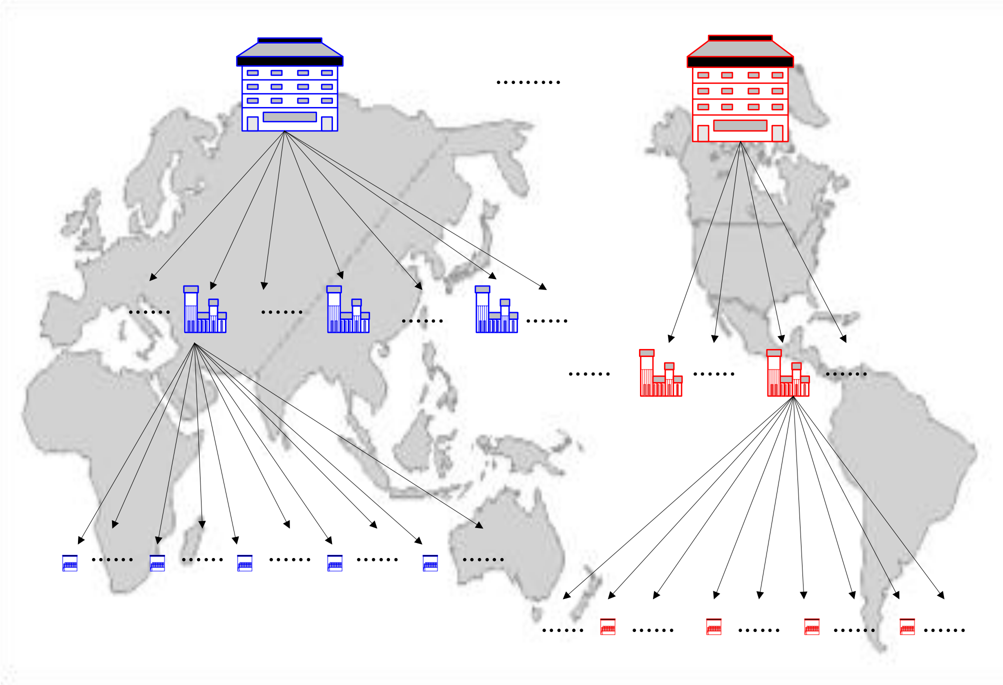

FIGURE 3-3 Three-layer hierarchical GL networks

3.3 Demand-spot hierarchical cluster analysis

The mechanism of hierarchical cluster analysis, as illustrated in Fig. 3-4, is composed of three steps including: (1) selection of distance metrics, (2) variable standardization, and (3) hierarchical clustering. The primary steps executed in the aforementioned are detailed in the following.

In the first step (i.e., selection of distance metrics), in general, hierarchical cluster analysis regards each object as a point in a multi-dimensional space defined by the values of each of its attributes. The distance between two objects is measured to determine the similarity of the objects in terms of each of its attributes. For this reason, the choice of a distance metric is the initial step of hierarchical cluster analysis. There are variety of distance metrics such as Euclidean distance, Mahalanobis distance, city block distance, and Minkovski distance, but Euclidean distance is the most common and intuitive and was used in this study.

The second step (i.e., variable standardization) aims to standard the variable. Variable standardization is an important step for hierarchical cluster analysis, since differences in units and the magnitude of the variance in each individual attribute would influence the computation result of distance metrics and it is facilitated to process the heterogeneity of decision variables. We obtained a total of 2 variable candidates for the decision variables, with the generalization that they were classified into the group of significant factors. The denotations as well as explications of these finalized decision variables are summarized as follow.

(1) σ_i^1 is represented the inbound cargo amount of i^{th} demand spot.

(2) σ_i^2 is represented the outbound cargo amount of i^{th} demand spot.

Therefore, the procedure of standardization with respect to σ_i^p is conducted, and herein, the standardized value of σ_i^p ($\tilde{\sigma}_i^p$) is given by

$$\tilde{\sigma}_i^p = \frac{\sigma_i^p - \bar{\sigma}^p}{S^p} \tag{1}$$

Where $\bar{\sigma}^p$ and S^p correspond to the values of the mean and standard deviation with respect to σ_i^p, respectively, as denoted by

$$\bar{\sigma}^p = \frac{\sum_{i=1}^{N} \sigma_i^p}{N}, \tag{2}$$

$$S^p = \left[\frac{\sum_{i=1}^{N} \left(\sigma_i^p - \bar{\sigma}^p \right)}{N-1} \right]^{\frac{1}{2}}. \tag{3}$$

Herein, N represents the number of customer of demand spots that are given from the original data.

After the procedures of selection of distance metrics and variable standardization, the final step is hierarchical clustering. Since the purpose of hierarchical cluster analysis is to combine objects into groups or hierarchical clusters, some rules of methods are required to determine how to form these groups or hierarchical clusters. Hence, hierarchical clustering algorithms are the rules or methods used for this purpose. Some of the popular algorithms are the centroid method such as the single-linkage method, the complete-linkage method, the average-linkage method and the Ward's method. Single-linkage is the primitive method of hierarchical clustering and its computation process is briefer than other method. In the single-linkage method, the distance between two clusters is defined as the minimum of the distances between all possible pairs of objects in the two clusters. Euclidean distance matrix (D) is constructed in which each element (ω_{ij}) represents the distance between a given pair of cluster i and j. Herein, we have D and ω_{ij} expressed as

$$D = \begin{bmatrix} \omega_{11} & \omega_{12} & \cdots & \omega_{1i} \\ \omega_{21} & \omega_{22} & \cdots & \omega_{2i} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{i1} & \omega_{i2} & \cdots & \omega_{ij} \end{bmatrix}_{i \times j}, \quad \omega_{ij} = 0, \text{ if } i = j, \quad \omega_{ij} = \omega_{ji}, \text{ if } i \neq j \tag{4}$$

In order to obtain hierarchical skeleton, the Euclidean distance matrix (D) is calculated three times to find out any arbitrary two demand spot minimum Euclidean distance by single-linkage. After hierarchical cluster, the hierarchical tree is shown in Fig. 3-5. The vertical axis of a hierarchical tree indicates the Euclidean distance where two objects or clusters merge to form a large cluster.

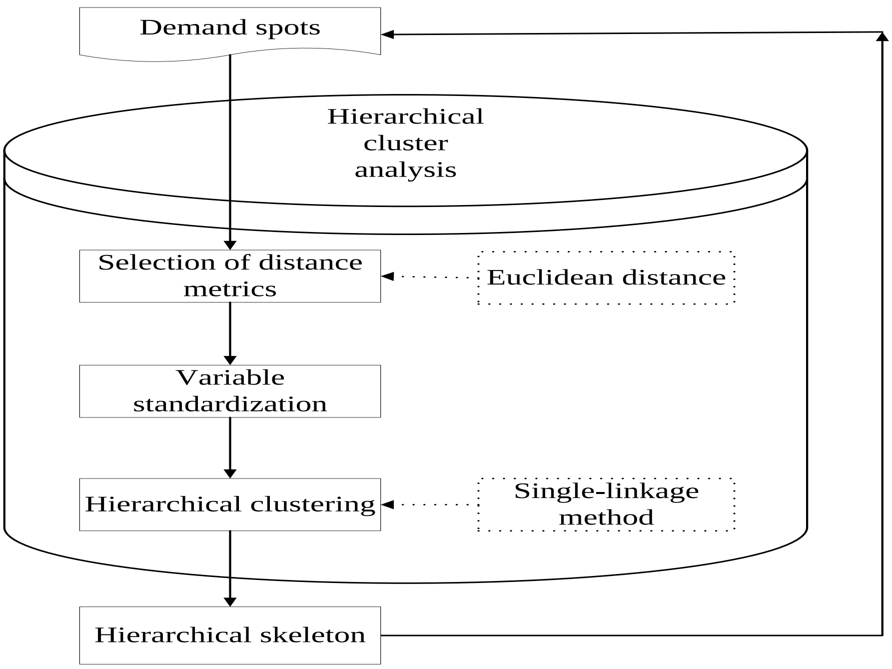

FIGURE 3-4 Conceptual framework for cluster analysis

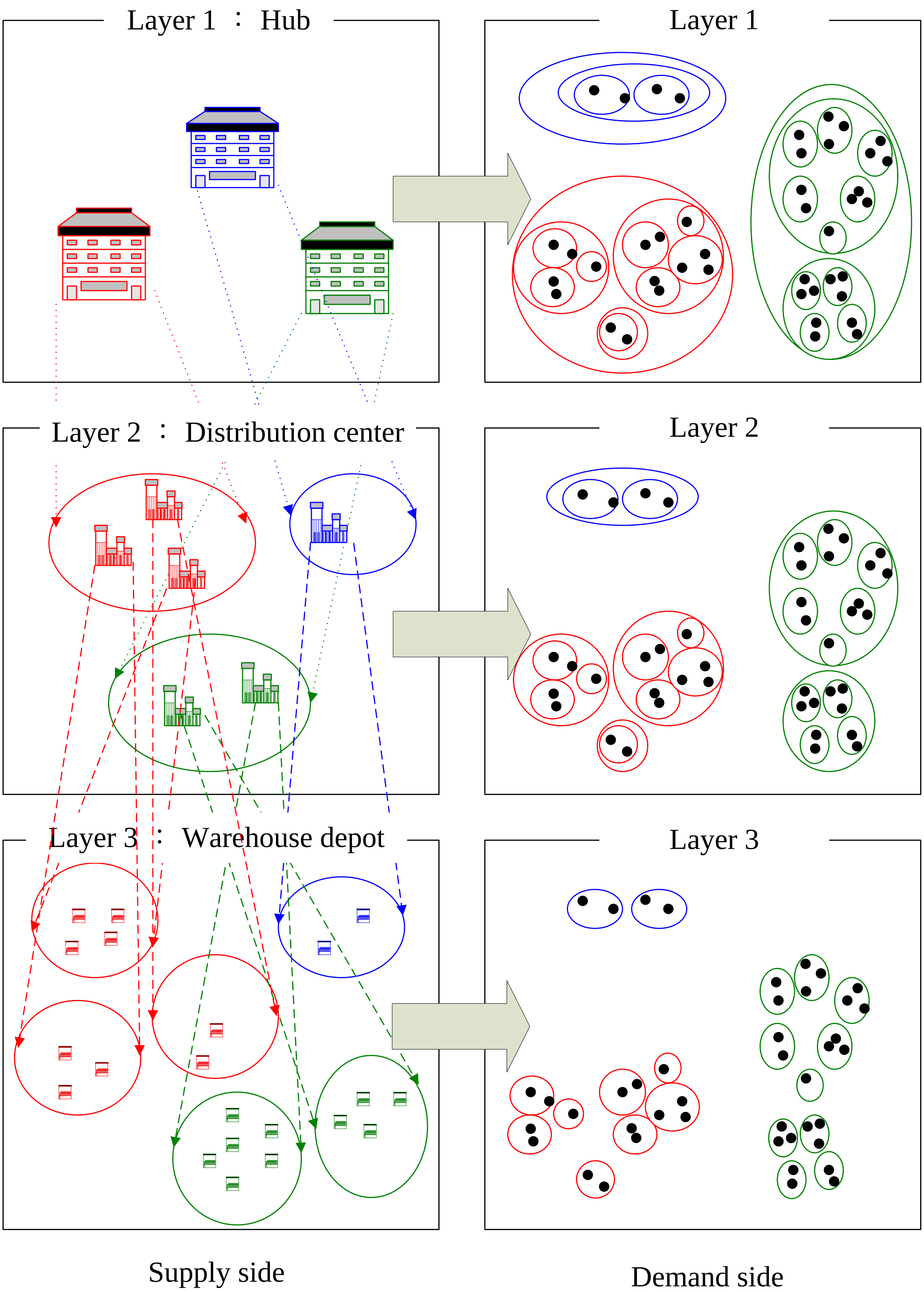

FIGURE 3-5 Conceptual framework for hierarchical tree

3.4 Facility networks configurations

This subsection presents the second and third mechanisms which use to construct facility networks by integer programming. Given the aforementioned assumptions, an integrated and composite multi-objective optimization model is formulated to seek equilibrium solutions with the goal of minimizing the hierarchical GL networks configurations cost, maximizing the net profit of hierarchical GL networks operational, and maximizing the satisfaction rate of customer demand, respectively. However, it is almost certain that these three goals will conflict with each other in the corresponding the hierarchical GL networks configuration process. A typical example is the trade-off between minimizing the hierarchical GL networks configurations cost and maximizing the net profit of hierarchical GL networks operational and the satisfaction rate of customer demand. And thus, the proposed system is formulated as a multi-objective optimization problem. The mathematical formulation of the proposed model is detailed below. All the notations for variables, including decision variables referring to the variables determined by the optimization process of the proposed model for hierarchical GL networks, are summarized in the below.

According to the proposed hierarchical GL networks system architecture, the composite multi-objective function ($\mathbf{\Theta}$) of the proposed model mainly contains three sub-objective functions: (1) normalized configurations cost of hierarchical GL networks ($\mathbf{\Theta}_1$) minimization, (2) normalized operational net profit ($\mathbf{\Theta}_2$) maximization, and (3) normalized satisfied rate of customer demand ($\mathbf{\Theta}_3$) maximization. Fig. 3-6 presents the related relationship between the composite multi-objective function ($\mathbf{\Theta}$) and three sub-objective functions ($\mathbf{\Theta}_1, \mathbf{\Theta}_2$, and $\mathbf{\Theta}_3$) and the affiliated factors of three sub-objective functions.

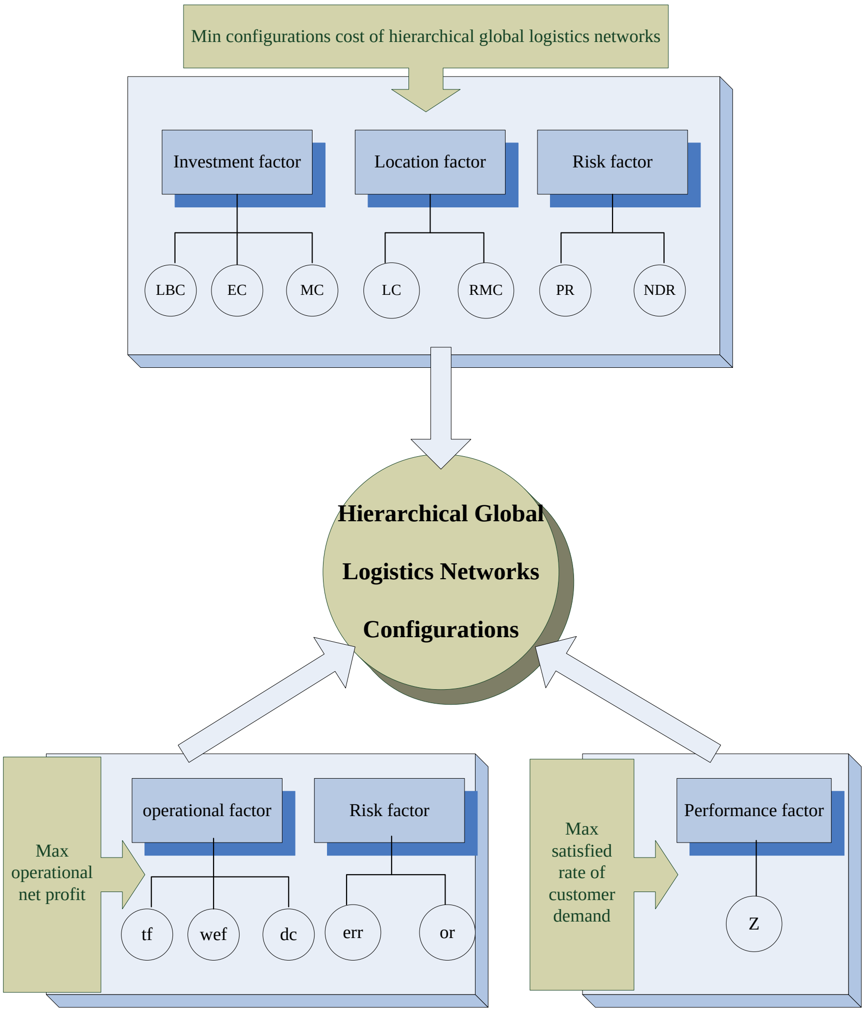

FIGURE 3-6 Conceptual framework for the composite multi-objective function

Considering the respective effects of $\mathbf{\Theta}_1$, $\mathbf{\Theta}_2$, and $\mathbf{\Theta}_3$ on $\mathbf{\Theta}$, three corresponding weights (w_1, w_2, and w_3) are specified that are associated with $\mathbf{\Theta}_1$, $\mathbf{\Theta}_2$, and $\mathbf{\Theta}_3$, respective. Three corresponding weights are also subject to the condition that the sum of w_1, w_2, and w_3 is equal to 1.

In addition, the difference in measurement scales associated with the hierarchical GL networks configurations cost, the net profit of hierarchical GL networks operational, and the satisfaction rate of customer demand may also influence the determination of optimal solutions. Therefore, the proposed multi-objective functions are rewritten as a composite normalized form $\mathbf{\Theta}$ which is given by

$$Max \quad \mathbf{\Theta} = \sum_{\sigma=2}^{3} w_{\sigma} \times \frac{\Theta_{\sigma} - \Theta_{\sigma}^{\min}}{\Theta_{\sigma}^{\max} - \Theta_{\sigma}^{\min}} - w_{1} \times \frac{\Theta_{1} - \Theta_{1}^{\min}}{\Theta_{1}^{\max} - \Theta_{1}^{\min}} \tag{5}$$

Therefore, these three sub-objective functions $\mathbf{\Theta}_1$, $\mathbf{\Theta}_2$, and $\mathbf{\Theta}_3$ are given, respectively, by

$$\Theta_1 = \frac{\Theta_1 - \Theta_1^{\min}}{\Theta_1^{\max} - \Theta_1^{\min}} \tag{6}$$

$$\Theta_2 = \frac{\Theta_2 - \Theta_2^{\min}}{\Theta_2^{\max} - \Theta_2^{\min}} \tag{7}$$

$$\Theta_3 = \frac{\Theta_3 - \Theta_3^{\min}}{\Theta_3^{\max} - \Theta_3^{\min}} \tag{8}$$

where $\Theta_1^{\max}$ and $\Theta_1^{\min}$ represent the maximum and minimum values associated with the cost $\mathbf{\Theta}_1$ oriented from the hierarchical GL networks; and, in contrast, $\Theta_2^{\max}$ and $\Theta_2^{\min}$ represent the maximum and minimum values associated with the net profit $\mathbf{\Theta}_2$ oriented from the hierarchical GL networks operational; and similarly, $\Theta_3^{\max}$ and $\Theta_3^{\min}$ represent the maximum and minimum values associated with the satisfaction rate oriented from the customer demand. The components of $\mathbf{\Theta}_1$, $\mathbf{\Theta}_2$, and $\mathbf{\Theta}_3$ are further detail below.

The hierarchical GL networks configurations cost ($\mathbf{\Theta}_1$) is measured mainly by adding the corresponding costs such as building cost (BC), land cost (LC), asset input cost (AIC), and related risk cost (RRC) for the configurations of hierarchical GL networks, as expressed in Eqs. (9).

$$\mathbf{\Theta}_1 = BC + LC + AIC + RRC \tag{9}$$

As can be seen in Eq (9) the aggregate cost associated with the building cost (BC) and asset input cost (AIC) are composed of two items, respectively. They are the raw material cost (RMC) and labor cost (LBC) in terms of building cost (BC) and the machine cost (MC) and equipment cost (EC) in terms of asset input cost (AIC), separately. In addition, the aggregate cost with the corresponding related environmental risk cost (RERC) is composed of two items where included political risk (PR) and natural disaster risk (NDR). The mathematical forms of the aforementioned components shown in Eq. (9) are further expressed as presented below.

$$\mathbf{\Theta}_1 = \sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\sum_{\forall j}\left(BC_{i_h^s,j} + LC_{i_h^s,j} + AIC_{i_h^s,j} + RERC_{i_h^s}^{\Theta_1}\right)\times X_{i_h^s,j}$$

$$= \sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\sum_{\forall j}\left[\left(RMC_{i_h^s,j} + LBC_{i_h^s,j}\right) + LC_{i_h^s,j} + \left(MC_{i_h^s,j} + EC_{i_h^s,j}\right) + \left(PR_{i_h^s} + NDR_{i_h^s}\right)\right]\times X_{i_h^s,j} \quad (10)$$

Similarly, the net profit of hierarchical GL networks operational ($\mathbf{\Theta}_2$) is measured mainly based on the total revenues (r) across 3-layer hierarchical GL networks minus the sum of the induced costs, which include the items of operational cost (oc), distribution cost (dc), and related operational risk cost (rorc) for the operations of hierarchical GL networks, as expressed in Eqs. (11).

$$\mathbf{\Theta}_2 = r - oc - dc - rorc \quad (11)$$

In the same way, as can be seen in Eq (11) the aggregate cost in terms of operational cost (oc) and related operational risk cost are also composed of two items, respectively. First, they are the tax fee (tf) and water and electricity fee (wef) in terms of operational cost (oc).

Next, the aggregate cost with the corresponding related operational risk cost (rorc) is composed of two items where included exchange rate risk (err), and human risk (hr). The mathematical forms of the aforementioned components shown in Eq. (11) are further expressed as presented below.

$$\mathbf{\Theta}_2 = \sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\sum_{\forall j}\left(r_{i_h^s,j} - oc_{i_h^s,j} - dc_{i_h^s,j} - rorc_{i_h^s,j}^{\Theta_2}\right)\times X_{i_h^s,j} \times Y_{i_h^s,j}$$

$$= \sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\sum_{\forall j}\left[r_{i_h^s,j} - \left(tf_{i_h^s,j} + wef_{i_h^s,j}\right) - dc_{i_h^s,j} - \left(err_{i_h^s,j} + hr_{i_h^s,j}\right)\right]\times X_{i_h^s,j} \times Y_{i_h^s,j} \tag{12}$$

Finally, we consider the last sub-objective function that is satisfied rate of customer demand ($\mathbf{\Theta}_3$) measured by providing the distribution amount (Y) divided by the original demand amount (D) in the unit time during the plan period, as express in Eq. (13). In other words, we promise that the upper layer facility must accomplish all service and work within four hours to lower layer facility.

$$\mathbf{\Theta}_3 = Z = t * \frac{Y}{D} \tag{13}$$

The mathematical forms of the aforementioned components shown in Eq. (13) are further expressed as presented below.

$$\mathbf{\Theta}_3 = \sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\sum_{\forall j} Z_{i_h^s,j} \times X_{i_h^s,j}$$

$$= \sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\sum_{\forall j}\left(\bar{t}_{i_h^s,j} \times \frac{Y_{i_h^s,j}}{D_j}\right)\times X_{i_h^s,j} \tag{14}$$

3.5 Related model constraints for hierarchical network

Considering the required conditions of the decision variables $X_{i_h^s,j}$ and $Y_{i_h^s,j}$, either compelled by corporation regulations and law or limited by operating capacities, eleven groups of constraints (Eqs. (15)-(25)) are involved in the proposed model, and their mathematical forms are given respectively by

$$\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} X_{i_h^s,j} = 1 \qquad ,\forall j \qquad (15)$$

$$\sum_{\forall j} Y_{i_h^s,j} \le \overline{Y}_{i_h^s} \qquad ,\forall (i_h^s,h,s) \qquad (16)$$

$$Z_{i_h^s,j} = \bar{t}_{i_h^s,j} \times \frac{Y_{i_h^s,j}}{D_j} \qquad ,\forall (i_h^s,j,h,s) \qquad (17)$$

$$\underline{Z}_{i_h^s} \le \sum_{\forall j} Z_{i_h^s,j} \le \overline{Z}_{i_h^s} \qquad ,\forall (i_h^s,h,s) \qquad (18)$$

$$\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} Y_{i_h^s,j} \le D_j \qquad ,\forall j \qquad (19)$$

$$\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} Z_{i_h^s,j} \ge G_j \qquad ,\forall j \qquad (20)$$

$$RERC_{i_h^s}^{\Theta_1} \le \delta_{i_h^s}^{\Theta_1} \qquad ,\forall (i_h^s,h,s) \qquad (21)$$

$$rorc_{i_h^s,j}^{\Theta_2} \le \delta_{i_h^s,j}^{\Theta_2} \qquad ,\forall (i_h^s,h,s) \qquad (22)$$

$$X_{i_h^s,j} \in \{0,1\} \qquad ,\forall (i_h^s,j,h,s) \qquad (23)$$

$$Y_{i_h^s,j} \ge 0 \qquad ,\forall (i_h^s,j,h,s) \qquad (24)$$

$$Z_{i_h^s,j} \ge \underline{Z}_j \qquad ,\forall (i_h^s,j,h,s) \qquad (25)$$

where $X_{i_h^s,j}$ and $Y_{i_h^s,j}$ are two major decision variables, which are determined according to the goal of minimizing the hierarchical GL networks configurations cost, maximizing the net profit of hierarchical GL networks operational, and maximizing the satisfaction rate of customer demand. Note that, as can be seen in the above three sub-objective item of Eq. (10), Eq. (12), and Eq. (14), respectively. According to $Y_{i_h^s,j}$ decision variables, $Z_{i_h^s,j}$ is a derivative decision variable and it represents the satisfied rate of customer demand in the unit time during the plan period. We given $\bar{t}_{i_h^s,j}$ is the unit time during the plan period to guarantee and content customer demand. $\underline{Z}_{i_h^s}$ and $\overline{Z}_{i_h^s}$ represent the satisfied rate of customer demand minimum and maximum required by enterprise's regulations for the hierarchical GL networks activities of corresponding distribution treatment at any given facilities. D_j and G_j are the original demand for amount of distribution and the lower bound of the satisfaction rate of customer demand in the unit time during the plan period, respectively. $\delta_{i_h^s}^{\Theta_1}$ and $\delta_{i_h^s,j}^{\Theta_2}$ are the risk functions in the terms of configuration and operation corresponding to the hierarchical GL networks.

Furthermore, Eq. (15) is specified to ensure that any given facility is assigned to merely sever a single original demand spot in order to avoid squandering the facility resource. Eq. (16) represents the corresponding limitation of aggregate distribution amount in any given facility. The above two constraints are aimed at two major decision variables to limit in order to conform the present situation of international express delivery enterprise.

Eq. (17) and (18) denotes the characteristics of derivative decision variables $Z_{i_h^s,j}$, the corresponding upper and lower bounds should be specified the respective governmental regulations and the corresponding basic requirements for international express delivery enterprise distribution resource allocation. Eq. (19) and (20) correspond to the restrictions of original demand spot associated, respectively, with given basic amount of distribution and the satisfaction rate of customer demand. From original demand spot point of view, the basic amount of distribution should be subject to the corresponding facility capacity, and thus is formulated as shown in (19) and (20).

In addition, considering the related risk caused by uncertain types of natural, operational, and artificial that is gathered in a given region or facility, in some cases, a natural disaster, e.g., earthquake and flood, an operational exchange, e.g., currency appreciation and depreciation, and a governmental administration, e.g., the regime polity, may issue regulations to restrict the aggregated distribution amount of international express delivery for regional risk management, as presented in (21) and (22). If such regulations do not exist in practice, the corresponding risk factor can be set to be approximately infinity.

It is noteworthy that, in addition to the aforementioned constraints, all the decision variables should be subject to the non-negative domain in order to meet the basic requirement of feasible solution following their definitions shown in follow. Corresponding, all the amount decision variables should be restricted to the real-value domain greater than or equal to zero; and the others are 0-1 binary decision variables, as shown in (23)-(25). Therefore, according to our proposed model, the optimal solutions of decision variables together with these updated functions will determine the best facility location and optimal distribution amount associated with each layer facility under the system-optimization condition for hierarchical GL networks.

3.6 Operational planning model and demand processing

The architecture of the proposed dynamic global logistics resource allocation system is composed mainly of three sequential phases: (1) demand processing, (2) vehicle assignment, (3) manpower assignment, which involves three major potential mechanisms in charge of respective functions of DRA model. Here phases (1) refer to the demand-oriented data processing conducted for the purpose of setting demand distribution patterns with respective service priority. The resulting output is then input to the remaining phases for dynamic optimization in allocating the time-varying global logistics resources available. The aforementioned there sequential mechanisms are carried out each time when the database of air express cargo demand is input to trigger a new global logistics distribution mission.

As can be seen in Fig. 3-7, these potential mechanisms are classified into two groups: (1) demand side, and (2) supply side. Here, demand side refers to the sources of air express demand from the private or public organizations; the settling distribution mechanism is defined as the generator which aims to efficiently and correctly forecast the resulting inbound historical air express data in response to the demands distribution from the affected areas in the crucial period.

Given the occurrence of air express demand distribution, resulting in different degrees of demand distribution associated with certain affected areas and years, the functionality of the supply side of proposed DRA system is triggered immediately. Therefore, based on the output of demand side, the following supply side is specified for proposed DRA system, which includes the determining the number of vehicles mechanism and the deciding the number of manpower mechanism, respectively. Herein, each respective mechanism of supply side through the real-time estimation of time-varying related parameters to the affected areas according to the estimated distribution priority associated with these areas. As can be seen in Fig. 3-8, the corresponding models and algorithms embedded in these operational phases are detailed in the following subsections.

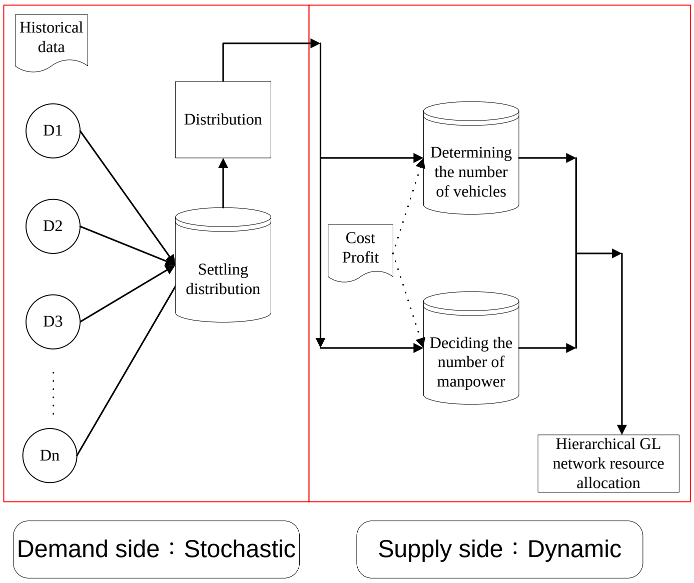

FIGURE 3-7 Conceptual model of the proposed DRA system

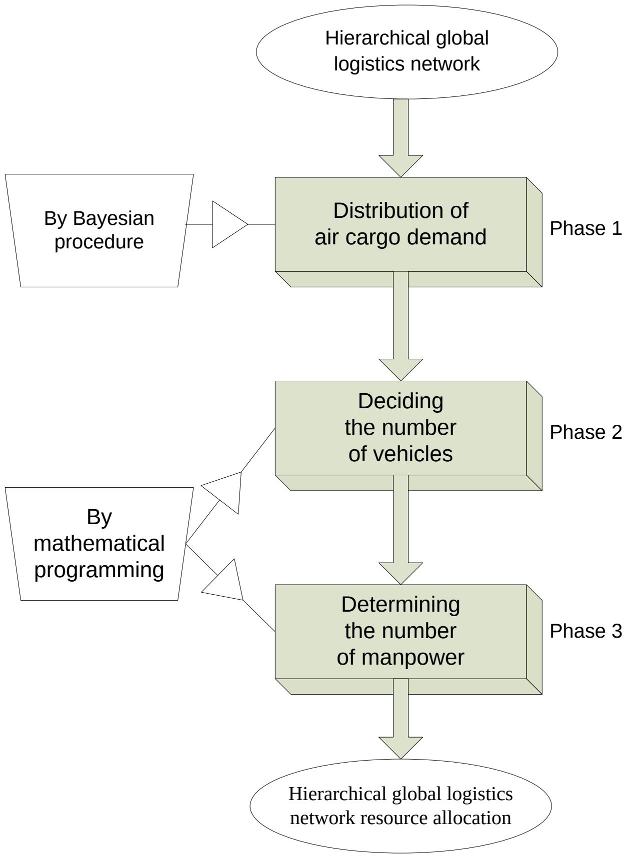

FIGURE 3-8 Resource allocation conceptual model

In addition, to specify the study scope and facilitate model formulation, four assumptions are postulated bellow.

(1) Only the single-product condition is considered in the proposed model.

(2) The time-varying quantity of product demands from historical data in any given time interval is given.

(3) Facility locations and capacities associated with of the proposed DRA model based hierarchical network system are known.

(4) Different types of vehicle and manpower are allowed.

The problem of demand estimation, is an important aspect in the analysis of probabilistic systems. It is generally assumed that the demand distribution has known parameters and is static throughout the planning horizon. In practice, the parameters have to be fixed subjectively, or statistically estimated using past demand information data. But it is almost impossible to specify exactly the true values of the parameters, especially in the absence of abundant demand information, as in the case of demand for air express cargo.

Moreover, the demand for an item is generally random, and its distribution is not known completely. The reason may be that the item is newly introduced in the market, or its demand is changing with time as in the fashion industry. Therefore, the Bayesian method of updating the demand distribution as and when fresh data becomes available, continuously improves the probability distribution, so that it may adequately represent the demand at any given point of time. In this paper, air express cargo demand estimating is the primary step, which is carried out to realize the time-varying demand associated with each original demand spot. Therefore, the time-varying air express cargo demand estimate model is formulated as

$$D_i(t) = a_i \times \delta_i(t) + z_{1-\alpha} \times STD_i(t) \quad (26)$$

where a_i is the parameter representing the average yearly demand; $D_i(t)$ represents the time-varying air express cargo demand associated with a original demand spot i in a given time interval t; $z_{1-\alpha}$ represents the respective statistical value chosen given that the tolerable possibility of time-varying air express cargo demand shortage is set to be α; $\delta_i(t)$ represents the estimated number of ; $STD_i(t)$ represents the time-varying standard deviation of air express cargo demand associated with affected area i, which is give by

$$STD_i(t) = \frac{\sqrt{\sum_{\varepsilon=0}^{t-1}\left[D_i(t-\varepsilon) - \bar{D}_i(t)\right]^2}}{t-1} \tag{27}$$

Where $\bar{D}_i(t)$ represents the time varying mean value with respect to the time-varying demand $D_i(t)$, and it is given by

$$\bar{D}_i(t) = \frac{a \times \sum_{\varepsilon=0}^{t-1} \delta_i(t-\varepsilon)}{t} \tag{28}$$

It is noteworthy that the above simplified treatments proposed to address the concern of buffer demands appear reasonable in the operational cases of dynamic resource allocation. It is because that the time for data-processing and allocating logistics resources during the crucial rescue period are quite limited, resulting in our simplification incorporating the bound of the demand distribution headway rather than using variable lead times for the estimation of time-varying relief demand.

3.7 Resource allocation model

This subsection presents the resource allocation model which use to construct a mathematical model by integer programming. Given the aforementioned assumptions, an integrated and composite multi-objective optimization model is formulated to seek equilibrium solutions with the goal of the economic objective and environment objective. However, it is almost certain that these three goals will conflict with each other in the corresponding the resource allocation process. And thus, the proposed system is formulated as a multi-objective optimization problem. The mathematical formulation of the proposed model is detailed below. All the notations for variables, including decision variables referring to the variables determined by the optimization process of the proposed model under hierarchical GL networks, are summarized in the follow.

According to the proposed hierarchical GL networks system architecture, the composite multi-objective function (Φ) of the proposed model mainly contains three sub-objective functions: (1) normalized mode assignment (Φ_1) maximization, (2) normalized manpower assignment (Φ_2) minimization, and (3) normalized energy allotment (Φ_3) minimization. Fig. 3-9 presents the related relationship between the composite multi-objective function (Φ) and three sub-objective functions (Φ_1, Φ_2, and Φ_3) and the affiliated factors of three sub-objective functions.

This phase aims to assign resource to appropriate facilities under three goals, i.e., maximizing the aggregate mode assignment, and minimizing both the corresponding aggregate manpower operational costs and energy allotment. In addition, one distinctive feature of the proposed model is that in addition to vehicles standing by in the depot, the time-varying proportion of en-route vehicles returning to the depot during a given time horizon T is also considered for the use of vehicle assignment in this phase. Conveniently, the multiple-objective optimization based approach is used in this phase, and the corresponding composite objective function (Φ) is given by

$$Max \quad \Phi = w_1 \times \Phi_1 - w_2 \times \Phi_2 - w_3 \times \Phi_3 \tag{29}$$

where w_1, w_2, and w_3 are positive, and the sum of these three weights should be equal to 1; Φ_1, Φ_2, and Φ_3 represent the normalized forms of the corresponding aggregate operations vehicle loading rate, operational costs and delivery time, respectively, and are given by

$$\Phi_1 = \frac{\Phi_1 - \Phi_{min}}{\Phi_{max} - \Phi_{min}} \tag{30}$$

$$\Phi_2 = \frac{\Phi_2 - \Phi_{min}}{\Phi_{max} - \Phi_{min}} \tag{31}$$

$$\Phi_3 = \frac{\Phi_3 - \Phi_{min}}{\Phi_{max} - \Phi_{min}} \tag{32}$$

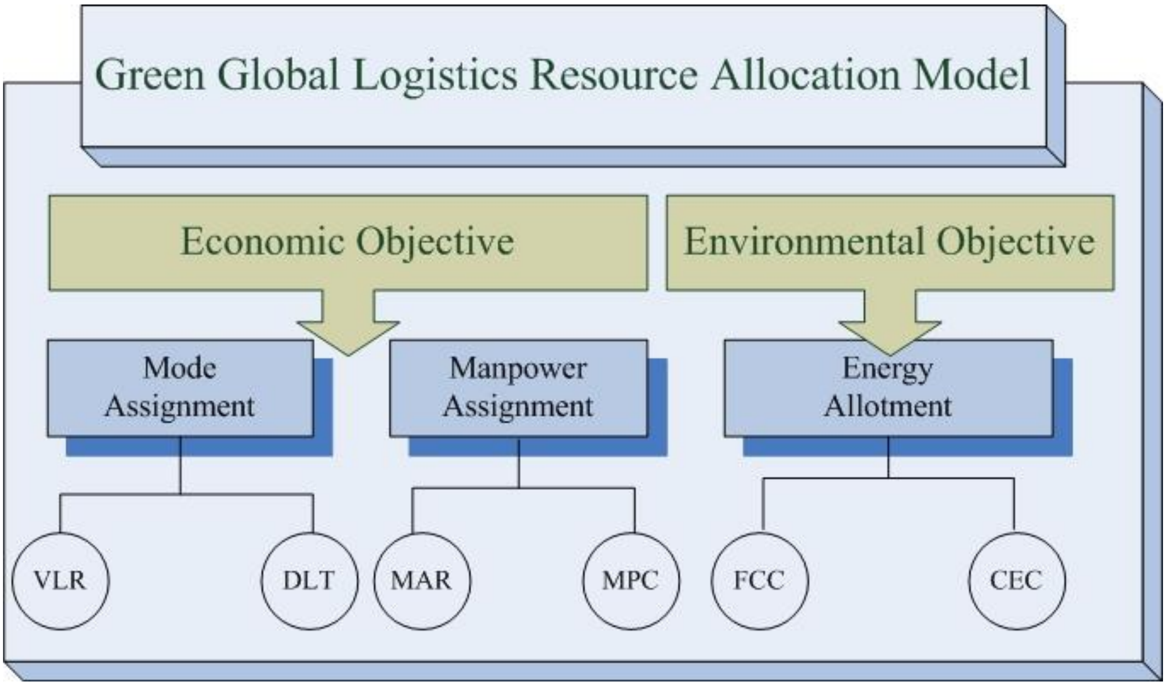

FIGURE 3-9 Conceptual framework for resource allocation multi-objective function

VLR and DLT represent the normalized forms of the corresponding aggregate operations vehicle loading rate and delivery time, respectively, and are given by

$$\bar{VLR} = \frac{VLR - VLR_{\min}}{VLR_{\max} - VLR_{\min}} \tag{33}$$

$$\bar{DLT} = \frac{DLT - DLT_{\min}}{DLT_{\max} - DLT_{\min}} \tag{34}$$

Maximizing the aggregate vehicle loading rate (VLR), and minimizing delivery time (DT) for the resource allocation, as expressed in Eqs. (35). In the same way, as can be seen in Eq (36)-(37) the aggregate vehicle loading rate and delivery time in terms of operational time and related vehicle type are also composed of follow items, respectively.

$$Max\ \Phi_1 = w_{VLR}\,\bar{VLR} - w_{DLT}\,\bar{DLT} \tag{35}$$

$$VLR = \sum_{\forall t}\sum_{\forall l}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} \frac{V(t)_{i_h^s} \times P_{l,i_h^s}(t)}{\tilde{U}_{l,i_h^s}} \tag{36}$$

$$DLT = \sum_{\forall t}\sum_{\forall l}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s}\left[\left(|t - \underline{T}|\right) + \left(M_{i_h^s} \times st_{i_h^s}\right)\right] \times P_{l,i_h^s}(t) \tag{37}$$

MAR and MPC represent the normalized forms of the corresponding aggregate manpower assignment rate and manpower cost, respectively, and are given by

$$\bar{MAR} = \frac{MAR - MAR_{\min}}{MAR_{\max} - MAR_{\min}} \tag{38}$$

$$\bar{MPC} = \frac{MPC - MPC_{\min}}{MPC_{\max} - MPC_{\min}} \tag{39}$$

Maximizing the aggregate manpower rate (MAR), and minimizing manpower cost (MPC) for the resource allocation, as expressed in Eqs. (40). In the same way, as can be seen in Eq (38)-(39) the aggregate manpower assignment rate and manpower cost in terms of operational time and related manpower and vehicle type are also composed of follow items, respectively.

$$Max\ \Phi_2 = w_{MAR}\ \bar{MAR} - w_{MPC}\ \bar{MPC} \tag{40}$$

$$MAR = \sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} \frac{(V(t)_{i_h^s} / u_{g,i_h^s}) \times Q_{g,i_h^s}(t)}{\tilde{U}_{g,i_h^s}} \tag{41}$$

$$MPC = \sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} (V(t)_{i_h^s} / u_{g,i_h^s}) \times mc_{g,i_h^s} \times Q_{g,i_h^s}(t) \tag{42}$$

FCC and CEC represent the normalized forms of the corresponding aggregate fuel consumption cost and CO2 emission cost, respectively, and are given by

$$\bar{FCC} = \frac{FCC - FCC_{\min}}{FCC_{\max} - FCC_{\min}} \tag{43}$$

$$\bar{CEC} = \frac{CEC - CEC_{\min}}{CEC_{\max} - CEC_{\min}} \tag{44}$$

Maximizing the aggregate fuel consumption (FCC), and minimizing CO2 emission cost (CEC) for the resource allocation, as expressed in Eqs. (45). In the same way, as can be seen in Eq (46)-(47) the aggregate fuel consumption cost and CO2 emission cost in terms of related economic indicator and transportation distance are also composed of follow items, respectively.

$$Min\ \Phi_3 = w_{FCC}\ \bar{FCC} + w_{CEC}\ \bar{CEC} \tag{45}$$

$$FCC = \sum_{\forall t}\sum_{\forall l}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} dis_{i_h^s} \times fc_{i_h^s} \times P_{l,i_h^s}(t) \tag{46}$$

$$CEC = \sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} \frac{V(t)_{i_h^s}}{\tilde{U}_{l,i_h^s}} \times CV_{l,i_h^s} \times ec_{l,i_h^s} \times P_{l,i_h^s}(t) \tag{47}$$

Considering the required conditions of the decision variables $V(t)_{i_h^s}$ and $P(t)_{i_h^s}$, either compelled by corporation regulations and law or limited by operating capacities, ten groups of constraints (Eqs. (48)-(57)) are involved in the proposed model, and their mathematical forms are given respectively by follow. Eqs. (48)-(52) are related to mode assignment constraints and Eqs. (53)-(57) are related to manpower assignment constraints.

$$\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} \gamma_{i_h^s} \times V(t)_{i_h^s} \times P_{l,i_h^s}(t) \le \tilde{\Gamma}_l \quad \forall l,t \tag{48}$$

$$\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} V(t)_{i_h^s} \times P_{l,i_h^s}(t) \le \tilde{U}_l \quad \forall l,t \tag{49}$$

$$\sum_{l=1}^{N_l(t)}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} V(t)_{i_h^s} \times P_{l,i_h^s}(t) \le \sum_{l=1}^{N_l(t)} \tilde{U}_l \quad \forall t \tag{50}$$

$$N_l(t) = N_l(t-1) + \text{int}\left\{E\left[\left(\tilde{N} - N_l(t-1)\right) \times \sigma(t)\right] \times (1-\varepsilon)\right\} \quad \forall t \tag{51}$$

$$P_{l,i_h^s}(t) \quad \forall l,i,s,h,t \tag{52}$$

$$\sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} Q_{g,i_h^s}(t) \le Q_{i_h^s}^T \tag{53}$$

$$\sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} Q_{g,i_h^s}(t) \le \tilde{Q}_{i_h^s} \quad \forall i_h^s \tag{54}$$

$$\sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} (V(t)_{i_h^s} / u_{g,i_h^s}) \times \xi_{g,i_h^s} \times Q_{g,i_h^s}(t) \le \tilde{\Xi}_{i_h^s} \quad \forall i_h^s \tag{55}$$

$$\sum_{\forall t}\sum_{\forall g}\sum_{\forall s}\sum_{\forall h}\sum_{\forall i_h^s} (V(t)_{i_h^s} / u_{g,i_h^s}) \times Q_{g,i_h^s}(t) \le \tilde{U}_{i_h^s} \quad \forall i_h^s \tag{56}$$

$$Q_{g,i_h^s}(t) \quad \forall g,i,s,h,t \tag{57}$$

Therefore, according to our proposed model, the optimal solutions of decision variables together with these updated functions will determine the best resource allocation and optimal distribution amount associated with each layer facility under the system-optimization condition for hierarchical GL networks.

CHAPTER 4 NUMERICAL STUDY

4.1 The basic scenario

To illustrate the applicability of the proposed model for hierarchical GL networks configurations, a simplified numerical study in determining the appropriate locations for siting among hub, distribution center, and warehouse depot facility was conducted. In this case study, we built specific composite multi-objective optimization model for the international express delivery enterprise based on the proposed hierarchical GL networks conceptual framework. Then, using collected statistical as well as official survey data, we estimated both input data (e.g., the original international express delivery demands), and primary parameters (e.g., the corresponding network-induced constructional costs in the proposed hierarchical GL networks framework). Using the proposed method, the optimal solutions of the specified decision variables were determined, and the resulting objective functions were then compared with the existing operational performance of DHL express company. In addition, sensitivity analyses aiming at certain key parameters were conducted to assess the proposed model's practicality in different scenarios.

4.2 Experimental design and data collection

The numerical study mainly aims at the discussion on the case of one international express delivery company DHL, which involves more than two million employees, four hundred aircrafts, and 76 thousand fleets servicing more than one and twenty hundred thousand cities and 235 countries around the world. The current international express delivery cargo capacity is more than one billion, accounting nearly for about 30% of the total international express delivery cargo of global. Currently, the international express delivery is operated and managed by DHL, FedEx, UPS, and BAX, which is an oligopolistic business enterprise and almost dismembered the global express delivery demand. In addition, there are four headquarters in the DHL global network around the world. Among these headquarters, two are located in Bonn, Germany, and London, UK, European and others are located in Singapore, Asia and Plantation, U.S.A, America, respectively. Presently, each headquarter has two to five respective hubs in operation, and thus a total of 12 hubs are considered in current situation. In addition, considering some practical difficulties and limitations of real data acquisition in this study, the corresponding international express delivery demands are assumed to be mainly supplied from among Taiwan, China, and U.S.A, which, as mentioned previously, are the three representative international express delivery cargo sources in the world. Furthermore, due to the regulation restrictions in Taiwan Strait transnational cargo transportation between Taiwan and China are not considered in this case study.

Accordingly, we have three international express delivery cargos suppliers, 15 original demand spots in Taiwan, 116 original demand spots in China, and 260 original demand spots in U.S.A. involved in the case study, thus forming an integrated logistics network structured. However, in this case study, the original demand spot are given and estimated from the population data. We give an original demand spot as the populations are more than three, five, and one hundred thousand in Taiwan, China, and U.S.A., respectively, and thus the estimated values of original demand spots are summarized in Table 4-1. Given that the amount of providing the distribution amount and the located choice action is defined by one region, and the planning facility, we then have respective problem scope specified by 3429 decision variables subject to 1068 respective constraints.

TABLE 4-1 Estimated original international express delivery cargo demand spot amounts in three regions

Taiwan	China	U.S.A.
15	116	260

In the scenario of input data acquisition, the each original demand spot demands were mainly estimated. Due to the difficulty in collecting each original demand spot demand data for business security concerns, we estimated the aforementioned original demand spot demands data through the following procedures. First, based on the collected each city population data from database of Taiwan, China, and U.S.A and national income of Tai, China, and U.S.A., we estimated the demand amount of each original demand spot using product of national income and populations, which is regarded as an appropriate value for the original demand, accounting to our survey to operators of DHL. Then, according to the previous research, the international express delivery cargos demand associated with each original demand spot were estimated using the aforementioned the original demand multiplied by the 10% ratio of the respective original demand amount relative to product of the populations and national income.

Therefore, according to the measure form related data, these original demand spots were divided into several sub-regions by geography in this case study, including the region of

China and the region of U.S.A. The region of China were divided into seven sub-regions, including Chinese northern, Chinese central, Chinese southern, Chinese eastern, Northern-east, Northern-west, and Southern-west; similarly, the region of U.S.A. were also divided into six sub-regions, including New England, Atlantic, Mid-west, South, Rockies, and Pacific, individually. All the provinces of China and the states of U.S.A. of the aforementioned sub-regions are summarized in Table 4-2. Note that the region of Taiwan was not further partitioned due to the area of Taiwan is too relatively smaller.

TABLE 4-2 Divided in three regions

Taiwan	None
China	Chinese northern：Beijing、Tianjin、Hebei、Shanxi、Inner Mongolia Chinese central： Henan、Hubei、Hunan Chinese southern：Guangdong、Hainan、Hong Kong、Macao、Guangxi Chinese eastern：Shanghai、Shandong、Jiangsu、Anhui、Zhejiang、Jiangxi、Fujian Northern-east：Liaoning、Jilin、Heilongjiang Northern-west：Shaanxi、Gansu、Qinghai、Ningxia、Xinjiang Southern-west：Chongqing、Sichuan、Yunnan、Guizhou、Tibet
U.S.A.	New England：Connecticut、Maine、Massachusetts、New Hampshire、Rhode Island、Vermont Atlantic：Delaware、District of Columbia、Florida、Georgia、Maryland、New Jersey、New York、North Carolina、Pennsylvania、South Carolina、Virginia、West Virginia Mid-west：Illinois、Indiana、Iowa、Michigan、Minnesota、Nebraska、North Dakota、Ohio、South Dakota、Wisconsin South：Alabama、Arkansas、Kentucky、Kansas、Louisiana、Mississippi、Missouri、Oklahoma、Tennessee、Texas Rockies：Arizona、Colorado、Idaho、Montana、New Mexico、Utah、Wyoming Pacific：Alaska、California、Hawaii、Nevada、Oregon、Washington

4.3 Parameters setting

The model parameters estimated in this scenario are classified into three groups: (1) cost-related parameters, (2) risk related parameters, and (3) boundary conditions. They were estimated mainly using interview survey data as well as the corresponding statistics.

Practically, it is difficult to estimate cost-related parameters, such as unit operational cost, directly from reported statistical data because of business confidentiality and security concerns. Therefore, the interviews with the corresponding key staff of the express operation and logistics-related sectors of DHL were conducted to collect related data. The interviews include both open- and closed-ended questions about the existing strategies in air express delivery and induced logistics management, as well as the potential limitations. The questionnaire was design mainly on the basis of the need to estimate the cost-related parameters of the model. For instance, given a respective cost item, the corresponding survey respondent was asked to measure the unit cost with an acceptable range. The analytical results of the interviews data were then processed to determine the unit operational costs and the boundaries using uniform distributions with respective ranges bounded by estimated upper and lower bounds, appearing in the profit-maximization objective function and in the corresponding constraints, respectively.

Risk-related parameters estimated in this scenario aim at the unit increments of money risks (m for short) for related environmental risk cost and related operational risk cost induced hierarchical GL networks configuration. They are classified into four groups associated five respective activities, including (1) regime polity ($m_{i_h^s}^{rp}$), (2) earthquake ($m_{i_h^s}^{e}$), (3) flood ($m_{i_h^s}^{f}$), (4) exchange rate ($m_{i_h^s}^{er}$), and (5) human ($m_{i_h^s}^{h}$). Among these risk-related parameters, $m_{i_h^s}^{rp}$ and $m_{i_h^s}^{h}$ is associated with the corresponding artificial organization and behavior, and the others are influenced for natural disaster and operational situation in the resulting hierarchical GL networks. As mentioned previously, a unit increment of risk-induced penalty refers to the monetary value of a particular penalty that is caused by a unit of given physical amount associated with a particular activity.

According to previous literature, such a national regime may include mainly either Democracy or Communism, which may affect the aspiration and the freedom of related business secrets for international express delivery enterprise. Conveniently, $m_{i_h^s}^{rp}$ was derived mainly from comparative measures of freedom by Freedom House and Business Environment Risk Intelligence (BERI) in this case study.

In the aspect of estimating the unit incremental risks $m_{i_h^s}^{e}$ and $m_{i_h^s}^{f}$ for the nature disaster, first, we averaged the aggregate earthquake and flood damage costs of these three regions in recent thirty years using the historical data provided by these central governments, individually. Second, the aggregate damage costs induced mainly by the earthquake and flood were measured using averaged the aggregate earthquake and flood damage costs multiplied by the ratio of the corresponding nature disaster frequently occurrence in the thirty recent years.

In contrast, exchange rate risk may mostly depend on foreign reserves, law of exchange, and foreign debts. Therefore, we estimated the exchange-oriented risk ($m_{i_h^s}^{er}$) by approximating the corresponding comparative measures of exchange risk form BERI, similar to the concept of the political risk cost of these three regions. Here, according to the method proposed, the exchange risk can be expressed by the amount of foreign debts divided by the amount of foreign reserves. In this case study, statistics of foreign debts and foreign reserves from these three central governments were used to estimate the corresponding exchange risk.

Similar to the risks induced by regime polity, human risk may be caused by either Democracy or Communism, contributing to the thinking of the workers and the education level of the society. Accordingly, we estimated ($m^h_{i^s_h}$) mainly from comparative measures of freedom by Freedom House and Business Environment Risk Intelligence (BERI) for the corresponding workers and society. It should be noted that the parameters $m^h_{i^s_h}$ may vary with the type of race, and particularly, the impacts of the white race may have an advantageous position around the world in current actual situation.

Accordingly, the cost-related and risk related parameters of the proposed composite multi-objective function ($\mathbf{\Theta}$) were estimated, where the parameters shown in the hierarchical GL networks-based the cost-minimum function ($\mathbf{\Theta}_1$) and net profit-maximum function ($\mathbf{\Theta}_2$) are summarized in Table 4-3 and 4-4, respectively. In addition, other primary parameters, e.g., the upper and lower bounds of logistics-related facilities and, shown in the constraints were also specified using the collected survey data and the corresponding corporation regulations. They are summarized in Table 4-5.

TABLE 4-3 Estimated parameters of the hierarchical GL networks-based cost-minimum function

Parameters							
Type of cost	$RMC_{i^s_h,j}$	$LBC_{i^s_h,j}$	$LC_{i^s_h,j}$	$MC_{i^s_h,j}$	$EC_{i^s_h,j}$	$PR_{i^s_h,j}$	$NDR_{i^s_h,j}$
Cost minimum							
F1	3	2	100	8	6	50	85
F2	6	6	110	4	9	35	60
F3	5	4	100	9	7	40	75

$: US dollars

TABLE 4-4 Estimated parameters of the hierarchical GL networks-based net profit-maximum function

Parameters						
Type of cost	$r_{i_h^s,j}$	$tf_{i_h^s,j}$	$wef_{i_h^s,j}$	$dc_{i_h^s,j}$	$err_{i_h^s,j}$	$hr_{i_h^s,j}$
Net-profit maximum / cost minimum						
F1	17	2	1.8	5	20	22
F2	12	1.5	1.2	4	25	17
F3	13	1.7	1.8	4.5	12	18

$: US dollars

TABLE 4-5 Primary parameters estimated in the constraints

	Parameters							
	$\bar{t}_{i_h^s,j}$	$\overline{Y}_{i_h^s}$	$\overline{Z}_{i_h^s}$	$\underline{Z}_{i_h^s}$	$\delta_{i_h^s}^{\Theta_1}$	$\delta_{i_h^s,j}^{\Theta_2}$	G_j	$\underline{Z}_j$
F1	3	60000	0.85	0.8	350	450	0.6	0.55
F2	5	85000	0.9	0.85	550	300	0.65	0.6
F3	4	55000	0.85	0.8	500	400	0.7	0.55

4.4 Analysis of numerical results

In this section, numerical studies are illustrated to demonstrate the applicability of the proposed hierarchical GL networks based model for the planning and operations of coordinated air cargo express delivery, given the predetermined the international express delivery cargos demand data and estimated parameters. The numerical studies were conducted in two different scenarios for different purposes. In the first scenario, the purpose is to evaluate the performance of the proposed model as compared to the existing performance (i.e., the express delivery enterprise case without coordination with three facilities such as hub, distribution center, and warehouse depot simultaneous). Herein, we assume that the weights associated with the hierarchical GL networks configurations cost sub-objective function, the net profit of hierarchical GL networks operational sub-objective function, and the satisfaction rate of customer demand sub-objective function are consistent, so that both w_1, w_2, and w_3 are equal to $0.\bar{3}$ in this case study. In addition, we investigate the effects of the induced macro and micro risks on the planning and operation of the hierarchical GL networks configuration by employing diverse combinations of weights shown in composite objective function. The second scenario summarizes the numerical results obtained from the sensitivity analyses of several target parameters, shown in boundary constraints. Note that all the preset parameters shown in Table3-5 remain the same in the first scenario, whereas some of them may change in second scenario for sensitivity analyses.

In these numerical studies, the Lingo 9.0 software package, which is a commercial optimization package broadly used for formulating and solving diverse optimization problems, was employed to search for the final solutions.

To assess the relative performance of the proposed hierarchical GL networks model in integrating 3-layers facility, we generated the optimal solutions using the proposed model, and then compared the resulting aggregate net profit with the existing operational performance. Note that the present GL networks system of DHL appears to be driven greatly by the net profit-maximum operational strategies, where the effects induced by the costs and risks are not incorporated and considered. Correspondingly, both the corresponding 3-layer GL networks and the factors of related risks have not yet been integrated as a comprehensive hierarchical GL networks framework in the existing operational case. To test the proposed model under such an operation condition, specifically, the case of setting the weight associated with the hierarchical GL networks-based net profit-maximum function to be 1 was mainly considered in this scenario. The comparison results are summarized in Table 4-6.

TABLE 4-6 Evaluation of relative system performance using the proposed model

Evaluation criteria	Aggregate net-profit (US$$10^9$)	Aggregate cost (US$$10^9$)
The proposed model	12.15	0.88
The existing operational strategy	10.42	0.96
Increase in net profit / decrease in cost	1.73	0.09
Relative improvement (%)	16.58	8.88
Overall improvement (%)	19.18	

Designed cases Weight setting w_1	w_2	w_3	Aggregate cost (US$$10^9$)	Aggregate Net profit (US$$10^9$)	Overall improvement (%)
The proposed model					
1	0	0	0.69	10.32	12.94
0.5	0.5	0	0.71	11.17	1.81
$0.\bar{3}$	$0.\bar{3}$	$0.\bar{3}$	0.79	10.9	10.49
0	0.5	0.5	0.84	11.52	6.83
0	1	0	0.88	12.15	19.18

Overall, the numerical results shown in Table 4-6 may reveal several significant generalizations.

First, aiming merely at maximizing the aggregate net profit, the proposed model may still outperform the existing GL networks system. This can be proved by comparing the results of the proposed model with the existing performance under the condition that the weight w_2 is set to be 1. In this case study, the overall improvement is 19.18%, resulting mainly from the significant improvement in the hierarchical GL networks-based aggregate net profit, which is as high as 16.58% if the proposed model is employed. Such a result may also imply that even if the induced the related cost and the satisfaction rate of customer demand effects are not considered, the existing GL networks operation and the corresponding operation strategy can still be improvement via appropriate hierarchical GL networks configuration.

Second, it appears that the induced the related costs and the satisfaction rate of customer demand for hierarchical GL networks can be significantly improved to a certain extent as the weight w_1 and w_3 associated with the hierarchical GL networks-based aggregate cost and the satisfaction rate of customer demand function increase. As can be seen in Table 4-6, the hierarchical GL networks based system performance can be improved from 1.81% to 19.18% within in different weights.

Following the aforementioned logic proposed to determine the locations of the corresponding facilities in hierarchical GL networks, the execution steps together with the corresponding numerical results are summarized as follows. The original demand spots were hierarchically grouped utilizing the proposed hierarchical cluster analysis method. Subsequently, the parameters about costs, time, and risk were considered into the proposed hierarchical GL networks model. According to the result, the best location to site hub facility is Taipei and distribution center facility is Kaohsiung in Taiwan. Similarly, the prime position of warehouse depot facility is in Banciao, Hsinchu, Taichung, Chiayi, and Tainan in Taiwan, as can be seen in figure 4-1, 4-2, and 4-3.

TABLE 4-7 Optimal facility location in three regions

Hub location	Distribution center location	Warehouse depot location
Taipei	Kaohsiung	Banciao
		Hsinchu
		Taichung
		Chiayi
		Tainan
Shenyang	Harbin	Qigihar
		Jiamusi
		Mudanjiang
		Jilin
	Changchun	Anshan
		Fushun
		Benxi
Beijing	Tianjin	Shijiazhuang
		Baotou
		Handan
		Tangshan
	Xian	Xianynag
		Taiyuan
Shanghai	Nanjing	Suzhou
		Wuxi
		Hefei
		Changzhou
		Huainan
	Jinan	Qingdao
		Huaibei
		Xuzhou

	Nanchang	Fuzhou
		Hangzhou
Chongqing	Chengdu	Guiyang
		Kunming
Hong Kong	Guangzhou	Swatow
		Jieyang
	Macau	Guilir
		Haikou
		Shenzhen
Los Angel	San Jose	Oakland
		Portland
		Seattle
		Honolulu
	San Diego	Anaheim
		Fresno
		Long Beach
Phoenix	Denver	Colorado Springs
		Aurora
	Las Vegas	Mesa
		Tucson
Chicago	Detroit	Grand Rapids
		Fort Wayne
		Omaha
		Toledo
		Milwaukee
	Indianapolis	Kansas City
		Minneapolis
		St. Paul
	Columbus	Cleveland
		Cincinnati
	Dallas	Oklahoma City
		New Orleans
		Nashville

Houston	San Antonio	El Paso
		Fort Worth
		Austin
	Jacksonville	Charlotte
		Virginia Beach
		Memphis
		Atlanta
		Miami
New York	Philadelphia	Pittsburgh
		Washington
		Baltimore
Boston	Worcester	Springfield
		Bridgeport
		Providence

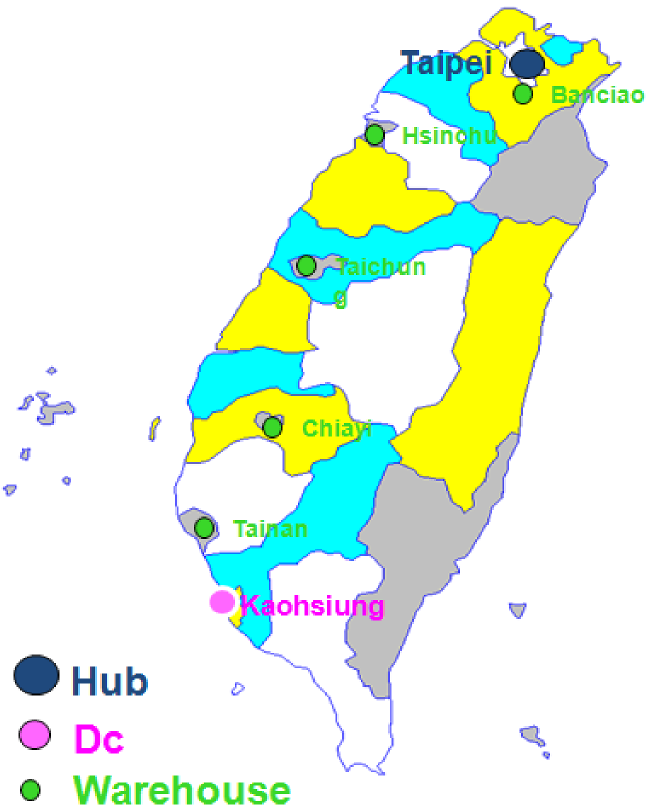

FIGURE 4-1 Hierarchical network configuration of Taiwan

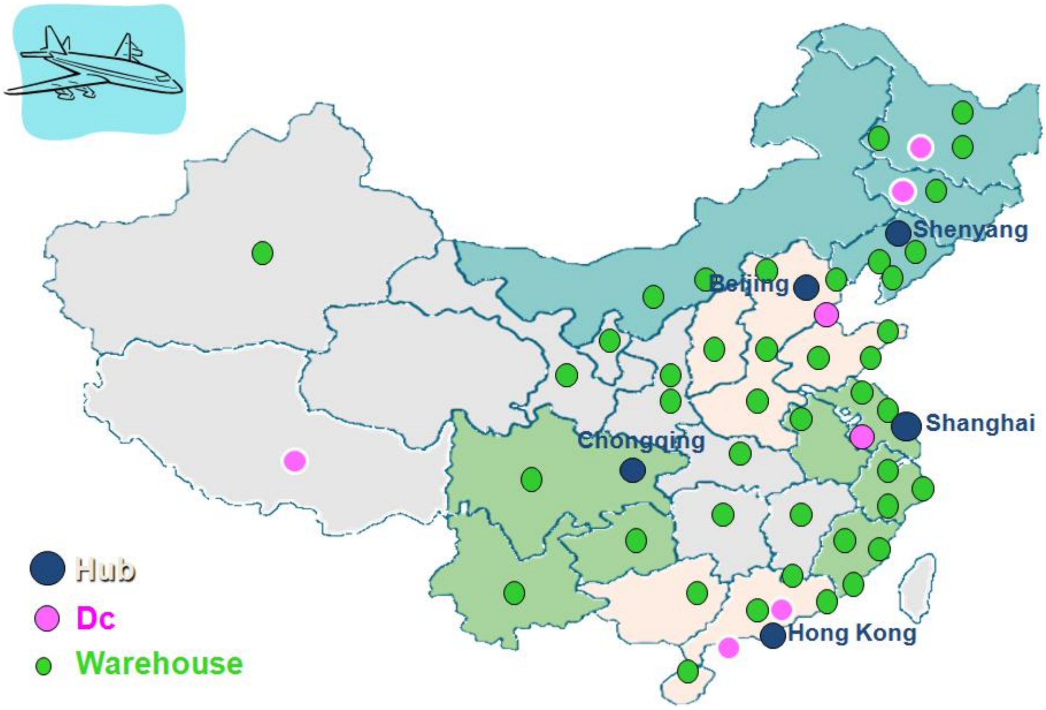

FIGURE 4-2 Hierarchical network configuration of China

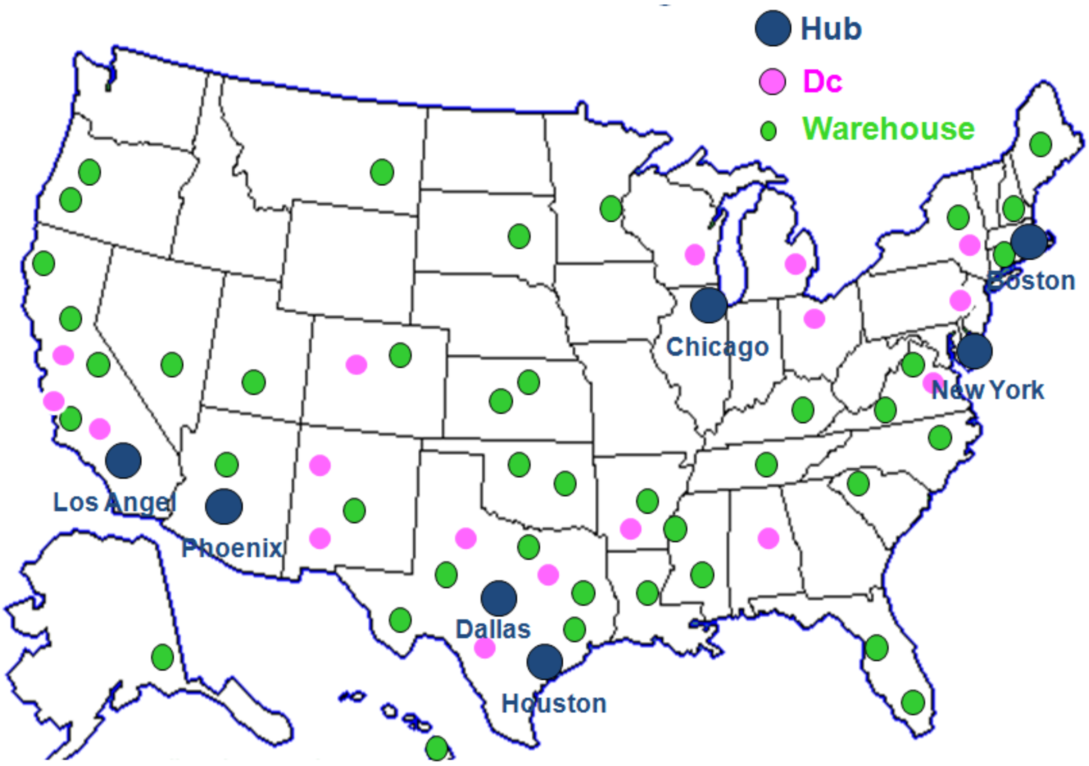

FIGURE 4-3 Hierarchical network configuration of U.S.A.

Herein, the numerical results presented in Table 4-7 also refer to the related facility optimal locations in China and thus may also reflect the potential rate of return on investment for international express delivery enterprise at each location candidate. Compared to the results of Taiwan, it appears that Taipei, Shenyang, Beijing, Shanghai, Chongqing, and Hong Kong are both the best location for siting hub facilities since it has the highest demand amount. Following, the optimal location for distribution center facility from north to south in China are Harbin, Changchun, Tianjin, Xian, Jinan, Nanjing, Nanchang, Chengdu, Guangzhou, and Macau, respectively. Table 4-7 has presented the locations of warehouse depots and the hierarchical relationship between facilities.

As can be seen in the U.S.A of Table 4-7, the corresponding facility locations for hub are Los Angel, Phoenix, Chicago, Houston, New York, and Boston. The locations of other facility and the hierarchical relationship between facilities are also summarized in Table 4-7 equally.

In addition, the above assessment results may raise another issue in terms of the potential tradeoff relationships between the growing original demand and the satisfied rate of customer demand. Accordingly, we conducted the sensitivity analyses aiming at two corresponding parameters, including (1) the original demand (D_j), and (2) the upper and lower bound of the satisfied rate of customer demand ($\underline{Z}_{i_h^s}$, $\overline{Z}_{i_h^s}$). In this scenario, the combination of weights $w_1 = w_2 = w_3 = 0.\bar{3}$ was chosen for all study cases. The corresponding numerical results in terms of the aggregate improvement relative to the existing system performance are summarized in Table 4-8.

According to the numerical results of Table 4-8, several implications are provided below.

(1) The reduction of original demands may contribute significantly to the aggregate

improvement of the system performance. The aggregate cost associated with the corresponding hierarchical GL networks can be improved by 32.93% as the original demands reduced by 50%.

(2) Given the necessary of increasing the satisfied rate of customer demand by 50% to replace other situations, the aggregate performance of the proposal hierarchical GL networks may remain controllable.

TABLE 4-8 Hierarchical GL networks system performance with different preset weight

Target parameter	Boundary increment (%)			
	-50	-25	+25	+50
	Variations in aggregate hierarchical GL networks costs			
D_j	15.89 (-32.93)	18.95 (-20)	29.67 (25.24)	30.43 (28.45)
$\underline{Z}_{i_h^s}$, $\overline{Z}_{i_h^s}$	17.02 (-28.16)	19.26 (-18.7)	28.75 (21.36)	31.14 (31.45)

Overall, the above numerical results have implied both the potential advantages of the proposed hierarchical GL networks, and the importance of appropriate hierarchical GL networks configurations strategies in determining the system performance.

Finally, the related resource allocation such as mode assignment and manpower assignment for hierarchical GL networks are shown in table 4-9 and table 4-10.

TABLE 4-9　Mode assignment for hierarchical GL networks system

	Mode assignment
Proposed cost	36280 US $
	Shanghai（4）, Taipei（2）
	Nanjing（5）, Jinan（6）, Nanchang（8）, Kaohsiung（4）
	Suzhou（3）, Wuxi（6）, Hefei（5）, Changzhou（6）, Huainan（4）
	Qingdao（7）, Huaibei（3）, Xuzhou（7）
	Fuzhou（6）, Hangzhou（4）
	Banciao（8）, Hsinchu（4）, Taichung（6）, Chiayi（3）, Tainan（5）

TABLE 4-10　Manpower assignment for hierarchical GL networks system

	Manpower assignment
Proposed cost	24790 US $
	Shanghai（15, 74）, Taipei（12, 62）
	Nanjing（11, 45）, Jinan（17, 57）, Nanchang（20, 55）, Kaohsiung（13, 52）
	Suzhou（12, 20）, Wuxi（15, 30）, Hefei（14, 28）, Changzhou（15, 27）, Huainan（11, 26）
	Qingdao（20, 31）, Huaibei（11, 20）, Xuzhou（22, 30）
	Fuzhou（14, 23）, Hangzhou（12, 20）
	Banciao（19, 28）, Hsinchu（12, 19）, Taichung（15, 23）, Chiayi（10, 17）, Tainan（14, 22）

CHAPTER 5 CONCLUSION

5.1 Conclusions

This paper has presented a new approach that integrates hierarchical cluster analysis and integer programming approaches to formulate a hierarchical GL networks model for dealing with the facility location problems of international express delivery enterprise by minimizing the total related costs and maximizing operational net profit and satisfied rate of customer demand. By specifying a 3-layer hierarchical GL networks framework, the critical activities risk, and corresponding state variables, a composite multi-objective function together with corresponding operational constraints are formulated.

Compared to previous literature on facility location and networks design problems, the proposed method has two distinctive features. First, the corresponding integrated supply and demand side of a specified 3-layer hierarchical GL networks is formulated with a generalized mathematical form, the propose method can readily solve the hierarchical facility location problems for the international express delivery enterprise around the world. Such a methodological measure is rare in previous literature, and has revealed its potential advantages in addressing elaborated hierarchical GL networks problem. Second, internal and external factors, e.g., fundamental requirements investment cost, basic requirements of operation costs, related operational and disaster risk, and satisfied rate of customer demand, are taken into account in the proposed model, thereby addressing and improving the performance of a hierarchical GL networks configuration.

Results from applying this model to a real study case indicate that Taipei has the highest potential advantages for international express delivery enterprise to locate hub facility in Taiwan. In addition, the best location to configure hub facility in China is Shenyang, Beijing, Shanghai, Chongqing, Hong Kong, respectively. Furthermore, Los Angel, Phoenix, Dallas, Houston, Chicago, New York, and Boston are the prime sites for establishing the hub facility in U.S.A.

The manager of a international express delivery enterprise can conveniently employ the propose model as a decision –making support tool to help strategically determine precedence for locating corresponding facilities, including hub, distribution center, and warehouse depot, according to the operational goals and overseas investment resources. In future research, extension of the proposed model to formulate the dynamic multi-resource allocation based on hierarchical GL networks configurations problems will be a topic of interest. Moreover, in depth identification of qualitative and quantitative influencing factors, such as demand variation, risk uncertainty, and time difference between places of different zone, also warrants more research for the extension.

Distribution policy is strict and restrictive in cases where all the nodes in the network send and receive cargo via a hub. This model introduces the delivery time restriction in addition to the other restrictions already contemplated in previous studies.

The objective function considered here consists of three factors; the first reflects the cost of transport between each origin/destination pair; the second and third, factors concern the cost arising from not delivering the goods within the agreed time limit. The second factor reflects the related operational cost when cargo makes a journey, while the third factor reflects the customer satisfied rate created by cargo which is delivered late because it spent too much time at the hub.

5.2 Directions for Future Studies

The hub, DC, and warehouse are in the middle of the supply chain and therefore dictate the efficiency and effectiveness of the supply chain. Given the increasing importance of the role of related facility in the supply chain, the facility configuration and resource allocation strategy can all but determine the success and failure of supply chain operations. This paper develops a mathematical model that aims to provide solution for real world facility configuration and resource allocation problems.

Despite numerous merits, the proposed model points to directions for future work:

(1) The model can be expanded to include more elements of risk and uncertainty involved in the facility configuration problem and it can be tested for the expanded time periods. Therefore, the future research theme should include multi-objective treatments which explicitly analyze the tradeoffs among cost, traffic access, market potential, and local incentives.

(2) The multi-commodity problem which considers both slow-moving and fast-moving products may be studied in the future.

(3) It is possible in some cases that rounding off customer allocations may not work due to tight facility capacity constraints and the customer maximum access time stipulation. In order to avoid non-unique assignments of facility to customers in the first place the more complex mixed-integer linear programming SSWRP should be solved.

(4) The multi-hierarchical network configuration, that considers the options of both direct shipment from manufacturing plants to customers and indirect shipment through either master distribution centers or regional warehouses, may be an intriguing subject for further studies.

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學歷

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榮譽

- 中華顧問工程司第四屆工程科技獎學金（2007）
- 東吳大學八十九學年度第二學期好學獎獎學金（2001）
- 東吳大學八十九學年度第一學期知學獎獎學金（2000）

證照

- 教育部講師證書（講字第０九一八０七號）
- 中華民國物流協會物流技術整合工程師（(94）物協證字第 18thN01 號）
- 英國皇家物流與運輸學會三級物流營運經理（S011722）
- 行政院勞委會乙級門市服務技術士（181-001239）

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