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Changing Geography of China’s International Air Transport Served by Chinese Airlines

Xumei Liu
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Xumei Liu entitled "Changing Geography of China's International Air Transport Served by Chinese Airlines." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Shih-Lung Shaw, Major Professor

We have read this thesis and recommend its acceptance:

Bruce A. Ralston, Thomas L. Bell

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Xumei Liu
August 2008

DEDICATION

To my family, without whom it would not be possible for me to come to the United States to continue my pursuit of higher education.

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ABSTRACT

This research examines international air transport served by Chinese airlines from 1990 to 2004. Specifically, this research examines how the spatial patterns of air transport networks changed during this period. Particular attention was given to the competition among the three major hubs designated by the Civil Aviation Administration of China: Beijing, Shanghai, and Guangzhou. This paper also measured regional differences denoted by air transport as well as the impacts of several significant incidents on China's international air transport.

Data were obtained from a series of China Transportation and Communication Yearbooks (1990-2004). Each yearbook compiles airline statistics of routes, number of scheduled flights, and passenger and freight volumes. These figures were imported into ArcGIS for relevant analyses. Two different types of analyses were carried out in this study: network analysis and descriptive statistical analysis. Network analysis was performed to measure structural development of the network as well as individual growth of the three major hubs. Descriptive statistical analysis was conducted to assess regional disparities and to evaluate the impacts of economic, social, and political events and circumstances on the airline industry.

Major changes in network connectivity were observed, which were largely due to the presence/absence of provincial capitals, tourist cities and/or secondary cities in the network. All three major hubs experienced low to moderate increase in accessibility from 1990 to 2004. Shanghai was most likely to develop into the most accessible hub in the network. Air traffic displayed a great disparity among different world regions. The largest air traffic flows resided in Asia. Europe placed second followed by North America and Oceania. Links between China and Africa were suspended after 1994 and connections with Latin America were absent during the entire study period. Several major declines in air traffic were associated with the 1997 Asian

Currency Crisis, the terrorist attacks on September 11, 2001, and the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003.

The study concludes that China's international airline network is moving towards a system with a high level of connectivity and great coverage.

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Chapter 1: Introduction

1.1 Research Background

Airports are among the most important elements of the infrastructure of modern cities. Their importance arises from the role they play in the globalization of production. In particular they play a critical role in the evolution of a knowledge-based economy as it relies so much upon face-to-face contact between its key participants (O'Connor, 1995). New or expanded airports are considered as critical to a region's sustained growth, in line with the view that an "airport is perhaps the most important single piece of infrastructure in the battle between cities and nations for influence in, and the benefits of, growth and development" (O'Connor and Scott, 1992, p.241)

China's transport sector is one of the largest sectors of the Chinese economy while aviation has been the fastest growing mode since the airline industry reforms in the early 1980s. China's civil air transport has grown by an average of 20% a year since 1980, which is 4.3 times the world average (Zhang, 1997). It is reported that China is the world's fastest growing aviation market with an increase of passengers from 69.6 million in 1999 to an estimated 214.7 million by 2014 (Granitsas, 2002). The International Air Transport Association (IATA) forecasts that China will become the largest Asia-Pacific market for scheduled passenger traffic by 2010 (Li, 1998). In a report presented by Boeing in 2003, China's civil aviation is predicted to be second only to the United States by 2020 (Lu et al., 2005). A rapid growth of air services to Chinese cities is observed, especially to Shanghai, Beijing and Guangzhou (O'Connor, 2003). China's aviation industry is undergoing a rapid expansion. This research is conducted in the context of socio-economic and political dynamics that shape the development of China's aviation industry.

1.2 Brief Introduction to China's Airline Industry

The airline industry in China has experienced significant development since the first airplane in China, a Farman biplane, was purchased by the Qing government from France and operated in a playground in the suburbs of Beijing in 1910 (Civil Aviation Resource Net of China, 2005). Almost a century later there were 754 planes (foreign carriers excluded) operating in China's airspace, 133 airports provided regular service for civil air transportation, and 132 cities received air transport service in 2004. By 2005, the air transport system had evolved into a network connecting 127 domestic cities with 80 foreign cities in 38 countries (Civil Aviation Administration of China, 2005). The general layout of the airport distribution is characterized by three major hub cities, namely, Beijing, Shanghai and Guangzhou, with other provincial capitals, tourist cities and secondary cities across the country (Lu et al., 2005) There are three eras representative of the development of China's airline industry: Pre-PRC (People's Republic of China) Era (1910-1949), Pre-Reform Era (1949-1978), and Post-Reform Era (1978-Present) (Jin et al., 2004).

Pre-PRC (People's Republic of China) Era (1910-1949)

The first 40 years of aviation in China saw the rapid rise of an industry for commercial and military purposes. Soon after 1910 when the first plane was introduced, airplanes were used for military purpose in China. It was in 1920 when the first commercial flight was operated between Beijing and Tianjin. Commercial airlines did not make any significant development until the end of the First Civil War in 1927, and thereafter the central government became aware of the importance of commercial airlines (Jin et al., 2004). Shanghai-Chengdu Aviation Administration Bureau was established in 1929 and much emphasis was put on the civil airline industry. By 1933,

three major domestic airlines in China were founded: China Airlines (a joint venture with a U.S. company), Eurasian Airlines (with a German company), and Southwest Airlines (with local business organizations in southwest China). By 1936, the air transport network had spread out nationwide, covering major cities except for northeast China. Afterward civil aviation was suspended during the War of Resistance Against Japan (1937-1945) and the Second Civil War (1945-1949) (Jin et al., 2004). It was not until 1936 that Southwest Airlines was able to operate its first international commercial flight from Guangzhou through Wuzhou, Nanning, and Longzhou to Hanoi (Guangzhou Chronicle, 2005). That flight was also the first international route in China.

Pre-Reform Era (1949-1978):

Civil aviation went through a gradual transition during this period. The Civil Aviation Administration of China (CAAC) was founded in 1949, soon after the founding of People's Republic of China. By 1954, the CAAC bureau was under absolute supervision of the Central Military Commission (Jin et al., 2004). Only 36 airports existed across the country at that time (Efendioglu and Murray, 2003). The air transport network was built primarily to connect Beijing and other cities for governmental and military purposes. As a result, demand for air services for the public was severely suppressed. The industry also suffered persistent financial losses primarily due to unsatisfactory performances of the traditional centrally-planned scheme (Zhang, 1997). The system suffered further from the Cultural Revolution (1966-1976) with only minimum passenger and freight traffic (Jin et al., 2004). Development in the airline industry stagnated during this period and increasing demand for reforms of the airline industry were building.

Post-Reform Era (1978 – Present):

The airline industry has experienced remarkable developments since China launched its economic reforms in 1978. Commercial airlines were greatly transformed by virtue of the reforms. The CAAC obtained its independence from the military in 1980, and decided its priorities in developing civil aviation in China. The CAAC implemented various reform measures in the 1980s in accordance with Deng Xiaoping's speech addressed to the commercialization of Chinese civil airlines on February 14, 1980 (Civil Aviation Administration of China, 2005). The reform measures included separating management of airlines and airports from the CAAC central office, transforming airlines to profit-seeking business entities, allowing local governments to operate their own airlines, encouraging competition, and relaxing the regulatory control over market entry, route entry, frequency, infrastructure construction and aircraft purchase (Wang, 1989; Zhang, 1997; Jin et al., 2004). These innovative measures gave great impetus to the rapid development of commercial air transport. By 2001, there were 34 airline companies in China. However, the majority of them were small companies among which there was wasteful competition and absence of economies of scale. Eventually, the most progressive measure was implemented in 2002. The CAAC announced airline consolidation on October 11, 2002. The original 34 airlines were reduced to 23 either by merger or by acquisition. The top nine stated-owned carriers among the 23 airlines formed three groups (Air China, China Eastern, and China Southern), known as the "Big Three". The "Big Three" located their bases of operations in three major hubs: Beijing, Shanghai, and Guangzhou respectively. The rest of the airlines were regional carriers. They formed two other groups: Hainan Airlines and Zhongtian Airlines (Lu et al., 2005). The consolidation prompted a complete separation of airlines from the CAAC. Airlines became profit-driven enterprise entities, a fair playing field was created without state subsidies, merger and acquisition and bankruptcy

protection were permitted and legalized, the government's control over pricing, route entry and flight scheduling was loosened. In general, the consolidation not only expanded the scale of major airline companies, but also greatly enhanced the competitiveness of airlines by introducing the market mechanism and modern management systems (Jin et al., 2004; Jin et al., 2005).

1.3 Research Justification

Geography is frequently defined as the study of spatial phenomena and provides an ideal framework in which to address transportation issues. Focused on the development of air transport networks that interlace over the Earth's surface, this thesis addresses an inherently spatial phenomenon. The sub-discipline of transportation geography provides powerful tools by which growth can be examined.

Over the past fifteen years Asia's growing air transport market has attracted increased interest from air transport geographers. Regionally focused research on Southeast Asia (Bowen and Leinbach, 1995; Bowen, 2000; Bowen, Leinbach, and Mabazza, 2002) has looked at many different aspects of the industry, including the role it plays in the political economy of the region. O'Connor and others studied the airline industry in the Australasian region (O'Connor and Scott, 1992; O'Connor, 1995; Hooper, 1998; O'Connor, 2003). Studies on China's civil aviation industry have mainly focused on its domestic sector. Zhang (1997) studied the regulatory and enterprise reform in China's airline industry and its impact on air transport development. It was found that air traffic volume and the number of routes significantly increased since the 2002 reforms. The study argued that the rapid growth of China's airline industry can be attributed to the increased disposable income, more leisure time, developing trade and tourism, and the airline industry reform. Hui et al. (2004) analyzed China's air cargo flows and its network from 1980 to

2000. The study found that the domestic freight network was like a tripod with Beijing, Shanghai, and Guangzhou being the major pillars. The international air freight network had a similar structure except that Hong Kong replaced Guangzhou as the third pillar. In the passenger sector, Jin (2001) studied the network of domestic air passenger flow in China. The study revealed that the majority of the flow had always concentrated on Beijing, Shanghai and Guangzhou since 1980 and a similar conclusion could be drawn about international passenger flow: more than 90% originated from these three cities. Jin et al. (2004) examined spatial patterns of domestic air passenger transport in China from 1980 to 1998. It was found that Beijing and Guangzhou spread their networks across the East, Middle, and West regions, and were clearly national hubs. Shanghai's centrality remained limited in terms of spatial ranges, and its dominance resided in the surrounding eastern coastal regions. However, Shanghai gained the fastest growth in air traffic among the three because of the economic prosperity of the area. The study also found that the domestic air transport center migrated toward Southeast China and that the migration of international air transport center was consistent with the trend of the domestic system. Lu et al. (2005) analyzed spatial characteristics of domestic air passenger transport in China and competition among airlines by applying statistical and visual approaches. The study revealed that Beijing, Shanghai and Guangzhou functioned as key hub cities on the network. However, a systematic hub-and-spoke network had not been formed yet. Efendioglu and Murray (2003) studied changes and challenges in China's airline industry due to the consolidation. The study revealed that until recently, factors such as geography, distance, and economic inequality among regions limited the ability of Chinese carriers to establish efficient hub-and-spoke systems based on essential scope and scale efficiencies, which have been very effective in the U.S. and in Europe. Jin et al. (2005) investigated airline consolidation and its effect on network structure. The study once again

confirmed the predominant position of Beijing, Shanghai and Guangzhou as major hubs. Nodal accessibility of each hub was significantly higher than any other node on the network. The networks of the "Big Three" were shifting from single hub to multi-hub and the adoption of hub-and-spoke structure became more obvious. The study concluded that the consolidation not only extended the geographical coverage of major airlines, but also improved their aggregate network connectivity.

China's international air transportation has, however, not been explicitly studied. Driven by the increasing domestic demand and international trade, China has experienced remarkable economic growth since its economic reforms in 1978 (National Bureau of Statistics of China, 2005). International trade has grown rapidly since 1978 with an average growth rate of 15.2% (Jiang et al., 2003). China has experienced fast economic growth as its role within the global economy has been reshaped by export-based industrialization. This increased export-based activity provides a significant boost to air traffic as many exports involve links between American and European corporate headquarters and local production facilities or subcontractors (O'Connor, 1995). No matter whether it is for foreign market or domestic need, a mature air transportation system is a prerequisite for a healthy and secure economy. As globalization proceeds, integration into the international airline industry is an important prerequisite for developing countries to access global flows of capital, goods, people, and information (Bowen, 2000). China's economy has grown rapidly over the last twenty years and its status in international economic and trading system is also steadily advancing. Together with the enormous size of China's population and the geopolitical importance of its location in Asia, all suggest that China will likely play a key role in shaping the pattern of airline networks in Asia and in linkages with other continents. Thus, a study of China's international air transport is warranted.

1.4 Research Objectives

The focus of this research is international air transport served by Chinese airlines from 1990 to 2004. This research studies how the spatial patterns of the air transport network changed during this period. Particular attention is given to the competition among the three major hubs designated by the CAAC: Beijing, Shanghai, and Guangzhou. This research also measures regional differences among world regions by examining the distribution of air traffic in different regions.

Economic, social, and political events and circumstances have great impacts on the airline industry. On one hand, the expansion of air transport has been driven by two principal factors: growing affluence and government policies such as deregulation, liberalization, privatization, and encouragement of competition, all of which are intended to improve services and drive prices down. On the other hand, economic slumps, overcapacity, mismanagement, and events that discourage air travel are notable deterrents in terms of air transportation growth (Pirie, 2006). The airline industry has experienced losses of profitability as a result of overcapacity, war, terrorism, and epidemics (Horan, 2002). Several important incidents happened in the late 1990s and early 2000s and have had far-reaching impacts on China and the rest of the world. The return of Hong Kong in 1997, the 1997 Asian Currency Crisis, the return of Macau in 1999, the terrorist attacks on the World Trade Center in New York and the Pentagon in Washington in 2001, China's entry into the WTO in 2001, China's airline consolidation in 2002, and the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003 are all significant events that pertain to this research. This study evaluates the impacts of these events on network structure and traffic flows over the network.

1.5 Thesis Organization

The remainder of this thesis is organized into four chapters of literature review, methodology, results and discussion, and conclusions respectively. Chapter Two provides a literature review first discussing the broad concepts of transport geography and air transportation, and then focusing more specifically on state intervention, bilateral agreements and “Open Skies”, and hub-and-spoke networks. Chapter Three explains the methodology of this study, detailing data acquisition, processing, and analyses. Chapter Four discusses the results of spatial and descriptive statistical analyses of China’s international air transport network. Chapter Five synthesizes the findings from this study and suggests future research directions.

Chapter 2: Literature Review

2.1 Transport Geography and Air Transportation

"Transportation is central to the study of geography, just as geography is central to the study of transportation" (Goetz, 2006, p. 230-231). Transportation industries, facilities, infrastructures and networks occupy substantial areas of geographical space and constitute complex spatial systems. On the other hand, geography is concerned with interrelationships among phenomena in a spatial setting and transport is frequently one of the most potent explanatory factors. Transport geography is thus concerned with the explanation, from a spatial perspective, of the socioeconomic, industrial and settlement frameworks within which transport networks develop and transport systems operate (Hoyle and Knowles, 1998). It is recognized that transportation is a system that considers the complex relationships among its core elements. These core elements are networks, nodes and demand. Transport geography must be systematic as one element of the transport system is linked with numerous others (Haggett, 2001). "Transportation geography is concerned with spatial interaction – describing, explaining, optimizing and predicting the movements of goods and people between disparate locations in space connected via transport networks" (Scott, 2006, p. 389-392). As a sub-discipline of geography, it centers on both the location and geographic pattern of transport systems and the magnitude of the movement or spatial interaction over the elements of such systems (Black, 2003).

Based on the medium by which the movements are supported, transportation modes may be grouped into three categories: land, water, and air. Within the field of transportation geography and the larger discipline of geography, an understanding of air transportation is essential to describing geographical concepts of connectivity and linkages, development patterns at various scales, and the global economy.

This research is concerned with commercial air transport, focusing on international airline industry. Ever since the first tentative 12-second flight of the Wright Flyer at Kitty Hawk, North Carolina, in December 1903, aircraft technology has advanced substantially. The B747 or A340 nowadays are capable of flying full loads, non-stop, half-way around the world. These significant technological advances have made air transport the paramount mode of long-distance passenger travel, both between and within countries. By dodging maritime, mountain and desert barriers, the development of air transportation industry has radically altered patterns of global accessibility (Graham, 1995).

From its onset, the development of air transportation system has resided in a context of national interests, a factor that remains a potent influence upon the contemporary patterns of the industry. An interlocking nexus of mail, empire and administration characterized the early attempts at developing intercontinental air transport during the 1920s, which were the pioneering years of commercial air transportation. During the 1930s, passenger services developed upon the initial framework of mail routes. The rapid evolution of this first phase of intercontinental air transport was interrupted by World War II. However, paradoxically, this provided a significant impetus to the development of all aspects of aircraft technology. On the other hand, the rapid post-war development of air transport has been associated with a complex of interrelated political and economic processes, representative of widespread and revolutionary changes in global social structures (Graham, 1995).

Admittedly, air transport has always been a global industry. The intercontinental routes, pioneered during the late 1920s and 1930s, were concerned with linking world-embracing empires and political spheres of influence (Graham, 1995). Later on, the industry was controlled by pan-global institutions, namely, the International Civil Aviation Organization (ICAO) and the

International Air Transport Association (IATA), and was subject to multilateral international conventions. In November 1944, representatives from 51 nations gathered in Chicago to discuss and establish a legal framework that would serve to guide and regulate the conduct of international civil aviation in the postwar era. As a result of the 1944 Chicago Convention and the subsequent 1946 Bermuda I Agreement, an international aviation regime was established based on a system of bilateral air transport agreements. Over the last 50 years, the Chicago Convention agreements and bilateral system have promoted an orderly development of international civil aviation. But in more recent years, this system has come under increasing reform pressure as a result of government deregulation, "open skies" and free trade policies, and airline globalization strategies, all of which indicate the increased importance of the international dimension in the geography of air transport (Goetz, 1995, p. 229-230).

2.2 State Intervention Impacting Air Transportation

In theory, air transport enjoys greater freedom of route choice than other modes because airplanes elude physical obstacles such as maritime, mountain and desert barriers which are commonly found on the Earth's surface. However, barriers created by strategic and political concerns have a significant influence on air transport (Rodrigue et al., 2006). Researchers argue that the mechanism of international air transport networks cannot be understood fully without examining issues of international trade, governmental policy and competitive strategy (O'Sullivan, 1980; Pustay, 1993; Debbage, 1994). Underlying processes governing the geography of international air transport networks are closely related to international trade patterns and strategic industrial policies among nations because international air passenger flows involve the sovereign air space of at least two different nation-states (Debbage, 1994). The air transportation industry

worldwide has gone through dramatic changes over the past 25 years. It is believed that the most sweeping changes have occurred in the institutional environment, where entrenched regulatory controls have been modified, eased, and in some cases removed, due to policies of liberalization or deregulation in the airline industry (Graham, 1995, 1998; Goetz, 2002). The decision to deregulate the airline industry can be seen as an integral part of a much broader policy agenda that has transformed the global economy (Goetz, 2002). Accompanied by technological advancement and economic dynamics across all industries, these forces have boosted the process of globalization, which is fundamentally changing the volumes, patterns, directions, ownership, and control of air transport passenger flows around the world (Goetz and Graham, 2004).

The airline industry is probably “one of the most highly regulated and nationally controlled industries throughout the world” (Wheatcroft, 1990, p.353). One of the most noteworthy examples of state intervention in the airline industry is probably the United States. The airline industry was governed by economic regulations in the U.S. before 1978 because the airline industry, as well as telephone, banking, and electric power, possessed characteristics of public utilities and were important “public interest” industries. Airline companies operated most efficiently at a very large scale because the prevailing technologies in the airline industry required large fixed costs. This inexorable economic law, known as economies of scale, resulted in either a classical monopoly or an oligopoly, where the monopolist or a few firms had the absolute control of output and prices. Therefore, the need for government regulation emerged to ensure that pricing would approximate actual costs, and that consumers would not be gouged through extraction of monopoly or oligopoly profits. However, the imposition of government regulation in the airline industry caused a loss of market efficiency, which became a major concern by the 1970s when the desirability of continued government regulation in the airline industry was questioned in a substantial body of economic

studies. Increasing maturity and balanced competition was seen in the airline industry. It was suggested that by discontinuing regulatory control from the Civil Aeronautics Board (CAB), markets would operate more efficiently and consumers could have a wider range of price/service options offered by carriers, and that competition would thrive and contribute to enhanced economic productivity (Goetz, 2002).

The Airline Deregulation Act (ADA) of 1978 in the United States was legislated in response to the criticism of the continuance of regulatory control over the airline industry and to the cost saving and marketing advantage that would incur as a result of deregulation. The ADA grants certificates to all airlines which are deemed "fit, willing, and able to properly perform air transportation" for a route and allows a carrier to terminate serving a route as long as the termination will not threaten the essential air service (US Government Printing Office, 1980). In general, deregulation involves the exposure of air transport to free market forces, achieved through the removal of most regulatory controls over pricing while permitting carriers to enter and leave markets at will (Goetz and Graham, 2004).

Similarly, governments in other parts of the world play an influential role in shaping their airline industry. Air service within Europe was largely regulated by a series of restrictive and anti-competitive bilateral agreements between European countries until the mid 1980s. In 1986, European nation states initiated discussion about establishing a more competitive, internal air transport market within Europe to complement reform in other economic sectors regarding trade and tariff. A three-aviation package decision was arrived at and, according to the decision, air transport liberalization within Europe was gradually achieved through three phases, which were implemented in 1987, 1990 and 1993, respectively (Debbage, 1994). Since then, the European Union (EU) has been actively deregulating its domestic air transport market through the adoption

of the three packages for liberalization (Tretheway, 1991; Marín, 1995). The first package implemented in December 1987 started to relax the established rules in the aviation industry. It limited the right of governments to disapprove the introduction of new fares for intra-EU traffic and gave some flexibility to airlines concerning seat capacity sharing. The second package in 1990, opened up the market further, allowing greater flexibility over pricing and capacity-sharing. It also gave all EU carriers the right to carry an unlimited number of passengers or cargo between their home country and another EU member state. The third package was introduced in January 1993; it granted all EU carriers with an operating licence freedom to provide services within the EU. It also granted airlines full freedom with regard to fares and rates (European Commission, 2005). The aviation industry of EU has grown tremendously since the adoption of the first package in 1987. Air transport development within the European Union goes hand-in-hand with the gradual liberalization and deregulation of European air traffic, which, in time, will eliminate national priorities of its member states and remove traffic barriers (Matthiessen, 2004).

In the ASEAN (Association of South-East Asia Nations) context, deregulation was considered probably "the only mechanism available to achieve a quantum leap in the development of the air transport industry" (Li, 1998, p.140). Bowen (2000) studied the development of the airline industry in Southeast Asia, where liberalization was one of the most important means through which regional governments sought to influence the development of airline networks. The airline industry was carefully integrated into development policy and was subject to a host of state-led efforts to guide its development. Governments regulated airline competition and determined the size and quality of airport infrastructure provided at hub cities. The emergence of new entrant airlines as a major component of liberalization could be seen in almost every country in Southeast Asia. The state plays an essential role in the development of air transport geography.

In Southeast Asia, governments in countries with rapidly developing economies administer development priorities by determining the extent of privatization, the scope of competition among foreign and domestic airlines, and the size and location of new airport infrastructure (Goetz and Graham, 2004).

The tide of deregulation (liberalization) is sweeping across the globe. China has also been taking substantial, albeit cautious, measures to deregulate its airline industry. From the foundation of the Civil Aviation Administration of China in 1949 to the consolidation in 2002 that separated airlines from the CAAC, the central government played a crucial role in the development of China's airline industry and aviation network structure. The government continues to exert influence on air transport by regulating price, market entry and route entry. Undeniably, state intervention has always been an essential part of the dynamics that shape the development of air transport and further deregulation may benefit the aviation industry as a whole.

2.3 Other Factors Impacting Air Transportation

The regime of regulatory control over airline industry can, for the most part, be traced back to the Paris Convention in 1919. The convention concluded that nation-states have absolute sovereign rights to the air space above their territory. The resolution elevated airline traffic to the level of a national resource that government should protect for the sake of national welfare. Consequently, the regulation of international air transport developed under a series of bilateral agreements between countries (Debbage, 1994). A typical bilateral agreement regulates carrier and route designations, specifies capacity and frequency of services, modulates prices, and oversees other commercial aspects of business operations. A bilateral agreement is based upon the principle of reciprocity, an equal and fair exchange of rights between countries that are different in

size and have airlines of varied strength (Oum, 1998). However, bilaterals are considered as increasingly redundant because they frequently cannot accommodate a fair and equal exchange of aviation rights, especially between countries with significantly different domestic markets (Debbage, 1994). Formation of alliances, strategic alliances with comprehensive code-sharing in particular, is in part stimulated to get around the restrictive bilateral air service agreements (Li, 1998; Vowles, 2000). It is possible that a level playing field could be created between two countries on the bilateral agreements through strategic alliance, code-sharing, and other concessions by the stronger side even if the flag carriers of the two countries are not equally competitive (Oum, 1998).

Research into international alliances has shown that airlines enter into alliances for reasons such as improved feeder access to a historically limited area and to reduce the threat of an outside carrier entering certain markets (Youssef and Hansen, 1994). The fundamental justification for entering into these agreements is the objective of obtaining greater market access (French, 1997). During the early 1990s, strategic alliance was characteristic of the consolidation of airlines in the United States (Debbage, 1994). Southeast Asia airlines entered global alliance as a survival strategy during the Asia Currency Crisis in that membership or code-sharing agreements offered the prospect of mitigating their financial problems by consolidating traffic and rationalizing services (Rimmer, 2000). According to a survey by Airline Business, five groups of airlines accounted for almost 60% of world air traffic (Pinkham, 2001). Pearson's study of the North Atlantic region suggested "alliances do shift market share significantly and are often critical to the growth of airports and individual markets particularly when alliance members allow strong hubs to be connected to each other" (Pearson, 1997, p.51). Essentially, the alliance has a critical role in shaping air traffic patterns around the world (O'Connor, 2003).

Another notable regulatory force that has shaped the airline industry is the "Open Skies" bilateral/multilateral agreement. An "Open Skies" agreement grants foreign airlines access to, from, and beyond the countries who adopt "Open Skies" in exchange for reciprocal traffic rights in their own home markets (Bowen, 2000). A so-called "Open Skies" bilateral/multilateral agreement, allows unrestricted market entry and code-sharing alliances, permitting any airline virtually unlimited access to any market within their boundaries (Goetz and Graham, 2004).

The idea of "Open Skies" was initiated by the United States. The United States initiated a pro-competitive, pro-consumer agenda in the late 1970s in response to the protectionist governmental policies and restrictive bilateral agreements. In 1978, the United States Civil Aeronautics Board (CAB) issued an order requiring the IATA to demonstrate why the CAB should not withdraw IATA-based tariff agreements. The order resulted in the erosion of IATA's power and a multilateral compromise of European nations, which were deemed the origin of the US "Open Skies" initiative. The United States continued to propagate its "Open Skies" initiative by successfully concluding a series of liberal bilateral agreements with over 20 nations between 1978 and 1982 (Dresner and Tretheway, 1992).

In March 1992, the United States initiated the negotiation of transborder "Open Skies" agreements with all European countries. The first US "Open Skies" agreement was signed in September 1992 between the US and the Netherlands. In the following four years, 11 European countries as well as Canada, signed "Open Skies" agreements with the US. The United States announced its "Open Skies" initiative in Asia in summer 1996, and Singapore was the first Asian country that signed an agreement with the US in 1997, followed by Brunei, Malaysia, Taiwan and New Zealand (Oum, 1998).

The United States "Open Skies" initiatives in Asia posed a marked threat to Asian carriers.

The US intended to negotiate for unlimited freedom in establishing hubs in Asian countries, and thus US carriers could provide high-frequency services using smaller aircraft within Asian markets, while enjoying economies of larger airplanes in the trans-Pacific markets (Oum, 1998). Competing with mega-carriers from developed countries with much larger domestic traffic bases is generally disadvantageous to relatively small carriers in developing countries. Thus ASEAN Transport Ministers faced a challenge to develop an innovative "Open Skies" regime which would accommodate its member carriers to the changed situation without seriously undermining the overall competitiveness and efficiency of the airline industry in its member countries (Li, 1998). Governments in Southeast Asia countries have been increasingly open-minded to international services provided by foreign airlines. Traffic rights were secured for Singapore Airline under its "Open Skies" policy and were integral to its emergence as one of the world's largest airlines (Bowen, 2000). Actually, most governments in Southeast Asia have endorsed the "Open Skies" initiative. The results were, however, mixed. Philippine adopted "Open Skies" in the 1970s to promote tourism (Tasker, 1977), and PAL (Philippine Airlines) collapsed in 1998 for which the officials blamed liberalization and asked the government to withdraw from "Open Skies" in order to facilitate PAL's proposed revival in 1999 (Shipping Times, 1999). Debbage (1994) argued that successful transition from the restrictive bilateral system to "open skies" multilateralism was vital to the competitiveness of airlines.

There are several external forces that have impacts on the development of air transportation, besides governmental and institutional policies that shape the development of airline industry. Economic slumps, overcapacity, mismanagement, and events that discourage air travel are notable deterrents in terms of air transportation growth (Pirie, 2006). Airline industry had experienced losses of profitability as a result of overcapacity, war, terrorism, and epidemics (Horan, 2002). Air

transportation growth was compounded by a sharp decrease in air traffic due to a succession of events external to the airline industry. The 9/11 attacks on New York and Washington in 2001, followed by the invasion of Afghanistan in 2002-2003, the Iraq war, the Severe Acute Respiratory Syndrome (SARS) epidemic in China, and the continuing disruption of international air traffic caused by enhanced security measures in airports (Goetz and Graham, 2004).

British Airways, the largest carrier in Europe, cut 7,000 jobs in October 2001, Air Canada slashed 9,000 jobs and curtailed its capacity by 20%, and Swissair filed bankruptcy and grounded all its worldwide flights (Efendioglu and Murray, 2003). International Air Transport Association statistics showed a global 4.4% decline in international scheduled passenger traffic in 2001 (IATA, 2002). According to the International Civil Aviation Organization, the combination of war and SARS led to further traffic decrease in the first part of 2003, which was expected to be a year of zero growth until a full recovery in traffic took place in 2004 and 2005 (ICAO, 2003). In general, major international carriers had been most severely affected by the succession of crises, suffering in particular from a fall in high-yield international business traffic. Carriers in North America, as well as in Europe, were hardest hit by the post 9/11 fall in demand, whereas it was airline companies in Asia and Australasia that went through the worst effects of the SARS crisis (Goetz and Graham, 2004).

Rimmer (2000) and Bowen (2000) studied the impacts of the Asian Currency Crisis on airlines in Southeast Asia. In 1998, the broadening economic crisis precipitated the collapse of several airlines in Southeast Asia and emergency restructuring at others. PAL (Philippine Airlines) was forced to suspend operations altogether by the Asian traffic collapse in mid-1998. Thai International and Garuda Indonesia stopped some of their pre-crisis international networks in mid-1998. Total international airline capacity fell in the Southeast Asia region. Southeast Asian

airlines redeployed aircraft to other markets, expanded or cut routes to mitigate the crisis. Airlines also entered global alliance as a survival strategy during the crisis in that membership or code-sharing agreements offered the prospect of mitigating their financial problems by consolidating traffic and rationalizing services.

Rimmer (2000) also suggested that there was a recession in global airline industry in early 1990s, associated with the Gulf War. Hong Kong air routes in general and Cathay Pacific's performance in particular had been impacted by the former British colony's reversion to China prior to the Asian Crisis, which adversely affected its tourism trade sector, especially from Japan.

2.4 Hub and Spoke Network and Network Analysis

Flows of people, commodities, information and capital all require a complex network of interconnection between origins and destinations. A special type of network, namely, the hub-and-spoke network is designed for servicing passenger, commodity or information flows between multiple origins and destinations (O'Kelly and Miller, 1994).

In many transportation or telecommunication networks, the cost of carrying a unit of traffic (passengers, cargo, or information) between two points decreases as the volume of traffic going through the link joining the two points increases. Consequently, it is often convenient to design networks in which traffic is concentrated on high traffic links, even if longer travel distances and/or longer travel time are incurred. In order to concentrate traffic, each point that offers traffic is connected to one or more transshipment or switching points through a link. The transshipment points, known as hubs, are in turn interconnected by high traffic links. Airline networks are examples of networks utilizing hubs (Marianov et al., 1999).

In the airline industry, hubbing is motivated by the economic advantages of increased

flight frequencies and by the economies of operating larger aircraft. High frequencies of service and larger aircraft would not normally be feasible if all city pairs in a system were served by non-stop flights. By consolidating passengers through a few selected airport hubs, an airline takes advantage of the resulting higher volumes by using large relatively efficient aircraft and can raise the frequency of service it offers passengers to compensate for the increased travel time incurred by the need to transfer (Kanafani and Ghobrial, 1985).

The deregulatory policies in airline industry opened the way for hubbing. Airline companies adjusted to the deregulated environment, and their network geography (node-linkage association) changed accordingly (Ivy, 1993). It became increasingly clear that concentrating flights at one or more hub cities in their networks could raise seat-occupancy level, and thus achieve scale economies using larger aircraft, and also maximize the number of on-line city-pair matchings available to passengers (Lopuszynski, 1986; Goetz and Dempsey, 1989; Ivy, 1993). The position of a hub was further strengthened as carriers simply added many more flights to many more destinations, medium-sized and small cities in particular, at these facilities to build up connectivity and create greater overall efficiency and market control at the hub (Bailey et al, 1985; Ivy, 1993) Significant amount of arrivals and departures are handled within a short time to allow the connections. This intense type of system has become known as a “hub-and-spoke” network. It is found that implementing hub-and-spoke networks is generally attractive to airline companies because they enjoy cost savings derived from concentrating flow density on network links between hub locations (Horner and O’Kelly, 2001).

In terms of network analysis, graph theory, an area of mathematics which examines the relationships or connections among members of a set, is the underlying mathematical foundation of measurement of networks. Graph theory defines a system of routes and places with flows as a

network. Points are referred to as nodes in a network, and links are termed as arcs in a network (Berge, 1962; Busacker and Saaty, 1965). In other words, a network is a graph that accommodates interaction or movement behavior explicitly. Nodes are locations where flows originate, terminate or transit while arcs are the conduits for flows between nodes (Miller and Shaw, 2001).

In general, four major characteristics of transportation systems can be employed as criteria in the network evaluation: (1) connectivity, (2) costs and distances, (3) accessibility, and (4) flows (Black, 2003). A series of indicators are developed to describe these various aspects of networks. Garrison and Marble (1962) devised several indices, namely, α, β, and γ, to calculate the connectivity of a network. Alpha (α) is a ratio of the existing circuits in a network to the maximum number of circuits possible. A circuit is defined as a finite, closed path in which the initial node of the linkage sequence coincides with the terminal node that exists in the network (Taaffe et al., 1996). Beta (β) is a ratio of the observed number of arcs to the number of nodes in a network, and gamma (γ) is a quotient of the observed number of arcs to the maximum possible number of arcs in a network. Garrison and Marble (1965) also examined the interrelationships among the three indices. They noted that α and γ were quite redundant. Actually, all the connectivity indices are so interrelated that it is unnecessary to use more than one such index in the study of network connectivity (Black, 2003). In this study, γ is applied to measure network connectivity because it is easiest to interpret and has obvious limits of near zero (for few arcs relative to the maximum possible) to one (for a completely connected network).

A major concern of network analysis is to find the dominant node of a network, which is generally referred to as the "problem of the leader" (Berge, 1962, p.135). In order to determine which node is the major node, as well as the relative ranking of all the other nodes in terms of connectivity dominance, a connectivity matrix needs to be constructed first (Black, 2003).

Matrices are frequently used in the study of network structure. A network can be represented numerically in the form of a matrix. Traditionally, we speak of n rows (origins) and m columns (destinations) in a network matrix. The n and m values correspond to the number of nodes in the network of interest, and the cell value may be used to represent the presence of a linkage, the direction of flow over a link, or any characteristic of these. In a connectivity matrix, the presence of a linkage in a network is represented by a 1, and the absence of a linkage is represented by a 0. The next step is to raise the connection matrix to a certain power and sum each of the derived matrices to form a new matrix. Any cell of the new matrix represents the total direct and indirect linkages of the respective nodes. Thus the relative dominance of each node in the network can be quantified by summing the row and column values. The question is to what degree the connectivity matrix should be raised. When the power is equal to the diameter of the network of interest all zero cells in the powered matrix disappear. For real-world transportation systems, this diameter value is rather difficult to obtain even though algorithms developed to solve this problem need only check for the presence of zeros in the final matrix because the result stabilizes when the matrix has non-zero entries in all of its cells (Black, 2003). Unfortunately, the current version of ArcGIS does not provide such a tool for determination of connectivity dominance. Instead, ArcGIS offers another powerful tool, namely, the OD cost matrix network analyst, to measure the relative dominance of a node in a network, which is discussed in the following paragraph.

Frequently, in the study of a transportation network, it may be necessary to examine the shortest paths between the nodes that make up the network. The OD cost matrix network analyst in ArcGIS presents a convenient tool to implement the shortest path analysis. An OD cost matrix is a table that contains the total impedance from each origin to each destination. Additionally, it ranks the destinations that each origin connects to in ascending order of the impedance it takes to travel

from that origin to each destination. Thus it provides information on the shortest path between two given nodes in a network.

Another significant attribute of network is network accessibility. Accessibility takes numerous forms in transportation research, most of which attempt to measure the locational advantage or disadvantage of a node relative to other elements of the network. A basic measure of accessibility, known as the associated number of a vertex, was devised by Shimbel (Shimbel, 1953). The index is derived from measuring the length of the shortest paths from all vertices of a network. Shimbel proposed a procedure involving the computation of a matrix. The cells of the matrix indicate the distance of the shortest path between all pairs of nodes in the network. The OD cost matrix network analysis is essentially the same as the matrix that Shimbel described. Thus, it can be used to calculate the network accessibility.

Last, but not least, network analysis often involves the analysis of flows, which is an indivisible part of the study of a network. Networks are, after all, built for the purpose of transporting people, commodities, information and capital between multiple origins and destinations. Many methods and models can be applied to the study of flows across a network. The optimal flow system, also known as the transportation problem of linear programming, is applied to cases when the distribution of a product is subject to a number of constraints. Common constraints are the capacity of a warehouse, the cost of shipping a unit of products, the timeframe from pickup to delivery and so forth. A classical example is the Hitchcock problem (Hitchcock, 1941). The problem may be illustrated as follows: there are five factories each of which has certain number of color TV sets that are to be distributed to three vendors. The cost of shipping a manufactured unit from each factory to each vendor is fixed. The problem is to distribute the products in such a way that the demand at all vendors is met, the supply at each of the factories is

not exceeded, and the overall cost of shipping the good is a minimum. In this case, linear programming can be applied to generate a set of optimal flows that satisfies all constraints. Another frequently mentioned flow analysis method is the gravity model. The gravity model predicts movement of people, information, and commodities between cities and even continents (Ullman, 1954). The classical gravity model takes into account the population size of two places and their distance in that larger places attract people, ideas, and commodities more than smaller places and places closer together have a greater attraction. Various versions of gravity models have been constructed on the basis of the classical model (see Voorhees, 1955; Wilson, 1967; Wilson, 1974), but all of them are built upon the principle that interaction between places is directly proportional to the product of their masses and inversely proportional to the distance between them (Black, 2003). Another important method worthy of mention is network autocorrelation. Network autocorrelation exists among random variables associated with the links of a network. It can be used in assessing the pattern (cluster, random, or dispersed) of flow-related incidents on a transportation network (Black, 1992). A good example would be to assess the distribution of car accidents between mileposts 315 and 375 on Interstate 40 in 2007.

These methods and models as well as many others enable transport researchers to analyze various aspects of transport flows. This paper, however, does not apply any of the methods mentioned above to the analysis of flows across China's international airline network because either the method is not relevant to the problem this study attempts to solve (e.g. optimal flow system) or the approach involves intensive mathematical and statistical calculations (e.g. the gravity model. To implement a gravity model, distance between China and overseas countries would need to be measured, populations calculation, and trade data between China and foreign countries would be available). One of this study's objectives is to identify flow distribution among

different world regions based on origin-destination flow data. In this case, network autocorrelation analysis seems to serve this purpose. Actually, network autocorrelation is primarily applied to the analysis of spatial data in which the basic units of observation are points, such as motor vehicle accidents on a road system, chemical contaminating agents in water supply systems, disease diffusion via transportation and social networks and so forth. Despite the fact that ArcGIS provides the spatial autocorrelation tool for spatial statistical analysis, its applications are quite limited if the basic unit of observations is the line. The tool identifies the central line among input line dataset. This functionality is apparently not really useful for the purpose of this study in that a single line does not reveal any information about the distribution pattern of air traffic. This study therefore applies descriptive statistical analysis to the measurement of regional differences denoted by air transport. Descriptive statistical analysis uses origin-destination flow data to map out flow distributions among different world regions. Air traffic flow to and from each region are summed up and then compared against other regions to measure differences among world regions. Additionally, this study applies descriptive statistical analysis to evaluate various economic, social, and political events and circumstances impacts on the airline industry.

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Chapter 3: Data and Analysis

3.1 Study Area

This research analyzes the geographic patterns of the international air transport network served by Chinese airlines from 1990 to 2004 with two foci: network developments and regional differences. 1990-2004 was chosen because the earliest year with the data reported in a consistent manner was 1990 and the latest year with published data when I compiled the data for this research was 2004. All data are from the Yearbook House of China Transportation and Communication (Yearbook House of China Transportation and Communication, 2008).

As for network developments, this research examines the network connectivity and accessibility of China's three major hub cities within the air transport system. Cities that have established international flight routes (direct or indirect) by Chinese airlines from 1990 to 2004 are examined in terms of the number of flights, passenger flows, and freight flows. There were 50 cities in China (excluding Hong Kong and Macau) that established direct or indirect routes with 99 cities in 47 countries from 1990 to 2004 (see Figure 1). Hong Kong and Macau are classified as overseas cities in this research. These two cities had developed their own air transport systems before their returns to China in 1997 and in 1999 respectively. After the returns, they are designated as Special Administrative Regions (SAR) by the Chinese central government and have more freedom in their operations than other Chinese cities. Routes are defined as direct or indirect based on the way they are reported in the China Transportation and Communication Yearbook. For instance, in a route from Beijing through Shanghai to San Francisco, the path from Beijing to San Francisco is recorded as an indirect route, while the segment from Shanghai to San Francisco is reported as a direct route. According to the United Nations' convention (United Nations, 2005), this study identifies six world macro regions and components (see Figure 2 and Table 1).

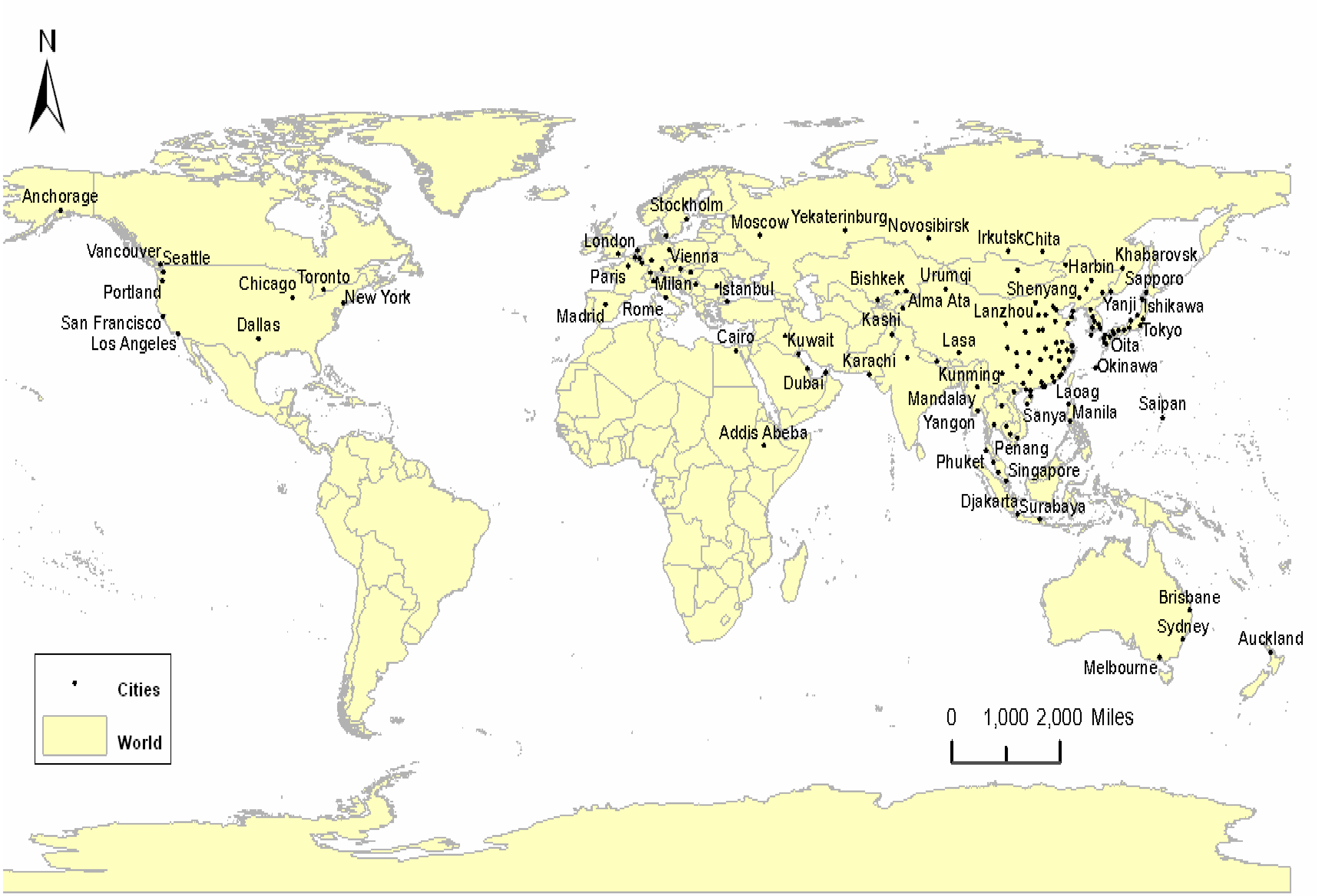

Figure 1. Cities that participated in the network from 1990 to 2004

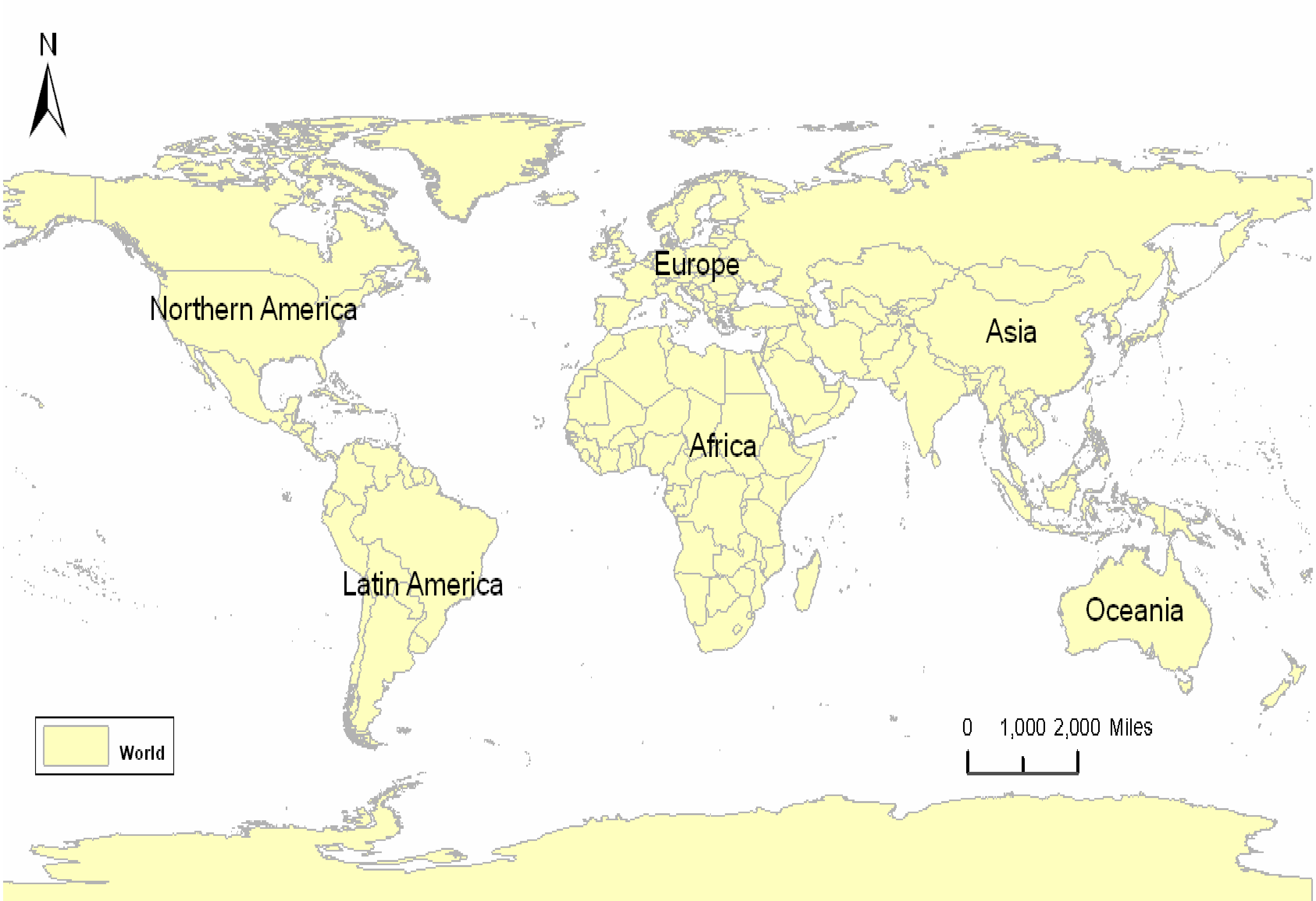

Figure 2. World macro regions

Table 1. World macro regions and components served by Chinese airlines during 1990-2004

Region	Africa	Asia		Europe	Northern America	Oceania
	Egypt	Bahrain	Pakistan	Austria	Canada	Australia
	Ethiopia	Burma	Philippines	Belgium	U.S.	New Zealand
		Cambodia	Singapore	Denmark		Northern Mariana Islands
		China	South Korea	France		
		India	Thailand	Germany		
		Indonesia	Turkey	Hungary		
		Iraq	U.A.E.	Italy		
Component		Japan	Uzbekistan	Luxembourg		
		Kazakhstan	Vietnam	Netherlands		
		Kuwait		Romania		
		Kyrgyzstan		Russia		
		Laos		Spain		
		Malaysia		Sweden		
		Mongolia		Switzerland		
		Nepal		U.K.		
		North Korea		Yugoslavia		
Total	2	25		16	2	3

Among the 50 domestic cities, three hub cities (Beijing, Shanghai, and Guangzhou) are selected and their spatial nodal accessibility levels are calculated in order to examine the competition among these three major hubs.

This research examines the geographic distribution of passenger and freight traffic among different world regions from 1990 to 2004. By comparing passenger and freight volumes in and out of each region, we can observe regional disparity with respect to air transport. Traffic flows are reported as aggregate numbers per route in the China Transportation and Communication Yearbook. For instance, on a route from Beijing through Sharjah to Paris, the total passenger volume in 2004 was 65,380. This aggregate statistic did not indicate how many passengers embarked or disembarked at the intermediate city (i.e., Sharjah in this example). Such intermediate nodes present a problem when there is a need to calculate the traffic volumes by world regions. If the intermediate city is located in the same region as the destination city, there is no decrease or increase in the traffic volume for the destination region. But, if intermediate cities are located in different regions, like the Beijing-Sharjah-Paris route, we cannot say with certainty that 65,380 passengers traveled between Beijing and Europe (i.e., Paris in this example) in 2004 because some passengers might have boarded or disembarked in Asia (i.e., Sharjah in this example). The same holds true for freight flows. Nevertheless, only few routes in the dataset have this problem. This study therefore assumes that the volume of passengers or freight between the origin and the destination of a route is the same as what is reported in the Yearbook.

3.2 Data Acquisition

The initial data acquisition was quite smooth. The China Transportation and Communication Yearbooks have been published since 1986 by the Yearbook House of China

Transportation and Communication as an official record of transportation operation and marketing performance. Dr. Shih-Lung Shaw went to Beijing in summer 2006 and collected these data. The National Library of China in Beijing holds the entire 20 volumes of the China Transportation and Communication Yearbook. Data were obtained directly from the yearbooks. However, due to the absence of information on freight flows from 1986 to 1989, this research only covers records from 1990 to 2004.

There are nine attributes recorded for each route. These attributes fall into two categories. One category contains spatial attributes, where the latitude and the longitude of cities are recorded according to the sequence of traffic flows. The other category holds descriptive attributes, which contains descriptive information about the origin, the destination, transit, world region, the number of flights, passenger volume, and freight volume (Table 2). Based on this division, two different types of analyses are performed. Air transport networks are rendered in ArcMap and relevant spatial analyses are performed to study changes in network structure. Descriptive statistical analyses are conducted to examine regional differences that resulted from air transport network development.

Table 2 Attributes of a route

Category	Field	Description
Spatial	Latitude	Stores latitude and longitude of cities
	Longitude	
Descriptive	Origin City	Stores the origin city's name
	Transit City 1	Stores the transit city's name
	Transit City 2	Stores the transit city's name
	Transit City 3	Stores the transit city's name
	Destination City	Stores the destination city's name
	World Region	Identifies world region where a city locates
	Flights	Records the number of flights
	Passengers	Records passenger volume
	Freight and Mail	Records freight and mail volume

Foreign airlines, such as United Airlines, Northwest Airlines, Continental Airlines, Lufthansa Airways, and British Airways also have flights serving China. These foreign airlines are not reported in the China Transportation and Communication Yearbook, and therefore are not discussed in this research. In addition, Hong Kong and Macau were returned to China in 1997 and 1999 respectively. These two cities are recognized as Special Administrative Regions by the Chinese government. Hence, this study classifies Hong Kong and Macau as a separate group that did not contribute to international air traffic flows of China. Last, but not the least, Taiwan's sovereignty has been a major concern in the international arena. In fact, there have been no scheduled direct routes between China and Taiwan. Hong Kong serves as a major transit airport for air passengers traveling between China and Taiwan. Taiwan therefore is not included in this study.

3.3 Data Analysis

Network analysis, which focuses on the structure formed by the linkages and nodes in a network, is an important topic in the study of transportation geography. The term structure refers to the layout, geometry, or network pattern of transportation system (Garrison and Marble, 1962). It implies a set of spatial relations between distinguishable components of transportation networks in respect to each other and to the organized whole (Kansky, 1963). By measuring such relations we can describe the notion of structure in mathematical terms. Several measures and indices were developed and can be used for study of network structure. Some of the measures and indices are applied to this research to examine structural development of China’s international air transport network.

Nodes and linkages are the two fundamental elements in a network. When a network is

abstracted as a set of edges (linkages) that are related to a set of vertices (nodes), a fundamental question is to which degree all the vertices are interconnected with each other. The degree of connection between all vertices is defined as the connectivity of the network. It is probably one of the most important structural properties of the network (Taaffe et al., 1996).

Although we may measure the degree of connection between the vertices of a given network at a given point in time, the concept of connectivity is most meaningful when a given network is either (1) compared with other networks or (2) its growth is viewed through time (Taaffe et al., 1996). This study of changing geography of air transport networks over time falls nicely into the second category.

The first step of data analysis is data input. The raw data are in hard copy format and contain about 45,000 records over the 15-year study period. The data set consists of 50 domestic cities with direct or indirect flight routes to 47 foreign countries from 1990 to 2004. Spreadsheets are extensively used in this step to create, manipulate, and store data for the subsequent analyses.

As mentioned earlier, two different types of analyses are performed in this study. One is network analysis and the other is descriptive statistical analysis. As to the former, geographic information systems (GIS) provide powerful tools to store, organize, analyze, and visualize spatial data. Spatial patterns can be examined and interpreted using various GIS functions. Spreadsheet files, which contain data required to construct the network such as the latitude and the longitude of cites, the sequence of flows (origin, transit, and destination), are imported into ArcGIS. Air transport networks are then generated from the data for each of the fifteen years (i.e., 1990-2004). Figures 3 and 4 show snapshots of air transport networks of 1990 and 2002 respectively.

When first portraying the transportation routes spatially as a series of lines the routes were not portrayed correctly. It was found that ArcMap cannot display the routes from China to North

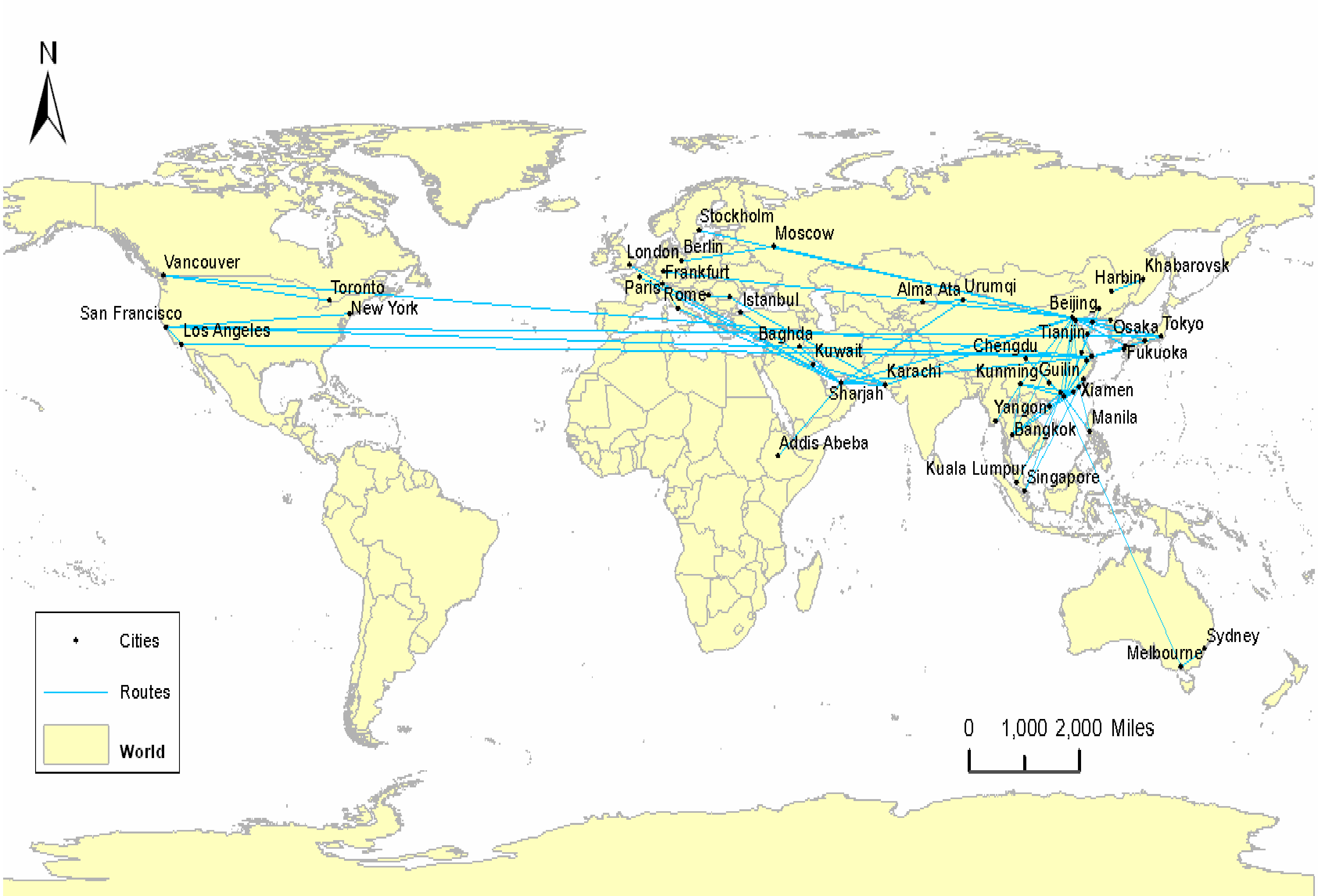

Figure 3. China's international air transport served by Chinese airlines in 1990

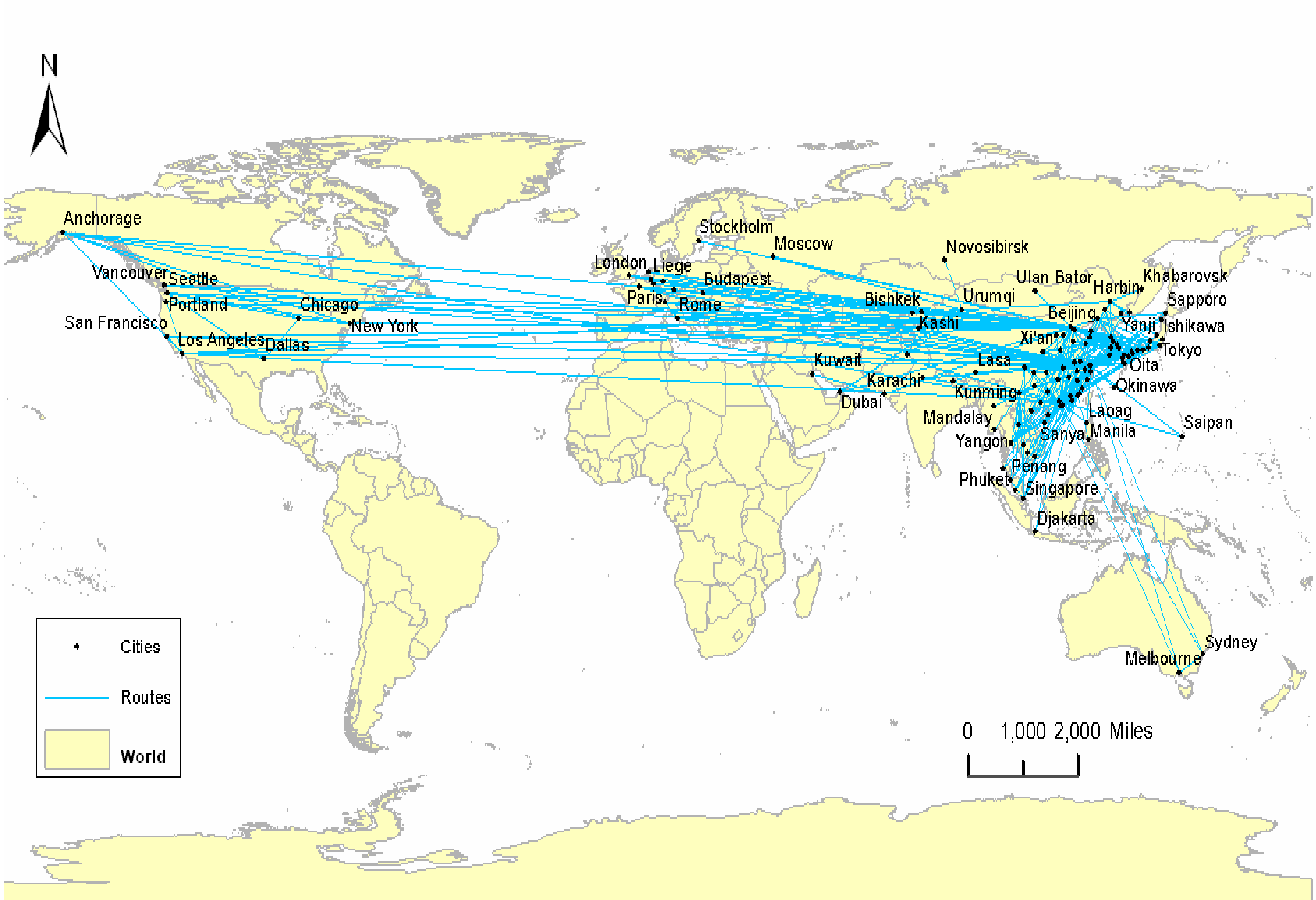

Figure 4. China's international air transport served by Chinese airlines in 2004

America properly. In order to correct this error and portray the data accurately I used a custom code based on the mathematical principles of the great circle path (Kern and Bland, 1948).

The routes between China and North America displayed in Figure 3 and Figure 4 fly over the continent of Europe. The actual flight routes, however, should fly over the Pacific Ocean. This inconsistency is due to the embedded algorithms in ArcMap which connect points represented by an X-Y coordinate pair without considering their relative positions on the Earth's surface. In other words, ArcMap simply renders the line as a vector connecting two X-Y coordinate pairs, which are typically in a format of latitude/longitude, on a map projection. However, a straight line on a map is not necessarily the shortest distance. Ships and aircraft usually follow the shortest path to minimize distance and save time and money, which is exactly the case in this research.

The shortest path between two points on a spherical surface is a segment of a great circle. A great circle is a circle on the surface of a sphere that has the same circumference as the sphere (Kern and Bland, 1948). A great circle is the path with the smallest curvature, hence it bears the shortest path between two points on the surface (Coolidge, 1952). To find the great circle path between two points on a sphere, we have to convert Cartesian coordinates (X-Y coordinates) to spherical coordinates (Arfken, 1985) using the haversines formula (Sinnott, 1984) in spherical geometry. This research, however, focuses on the visualization of airline networks rather than the process of finding the great circle path, and therefore does not discuss mathematical calculations with respect to the great circle path.

The visualization problem can be solved by programming with ArcMap under the Visual Basic programming environment. Like many Windows programs, ArcMap supports Microsoft® Visual Basic for Applications (VBA). The original codes were written by Dr. Cheng Liu in Avenue, a programming language used for customizing and developing applications in ArcView

3.x's. The platform used in this research is ArcGIS 9.2, the programming language is therefore changed to Visual Basic for Applications. I developed the new codes (see Appendix) with the assistance of Dr. Bruce Ralston, who provided helpful guidance about writing and debugging codes.

The algorithm of this application is quite simple. Given an X-Y coordinate pair of the starting and end points of a path to be drawn, the approach is to calculate the size of the angle between the beginning and end points of a path. That is, the angle on the sphere between the origin and the destination. Intermediate points are then calculated to build a polyline consisting of arcs that are 1/N of the path between the origin and the destination. The key is to obtain the X-Y coordinates of the intermediate points. We derive the X-Y coordinates of the intermediate points by dividing the angle between the beginning and end points into N small angles and then simply draw a line between the intermediate points using ArcMap. The line is the so-called great circle path. Figure 5 explains the theory of the application.

It should be noted that N can be set to any integer larger than 1. The larger the value of N, the more points that are rendered. The resulting line is also more precise. However, a larger N means more calculation involved even though it is done by codes running in the background. N is set to 100 in this application, which means 99 intermediate points are rendered along the path and altogether there are 101 points including the beginning and the end points. It turns out that 100 is not a bad parameter since the resulting lines are visually effective and function well. Figure 6 and 7 show snapshots of modified air transport networks of 1990 and 2002 respectively.

The visualization of air transportation networks helps us to obtain an overall image of network development during the study period. Yet to fully interpret the growth, the following

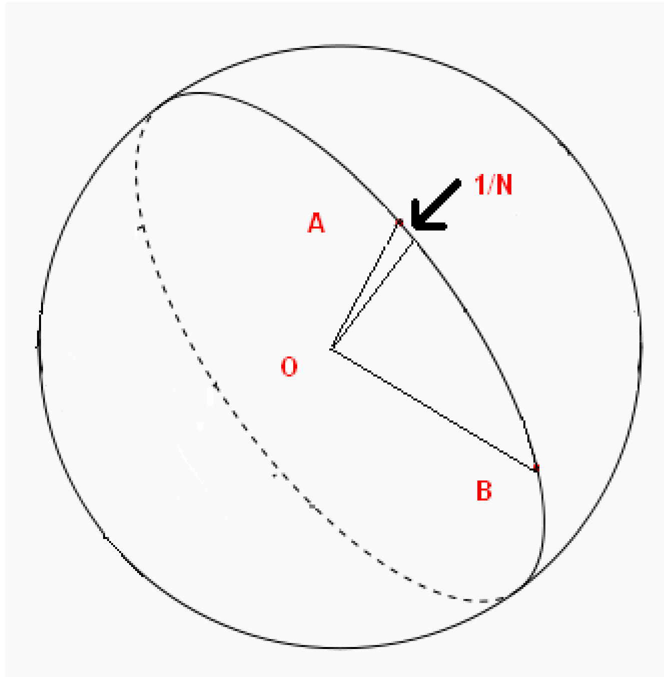

Figure 5: Great circle path

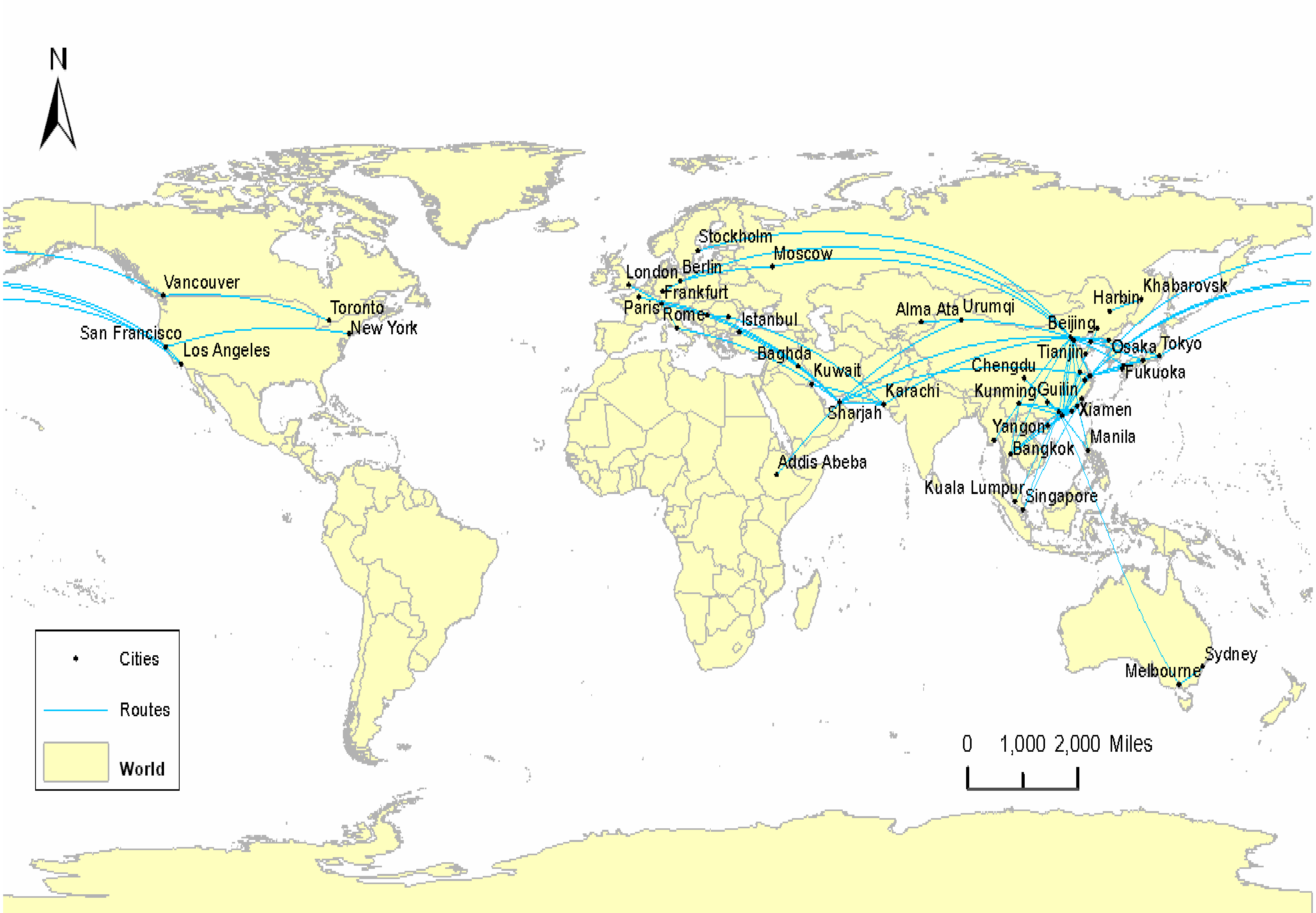

Figure 6. China's international air transport served by Chinese airlines in 1990 (modified)

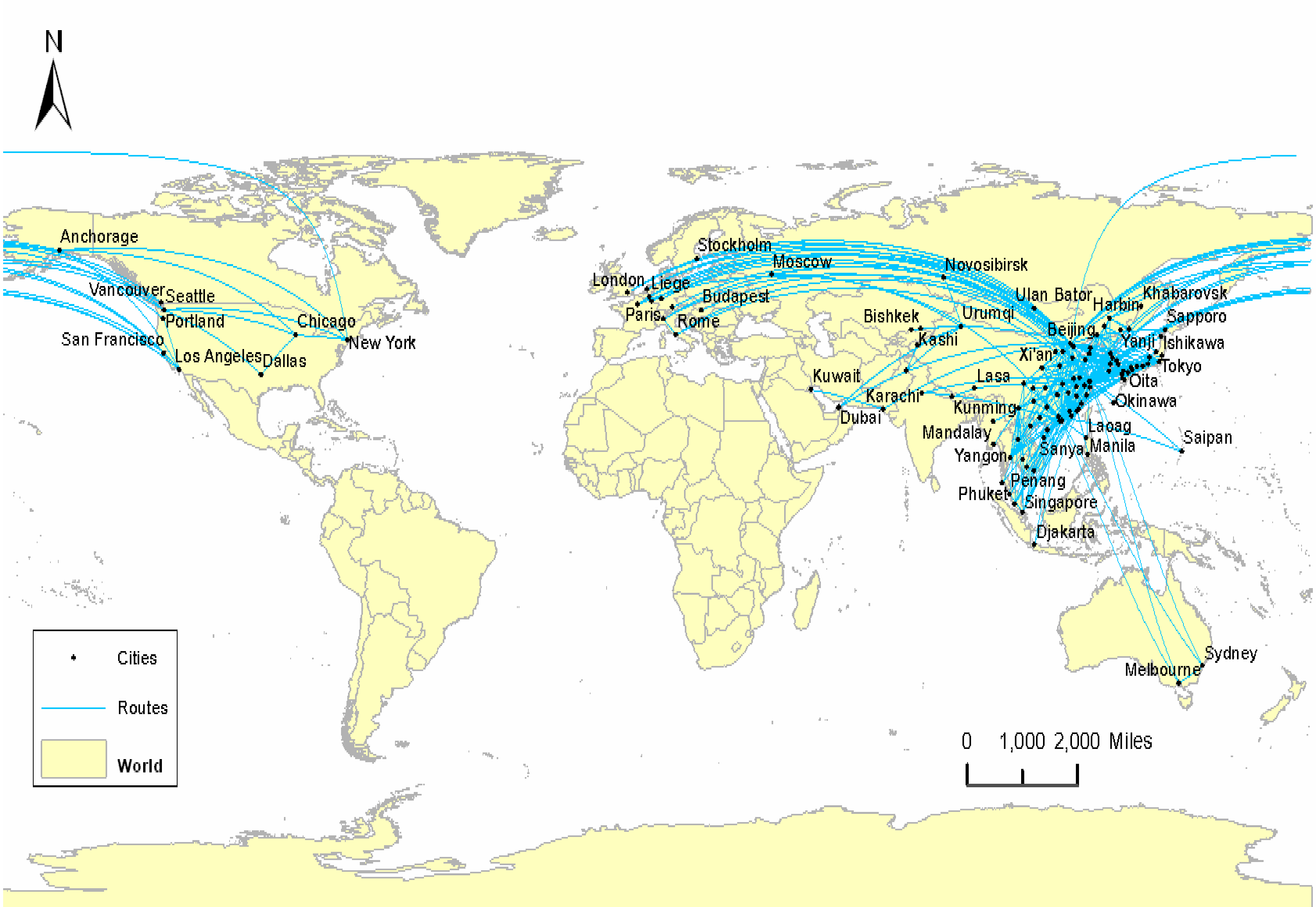

Figure 7. China’s international air transport served by Chinese airlines in 2004 (modified)

network analyses are performed.

The first one to be examined is the network connectivity. There are two basic indices to measure network connectivity: α and γ. These two indices were developed by Garrison and Marble (1961) and were first introduced in their unpublished report for the U.S. Army Transportation Research Command in 1962. Alpha (α) can be interpreted as a ratio between the observed number of circuits and the maximum possible number of circuits in a network (Kansky, 1963). A circuit is defined as a finite, closed path in which the initial node of the linkage sequence coincides with the terminal node (Taaffe et al., 1996). Airline routes are circuits in natural because where there is a departure, there is a return. Thus this study chooses γ over α to examine the structural development of the network. Gamma (γ) is a quotient of the observed number of linkages to the maximum possible number of linkages in a network. It is calculated using Equation (1).

$$\gamma = \frac{\mathrm{e}}{N(N-1)/2} \tag{1}$$

where N is the number of nodes in a network and e is the observed number of linkages. The numerical range for γ is between 0 and 1, where 0 denotes a set of nodes having no connections and 1 indicates a network of which every node is connected to all other nodes in the network. γ is a useful measure of the progression of a network over time (Rodrigue et al., 2006).

While γ is applied to represent the network connectivity, another significant characteristic of a network, nodal accessibility, gives us a closer look at how the components of a network (nodes and linkages) are interconnected at individual nodes. One measure of the nodal accessibility is to calculate the number of linkages required to travel between a given node and all other nodes in a network. In this paper, nodal accessibility of Beijing, Shanghai, and Guangzhou is calculated by measuring the number of linkages along the shortest path between each of them and all other cities.

Certain attributes are used to measure and model cost in a network, such as travel distance

or travel time. Network analysis often involves the minimization of cost in the calculation of a path. Common examples include finding the fastest route or the shortest route. In this research, I try to find the shortest route, in other words, to minimize the topological distance.

It should be noted that topological distance, as opposed to a distance using a geographical metric such as miles or kilometers, are used in this study. Topological distance treats any direct linkage as one regardless of the actual length of the link. A topological distance of two indicates that a stop/transfer is required between two given nodes on a network. The reason why topological distance is applied is because the focus of this study is the structural development of airline networks rather than the cost (i.e., flight time, airfare, and fuel) involved in the airline business, where actual geographical distance plays a leading role in determining the cost.

A practical procedure for finding the shortest path is offered by Shimbel (Shimbel, 1953). To determine the shortest path in a network, he suggested a procedure involving the computation of a matrix D. The cells of the matrix indicate the distance of the shortest path between all pairs of nodes in the network. Furthermore, Shimbel introduced an important measure of the network structure which is called the accessibility of a node to the network. This measure can be obtained by summing across the rows of matrix D and is defined as:

$$A_i = \sum_{j=1}^{n} D_{ij} \tag{2}$$

where Dij is the distance along the shortest path from node i to node j. Ai denotes the accessibility of node i. The smaller the numerical value of the sum of Dij, the greater the accessibility of node i to the network.

The OD cost matrix network analyst in ArcGIS presents a convenient tool to implement the shortest path analysis. A hypothetical network is provided and its OD cost matrix is calculated (Figure 8 and Table 3). Summing over the cell value in any row of the matrix gives the total

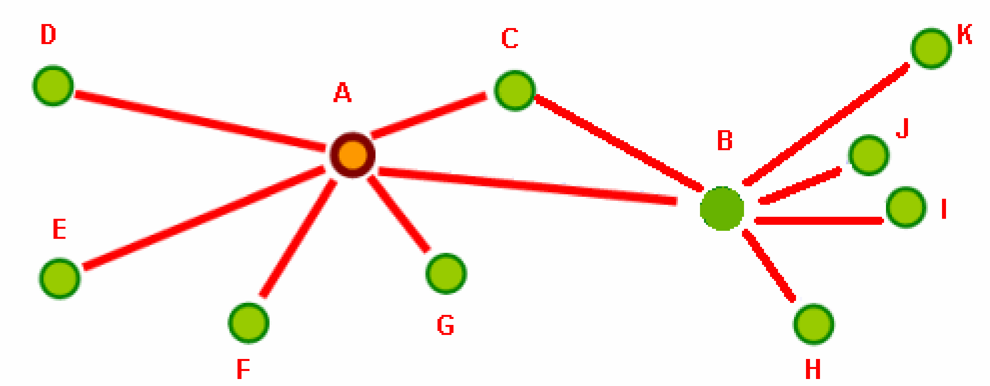

Figure 8. A hypothetical network

Table 3. OD cost matrix of a hypothetical network

ID	A	B	C	D	E	F	G	H	I	J	K	*Si*
A	0	1	1	1	1	1	1	2	2	2	2	1.4
B	1	0	1	2	2	2	2	1	1	1	1	1.4
C	1	1	0	2	2	2	2	2	2	2	2	1.8
D	1	2	2	0	2	2	2	3	3	3	3	2.3
E	1	2	2	2	0	2	2	3	3	3	3	2.3
F	1	2	2	2	2	0	2	3	3	3	3	2.3
G	1	2	2	2	2	2	0	3	3	3	3	2.3
H	2	1	2	3	3	3	3	0	2	2	2	2.3
I	2	1	2	3	3	3	3	2	0	2	2	2.3
J	2	1	2	3	3	3	3	2	2	0	2	2.3
K	2	1	2	3	3	3	3	2	2	2	0	2.3

distance along the shortest paths from the corresponding node to all other nodes in the network. These row totals are then divided by the minimum number of linkages possible for connecting that node with all other nodes in the network to derive a standardized index Si (Equation (3), see Shaw, 1993).

$$S_i = \frac{\sum_{j=1,n} D_{ij}}{N-1} \tag{3}$$

where Dij denotes topological distance along the shortest path from node i to node j. N is the number of nodes in a network. The lowest possible value of Si is 1, which means that node i has direct connections with all other nodes in the given network. A value of 2 for Si suggests that an average one stop/transfer is required to travel from the node i to any other node in the network. The higher the value of Si is, the less accessibility of a given node possesses.

In the hypothetical network of Figure 8, node A and node B have an *Si* index value of 1.4, node C has an *Si* index value of 1.8, and the *Si* index value of all other nodes on the network is 2.3 (see Table 3). This indicates that node A and node B have the highest accessibility level on the network, node C ranks second in accessibility, and all other nodes present a low accessibility with a high *Si* index value.

Network analysis results of China's international air transport network are presented and discussed in Chapter 4. Besides network analysis, this research conducts descriptive statistical analysis to measure regional differences denoted by air transport. Air traffic flow data are calculated and distributed to five world regions based on the origin or destination of the flow. For instance, 1,000 passengers were carried on the route of Beijing-New York in 1992, 2,000 passengers embarked on the route of Los Angeles-Shanghai in the same year, then a volume of 3,000 passengers were recorded in North America. This method is, however, error-prone if a transit is involved on a route and the transit city is not located in the same region as the

origin/destination city does. For example, the yearbook recorded a passenger volume of 5,000 on the route of Beijing-Tokyo-New York in 1993, but we cannot claim that 5,000 passengers landed in North America (i.e., New York in this example) in 1993 because some passengers might have boarded or disembarked in Asia (i.e., Tokyo in this example). The same holds true for freight flows. Nevertheless, only few routes in the dataset present such problem. This study assumes, therefore, that the volume of passengers or freight between the origin and the destination of a route is the same as what is reported in the yearbook. Flight, passenger, and freight distribution from 1990 to 2004 are calculated and the trend of the distribution is graphed out and discussed in Chapter 4.

Chapter 4: Results and Discussion

4.1 Change of Network Connectivity

Table 4 records the level of network connectivity from 1990 to 2004. As shown in Table 4, the connectivity of the network rose and fell during the study period. A sustained decrease was observed since 1990 and it reached its lowest point in 1993. Afterward the connectivity climbed up and attained a high level in 1995, followed by a slight drop in 1996. The development of the network reached a plateau since 1997 and remained a relative high level of connectivity during 1997-1999. The number started to decline again since 2000 until it fell to a low level in 2002. Finally, an increase was observed in the last two years of the study period.

Table 4. Network connectivity from 1990 to 2004

Year	Number of Linkages	Number of Nodes	Domestic	Overseas	γ
1990	198	54	18	36	0.1384
1991	194	55	13	42	0.1306
1992	256	81	32	49	0.079
1993	310	92	40	52	0.0741
1994	342	94	39	55	0.0782
1995	302	75	22	53	0.1088
1996	354	85	27	58	0.0992
1997	396	81	24	57	0.1222
1998	460	91	27	64	0.1123
1999	454	87	25	62	0.1214
2000	506	101	39	62	0.1002
2001	480	104	40	64	0.0896
2002	538	112	41	71	0.0866
2003	632	114	40	74	0.0981
2004	790	121	44	77	0.1088

It was found that the variation of the network connectivity was mainly caused by the change in the number of domestic cities that presented in the network. As shown in Table 4, there were 18 domestic cities in the network in 1990 and it decreased to 13 in 1991. The number increased drastically to 32 in 1992, reached an unprecedented height of 40 in 1993, and slightly dropped to 39 in 1994. Afterward it plunged to a low level of 22 in 1995 and varied slightly during 1996 -1999. As it approached to the 21st century the number of domestic cities greatly increased to 39 in 2000 and stayed stable with an average value no less than 40 during the last 4 years of the study period. The huge increase and decrease in the number were due to the entry/exit of provincial capitals, secondary cities, or tourist cities into/from the network, to name a few, Nanjing, Hefei, Luoyang, and Huangshan. These cities entered the network through their direct flights with Hong Kong and/or Macau. Other than that, these cities had no direct connections with any other overseas city in the network. That is, the presence of these cities increased the total number of nodes in the network; however, due to their relatively weak connections with other cities in the network, their contribution to the network connectivity was compromised. Similar conclusion could be drawn on overseas cities: the number of overseas cities exhibited an overall growth during the study period despite few minor fluctuations. The emergence of the newly opened overseas markets increased the total number of nodes in the network, but these foreign cities established connections with only few select cities in China such as Beijing, Shanghai, and Dalian. In conclusion, the growth in the number of linkages in the network was disproportionate to the increase in the number of nodes in the network. This disproportion explains the variation of the network connectivity and especially clarifies the dip in 1993 and 2002 and the climax in 1997 and 1999.

Several significant social and political events happened during this period. For instance, Hong Kong was returned to China in 1997, as well as Macau in 1999, which presumably had great

impacts on the network structure. In fact, connections between domestic cities and Hong Kong/Macau had already existed before the returns. According to China Transportation and Communication Yearbook, routes connecting mainland China and Hong Kong existed prior to 1990 and there was a record high of 37 scheduled flights between domestic cities and Hong Kong in 1993 as well as in 1994, and scheduled flights between mainland China and Macau emerged in 1995 and the number of flights varied slightly since then (an average of 5 flights per year). So the returns of Hong Kong and Macau did not actually contribute to the expansion of the network even though the number of scheduled flights between mainland China and Hong Kong/Macau increased to 42 in 2000 (36 of Hong Kong and 6 of Macau). Other constructive events such as China's entry into the WTO in 2001 and the airline consolidation in 2002 likely brought about favorable changes to the network structure: a large number of new direct routes was established between China and the Asia Pacific region in 2002, particularly between China and South Korea and Japan, for instance, Shanghai-Jeju, Shanghai-Gwangju, Shanghai-Oita, Chengdu-Tokyo, and Chengdu-Osaka emerged. Numerous new nonstop flights were launched between China and Southeast Asia, Europe, and North America in 2003, such as Shanghai-Phuket, Beijing-Kuala Lumpur, Shanghai-Rome, Shanghai-Amsterdam, Beijing-New York, and Beijing-Portland, and a sustained increase in the network connectivity has been observed since 2002. On the other hand, vicious events such as the 1997 Asian Currency Crisis, the September 11, 2001 terrorist attacks, and the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003 in China, severely struck the global airline industry (IATA, 2002; ICAO, 2003; Goetz and Graham, 2004). However, they did not pose any major problem for the development of China's international air transport network. Arguably, these events are most likely to affect traffic volumes rather than the network structure, which is discussed in the following section. In general, the trend of China's expanding

international airline network is towards a system with a high level of connectivity and great coverage.

4.1 Change of Nodal Accessibility

Table 5 records the level of nodal accessibility of the three major hubs from 1990 to 2004. D_B stands for the topological distance along the shortest path from Beijing to all other nodes in the network and S_B denotes the standardized index Si of Beijing (see Equation (3)). D_S and D_G refer to the topological distance along the shortest path from Shanghai and from Guangzhou to all other nodes respectively, and S_S and S_G represent the standardized index Si of Shanghai and Guangzhou respectively.

The variation of nodal accessibility from 1990 to 2004 is displayed in Figure 9. As shown in Figure 9, Beijing ranked the highest in accessibility during the entire study period, with the exception of 2004 when Shanghai knocked off Beijing and became top one. Beijing's high ranking was due to Beijing's relatively small D_B value as compared with Shanghai and Guangzhou, and its small D_B value was associated with the large number of direct connections Beijing had from 1990 to 2004 (see Table 6). As shown in Table 6, Beijing, by and large, exceeded Shanghai and Guangzhou in the number of direct connections. Basically, the more direct connections a city has, the smaller the topological distance along the shortest path from the city to all other cities in the network is. As a result, Beijing's high ranking was observed. Shanghai placed second in accessibility from 1990 to 2003. Its accessibility was relatively low from 1990 to 1995. Its accessibility started to increase in 1996. Shanghai has been catching up fast since then, which made it a keen competitor to Beijing. Similarly, Shanghai's 2nd place was due to its small number of direct connections with other cities, and its rapid growth in accessibility since 1996 was related

Table 5. Nodal accessibility of Beijing, Shanghai and Guangzhou from 1990 to 2004

Year	Number of Nodes	D_B	S_B	D_S	S_S	D_G	S_G
1990	54	89	1.679	106	2	117	2.208
1991	55	81	1.5	106	1.963	106	1.963
1992	81	138	1.725	165	2.063	171	2.138
1993	92	160	1.758	186	2.044	196	2.154
1994	94	172	1.849	193	2.075	203	2.183
1995	75	126	1.703	152	2.054	158	2.135
1996	85	125	1.488	146	1.738	155	1.845
1997	81	118	1.475	138	1.725	145	1.813
1998	91	152	1.689	174	1.933	197	2.189
1999	87	138	1.605	161	1.872	189	2.198
2000	101	168	1.68	186	1.86	211	2.11
2001	104	173	1.68	192	1.864	220	2.136
2002	112	185	1.667	192	1.73	242	2.18
2003	114	183	1.619	194	1.717	241	2.133
2004	121	198	1.65	192	1.6	254	2.117

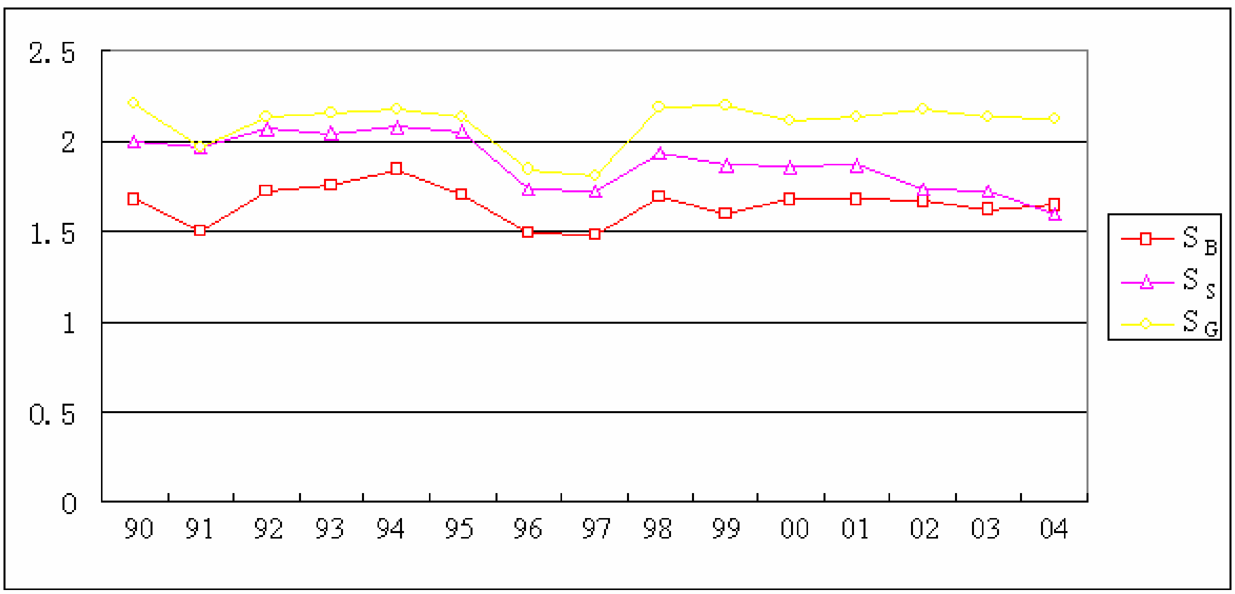

Figure 9. Nodal accessibility of Beijing, Shanghai, and Guangzhou from 1990 to 2004

Table 6. Number of direct connections with Beijing, Shanghai, and Guangzhou from 1990 to 2004

Year	Beijing			Shanghai			Guangzhou		
	Overseas	Domestic	Total	Overseas	Domestic	Total	Overseas	Domestic	Total
1990	11	7	18	9	1	10	6	2	8
1991	13	7	20	9	1	10	7	3	10
1992	13	7	20	10	2	12	7	3	10
1993	13	11	24	14	2	16	8	2	10
1994	18	7	25	16	2	18	9	3	12
1995	21	6	27	15	2	17	10	3	13
1996	23	9	32	21	3	24	11	4	15
1997	26	9	35	21	3	24	13	4	17
1998	25	8	33	25	2	27	13	3	16
1999	26	8	34	25	2	27	11	2	13
2000	24	8	32	27	2	29	11	2	13
2001	24	8	32	27	3	30	13	1	14
2002	27	8	35	34	7	41	14	1	15
2003	31	10	41	40	7	47	16	1	17
2004	33	12	45	47	11	58	19	4	23

to the major increase in the number of direct connections Shanghai had since then (see Table 6). Guangzhou possessed the lowest accessibility among the three, which is explained by its smallest number of direct connections with other cities during the entire study period (see Table 6).

In general, the accessibility of the three cities showed little variation over the entire study period except for 1991, 1996, and 1997. All three cities experienced a significant increase in accessibility in 1996 and 1997. The increase can be explained by the emergence of new direct connections in the network. As shown in Table 5, the number of nodes increased while D_B, D_S, and D_G decreased in 1996 and 1997 as compared to 1995. This indicated that direct connections emerged on certain routes where they were not available prior to 1996. For instance, a transit was required between Beijing and Seattle, Beijing and Anchorage, Beijing and Qingdao, and Shanghai and Guangzhou in 1995 while they were nonstop flights in 1996 and 1997. Direct connections replaced indirect connections and consequently the value of D_B, D_S, and D_G declined. Thus a high level of accessibility of all three cities was observed. Another major increase in accessibility was found in Beijing and Guangzhou in 1991. The increase was due to the replacement of indirect connections by direct ones as well as the removal of many isolated cities from the network with which neither Beijing nor Guangzhou was directly connected. For instance, in 1990 a transit was required between Beijing and Zurich, Beijing and Paris, and Beijing and Berlin, whereas in 1991 they were nonstop flights. Besides, several isolated cities, such as Nanjing, Chengdu, Qingdao, and Fuzhou withdrew from the network in 1991. These cities were only connected with Hong Kong in 1990. Their disappearance in 1991 made D_B and D_G decline because they did not contribute to the value of D_B and D_G. For instance, a route of Beijing-Hong Kong-Nanjing added 2 to the value of D_B in 1990, whereas D_B declined in 1991 because there was no such a route present in the network. Lastly, an unusual drop in the number of nodes was observed in 1995, which

resulted in a low to moderate increase in accessibility of each city. As shown in Table 5, the number of nodes plunged to 75 in 1995 as compared to 94 in 1994. The decline was largely due to the removal of domestic cities from the network. There were 39 domestic cities present in the network in 1994, whereas there were 22 in 1995. These cities such as Chengdu, Nanjing, and Wuhan were only connected with Hong Kong in 1994. Similarly, their withdrawal from the network greatly reduced the value of D_B, D_S, and D_G and consequently the accessibility of each city increased.

The competition among Beijing, Shanghai and Guangzhou can also be measured by giving a closer look at the number of direct connections that each city established from 1990 to 2004. As shown in Table 6, Beijing exceeded Shanghai and Guangzhou in the number of direct connections with domestic cities during the entire study period. This indicated that Beijing had easier access to China's domestic airline network than Shanghai and Guangzhou did, which greatly enhanced Beijing's overall accessibility because domestic connections were taken into account in calculating a city's accessibility. Besides, certain foreign cities, such as Islamabad, Alma Ata, and Novosibirsk could only be reached through Urumqi, so Beijing's accessibility increased as a result of its exclusive connection with Urumqi as well as other exclusive routes (Beijing-Nanning and Beijing-Dalian). Beijing also had the largest number of direct connections with overseas cities until 2000. Overall, Beijing exceeded Shanghai and Guangzhou in the number of total direct connections except for the last three years of the study period. This pattern, for the most part, is consistent with the trend revealed in Figure 9 that Beijing ranked first in nodal accessibility followed by Shanghai and Guangzhou. The inconsistency was observed in 2002 and 2003 when Beijing's accessibility exceeded Shanghai's even though Beijing had a smaller number of direct connections than Shanghai did. As shown in Table 6, Shanghai had the largest number of direct

connections in 2002 and 2003. Accordingly, Shanghai's accessibility would be the greatest among the three. In fact, a large number of cities (11 out of 41) with which Shanghai were directly connected were quite isolated such as Phnom Penh, Okinawa, Oita, and Jeju. These cities were not connected with any other city in the network except with Shanghai. Besides, the absence of direct connections between Shanghai and Guangzhou and between Shanghai and Urumqi greatly weakened Shanghai's accessibility in that Guangzhou was a major hub and Urumqi emerged as a regional hub in the network. Thus the overall accessibility of Shanghai was compromised.

The impacts of those significant events had on the major hubs are also examined. It appears that Shanghai derived more benefits from the airline consolidation than the other two hubs. As shown in Table 6, Shanghai enjoyed a large increase in the number of direct connections as compared with Beijing and Guangzhou since 2002. Other than that, no significant increase or decrease in nodal accessibility or in the number of direct connections was observed during the study period. Arguably, Shanghai will replace Beijing to become the most accessible hub in the foreseeable future, and Guangzhou's accessibility can be greatly enhanced by improving its weak connections with overseas and domestic cities. In general, the pattern of competition among the three major hub cities revealed in Figure 9 is consistent with the finding of Jin et al.'s (2004) study that China's international air transport center migrated toward Southeast China.

4.3 Regional Differences

There are 6 world macro regions designated by the United Nation, of which 5 regions established connections with China via Chinese airlines from 1990 to 2004: Africa, Asia, Europe, North America, and Oceania. The exception was Latin America with which no connection was ever established during the entire study period (see Table 7). According to the CAAC, the first

international flight between Latin America and China via Chinese airlines was launched on December 10, 2006. The route (Beijing-Madrid-Sao Paulo) was operated by Air China. A possible explanation for this long absence is the low level of air travel between China and Latin American countries. Table 8 shows the number of foreigner tourists by region. Data were compiled from National Bureau of Statistics of China (statistics from 1991 to 1994 are missing). As shown in Table 8, the number of tourists from Latin America was significantly smaller than from other regions. Low demand for overseas travel suppressed the development of air routes between China and Latin America which in turn further weakened the demand for air travel. Similarly, the number of tourists from Africa was also marginal, which could explain the suspension of airline service between Africa and China after 1994 (see Table 7). Actually, connections between China and Africa via Chinese airlines did not reemerge until 2006 when China Southern operated the route of Beijing-Dubai-Lagos on December 30, 2006 (CAAC, 2007). In contrast, the largest volume of tourists recorded was in Asia and accordingly air passenger volume within Asia was the highest among the six regions (see Table 9 and Figure 10). Europe was the second largest region in terms of number of tourists, followed by North America and Oceania. Consequently, the same ranking was observed in the air passenger sector (see Figure 11).

. As to the freight sector, freight volume within Asia greatly exceeded other regions (see Table 10 and Figure 12). Asia's top ranking can be explained from an economic perspective. According to China's foreign trade statistics (National Bureau of Statistics of China, 2005), China's major partners in international trade (imports plus exports), were the following countries/territories: Japan, the United States, the European Union, Hong Kong, ASEAN, South Korea, Taiwan, Australia, and Russia. Despite their relative rankings varied from time to time, trade volume within Asia has always been the largest. Table 11 records foreign trade volume by

Table 7. Flight distribution among world macro regions from 1990 to 2004

Year	Africa	Asia	Europe	Latin America	North America	Oceania
1990	64	5033	1414	0	601	104
1991	24	5714	1727	0	685	104
1992	145	7018	2270	0	671	104
1993	90	8846	2168	0	1111	50
1994	54	9931	1994	0	1074	106
1995	0	14218	2316	0	640	104
1996	0	17593	2679	0	1207	188
1997	0	20540	3606	0	1814	591
1998	0	24236	3934	0	2436	604
1999	0	27366	4005	0	2733	718
2000	0	29471	3741	0	2933	764
2001	0	36581	4369	0	2596	355
2002	0	48406	5104	0	2706	334
2003	0	44295	5629	0	3980	1288
2004	0	67690	7925	0	5526	2140

Table 8. Number of foreigner tourists by region (Unit: 10000 person-times)

Region \ Year	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Africa	1.17	4.08	4.72	4.91	5.43	5.21	6.56	7.32	9.85	10.42	17.34
Asia	91.52	338.26	406.51	428.17	400.06	499.27	610.15	686.42	864.38	726.50	1073.66
Europe	44.63	159.06	163.30	201.83	181.33	211.27	248.90	268.38	282.58	259.76	377.57
Latin America	2.36	5.37	7.62	7.66	7.46	7.59	8.29	7.45	9.71	8.01	13.25
Northern America	28.08	64.36	73.30	79.05	87.33	95.01	113.28	120.31	141.25	105.28	165.67
Oceania	6.35	15.85	17.34	19.35	22.48	24.38	28.18	30.97	35.37	30.01	45.21

Table 9. Passenger distribution among world macro regions from 1990 to 2004

Year	Africa	Asia	Europe	Latin America	North America	Oceania
1990	6140	739036	185735	0	136589	19858
1991	1458	982140	271835	0	171089	32745
1992	11067	1301384	371502	0	182630	35930
1993	5830	1467496	311140	0	248115	17005
1994	7116	1813920	306631	0	308932	34713
1995	0	2471479	448711	0	174868	37791
1996	0	3049063	517407	0	340663	62612
1997	0	3517388	657634	0	503162	155728
1998	0	3544882	726433	0	591292	163500
1999	0	4459405	821339	0	637060	203693
2000	0	4554397	822630	0	618313	245610
2001	0	5748273	800987	0	464103	107728
2002	0	6803563	981208	0	553632	112686
2003	0	5388242	885179	0	504613	331852
2004	0	8786063	1435139	0	821176	531642

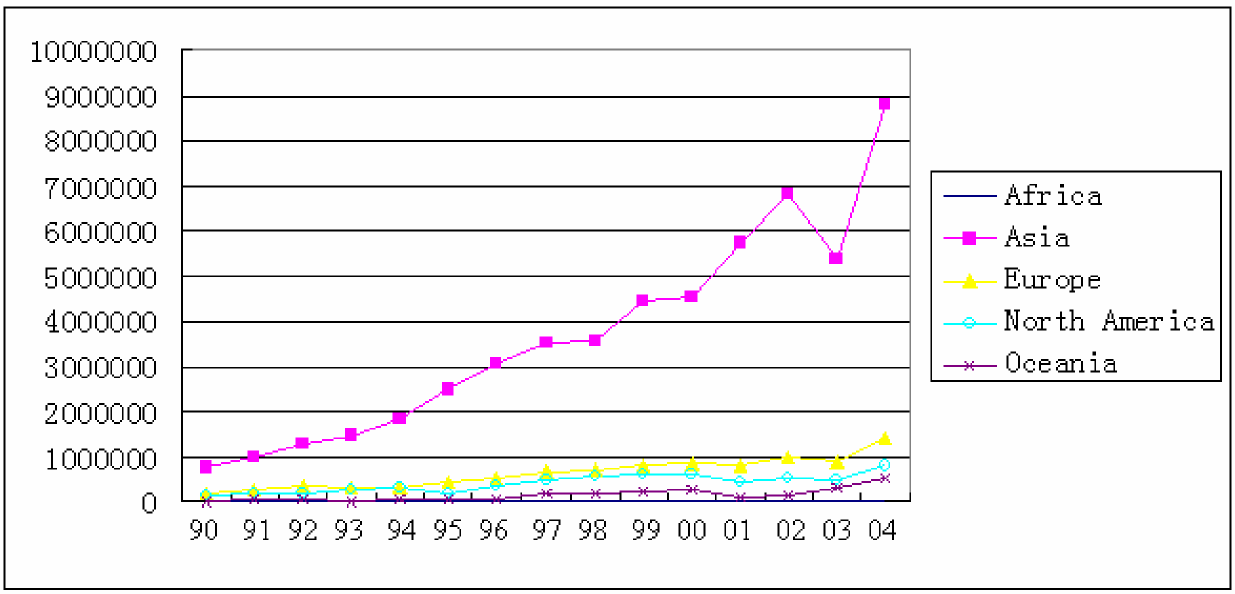

Figure 10. Passenger distribution among five world macro regions

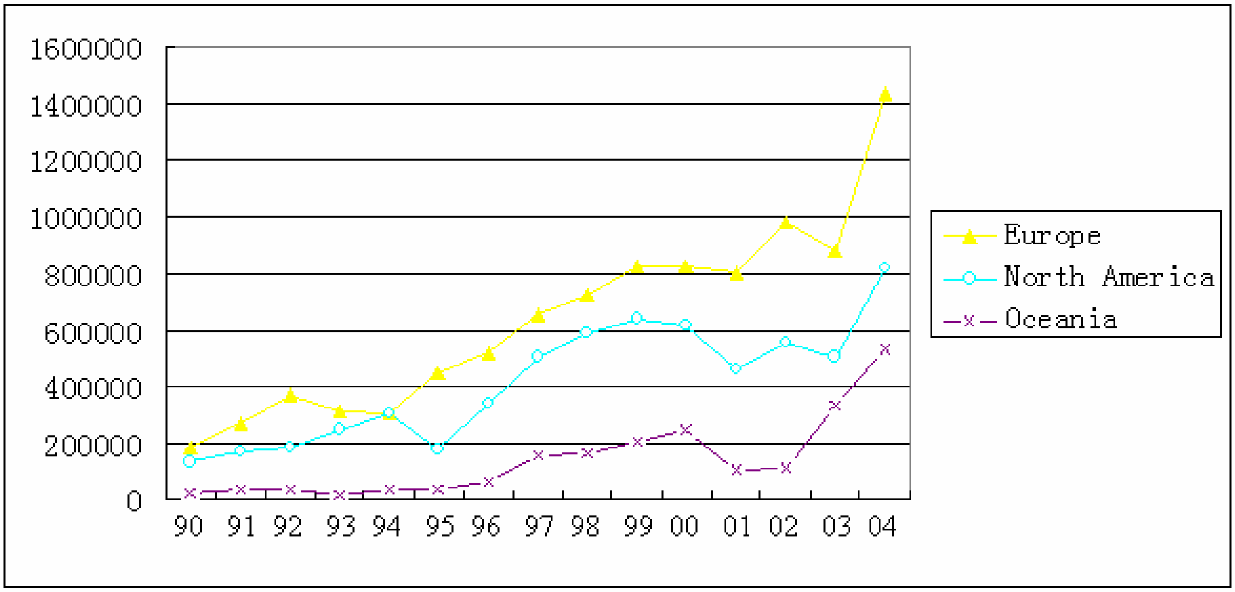

Figure 11. Passenger distribution among Europe, North America, and Oceania

Table 10. Freight distribution among world macro regions from 1990 to 2004 (Unit: ton)

Year	Africa	Asia	Europe	Latin America	North America	Oceania
1990	343	41431	16843	0	15031	1131
1991	111.9	52106	22620	0	17932.5	1387.8
1992	579.4	64236.5	31723.1	0	18754.2	1458.6
1993	380.6	82584.7	30737.7	0	37260.3	680
1994	279.6	87113.7	27100.8	0	28573.7	1527.9
1995	0	113099.9	38439.1	0	20300.6	1722.7
1996	0	129622.6	41632	0	39905.3	2504.9
1997	0	152404.2	61052	0	54611.6	7723.3
1998	0	149256	72102	0	52861	8496
1999	0	207640.2	96479.9	0	91004.8	10665.8
2000	0	225111.5	104707	0	109485.4	10885.9
2001	0	172801.6	95336.3	0	76026.2	3308.9
2002	0	197828.2	114452.1	0	83250.6	3614.6
2003	0	203075.1	153097.5	0	185969.6	8868.7
2004	0	279437.7	199209.1	0	288974.4	12017.1

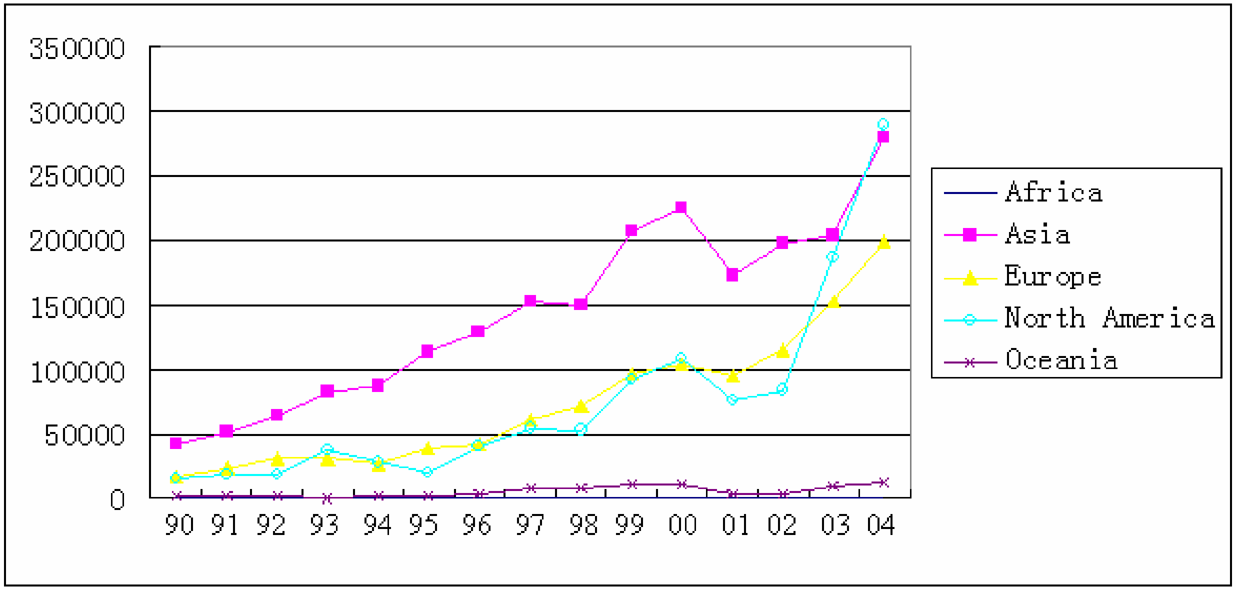

Figure 12. Freight distribution among five world macro regions

Table 11. Volume of imports and exports by region (Unit: USD 10000)

Region \ Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Africa	264263	392122	403082	567300	553587	649013	1059708	1079952	1238836	1854184	2945928
Asia	14221565	17004950	17468084	19736260	18523504	20424334	27365011	28813909	36303033	49547835	66490646.8
Europe	4378863	5079024	5151412	5474428	5973511	6812664	8626564	9764102	11024571	15786463	21138553
Latin America	470224	611416	672548	837651	831215	826186	1259549	1493889	1782440	2680681	4000062
North America	3860218	4504444	4702729	5293195	5930284	6620376	8139310	8788218	10514619	13639397	18526063
Oceania	463946	492365	589779	607165	580150	730387	978757	1036728	1212288	1588998	2350431

region. Data were also compiled from National Bureau of Statistics of China (statistics from 1990 to 1993 are missing). As shown in Table 11, Asia greatly overtook other regions in trade volume. Europe came in second with a much smaller amount followed by North America, and trade volume with Oceania, Latin America and Africa was extremely low as compared with Asia, Europe or North America. While the proportions are not necessarily replicated for air freight, air freight, in the main, should follow the pattern. In fact, similar ranking did exist among different world regions with respect to air freight traffic (see Table 10 and Figure 12): the largest freight volume was recorded in Asia from 1990 to 2003; Europe ranked second and occasionally was overtaken by North America; North America, for the most part, placed third notwithstanding it exceeded Asia in 2004; Oceania ranked 4^{th} during the entire study period; and Latin America and Africa did not come into picture because of the absence of airline links as mentioned previously. Variation in the relative ranking among Asia, Europe and North America was probably due to the freighter flights between China and North America. According to the yearbook, China started to operate freighter flights connecting North America since 1996. The dedicated freighter routes greatly increased the capacity for freight transportation between North America and China. But there were no such specialized connections between China and Europe or within Asia. The variation could also arise from the fragmented data in that the recorded freight volumes were those carried by Chinese airlines, foreign carriers' market share were not included in this study.

The impacts of various economic, social, and political events and circumstances on international air travel were also examined. It was found that several major variations were associated with those incidents. As shown in Figure 10, Asia experienced a big decrease in passenger volume in 2003, Europe and North America suffered a great loss in passenger traffic in the same year (see Figure 11). The decrease was consistent with the fall in tourists volume in 2003

(see Table 8). The outbreak of Severe Acute Respiratory Syndrome (SARS) in China in 2003 was likely responsible for the decline. The highly contagious disease caused great damage to China's international air transport market. Obviously, passenger sector was the first to be affected, whereas freight traffic was not interrupted by the dreadful virus (see Figure 12), which was reasonable because the disease spreads upon personal contact. However, passenger traffic between Oceania and China significantly increased in 2003 (see Figure 11), which was very surprising considering the high lethality of the disease. This huge increase may have something to do with the large number of scheduled flights in 2003. As shown in Table 7, there were 334 flights connecting China and Oceania in 2002 and the number soared to 1288 in 2003. More flights indicated a stronger demand for air travel. Consequently, passenger traffic recorded a higher volume. Another significant decrease occurred in 2001, and it was likely associated with the terrorist attacks on September 11, 2001. As discussed in Chapter 2, the horrifying attacks had significant adverse impacts on the United States and the rest of the world. As far as airline business is concerned, a major decrease in freight traffic within Asia was observed, and passenger and freight traffic with North America, Europe, and Oceania significantly dropped in 2001. However, each region went through the economic aftermath and enjoyed reasonable increases in both passenger and freight traffic in 2002 (see Figures 10, 11 and 12). Asia and North America experienced another fall in freight traffic in 1998 (see Figure 12). The decline was probably due to the 1997 Asian Currency Crisis. Airlines suffered from a big loss in the high-yield international freight market. Total international airline capacity fell in the Southeast Asian region as a result of the broadening economic crisis in 1998 (Bowen, 2000). In fact, the adverse impacts of the crisis were also found in foreign trade. Asia reported a decline in foreign trade volume in 1998 (see Table 11). Additionally, North America experienced a major decline in passenger traffic as well as in freight traffic in 1995

(see Figures 11 and 12). The decline was likely caused by the cancellation of a large number of flights connecting China and North America in 1995. As shown in Table 7, there were 1074 scheduled flights in 1994 and the number plunged to 640 in 1995. The reason for cutting down on flights was unclear, but the impact was obviously unfavorable in that both passenger and freight traffic reported losses in that year. Basically, the pattern of the development of freight traffic revealed in Figure 12 is consistent with the findings by Jiang et al. (2003) that despite two drops in the years 1998 and 2001, air cargo throughout enjoyed a rapid growth.

In conclusion, the distribution of air passengers and freight displayed a great disparity among different world regions. The largest air traffic flows resided in Asia. The second largest traffic volume was between Europe and China. North America came in third, but North America had a great capacity for freight transportation because of the dedicated freighter flights connecting North America and China. Oceania placed fourth due to a relatively small amount of passenger and freight traffic. Air traffic volume recorded for Latin America and Africa was insignificant in that connection with Latin America was absent during the entire study period and links between Africa and China were suspended after 1994. Hopefully, this situation will improve with the recently launched routes of Beijing-Madrid-Sao Paulo and Beijing-Dubai-Lagos.

Chapter 5: Conclusion

China started its airline reforms in the early 1980s, which can be seen as an integral part of the much broader economic reforms launched in 1978 by the Chinese government. Since then, China's economy has experienced significant development and its aviation has been the fastest growing mode in the transport sector. The rapid growth of China's economy, the size of its population, and the sweeping tide of globalization, all lead to China's increasingly major role in shaping the pattern of airline networks with the rest of the world. In light of these great changes and challenges, this research was conducted to study the development of international air transport network served by Chinese airlines from 1990 to 2004.

The research first examined the overall growth of the network by measuring network connectivity level. It was found that there were a few major variations in network connectivity over the study period. The fluctuation was largely caused by provincial capitals, secondary cities and tourist cities' entry into or exit from the network. As the epitome of state intervention, the airline consolidation in 2002 greatly enhanced network connectivity and is believed to continue to do so. More cities (domestic and overseas) entered the network and the number of linkages greatly increased. Arguably, the trend of China's expanding international airline network is towards a system with a higher level of connectivity and greater coverage.

The research then examined nodal development of the three major hub cities by measuring their nodal accessibility level. It was found that all three cities had experienced low to moderate increases in accessibility. Specifically, Shanghai had a relatively large increase in accessibility while increases in Beijing and Guangzhou were minor. The study also evaluated competitions among the three major hubs by comparing their nodal accessibility. In general, Beijing maintained as the most accessible hub during the study period, Shanghai placed second yet was catching up

very fast in recent years. It actually overtook Beijing in accessibility in 2004. Arguably, Shanghai will develop into the most accessible hub in the network. Guangzhou was the least accessible hub over the study period, but its accessibility can be greatly enhanced by improving its weak connections with overseas and domestic cities.

In addition, this paper assessed regional differences denoted by air transport by examining the distribution of air traffic among different world regions. It was found that the distribution of air passengers and freight displayed a great disparity among different world regions. The largest air traffic flows resided in Asia. Europe came in second followed by North America. However, increasing competition between North America and Asia in the freight sector was observed since 2003. Arguably, North America will replace Asia to become the dominant player in the freight market because of the dedicated freighter flights between North America and China. Oceania placed fourth due to a relatively small amount of passenger and freight traffic. Links with Africa were suspended after 1994 probably because of the weak demand for air travel between China and Africa countries. Connection with Latin America was absent during the entire study period. In the meantime, the study identified several major declines in air traffic during the study period. The declines were associated with the 1997 Asian Currency Crisis, the terrorist attacks on September 11, 2001, and the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003.

Lastly, this paper would like to address competitions from foreign airlines on China's international routes. On one hand, the airline deregulation, "open skies" initiative, and merger and strategic alliance offer great opportunities for foreign airline companies to penetrate the market. On the other hand, restrictive bilaterals, regulatory control over pricing, and safety concerns restrain air transport network from expanding. Foreign airlines, while they pursue joint ventures with domestic companies under the new regulations, continue to assault the marketplace by

establishing new international flight routes to and from China. Last Spring, a nonstop flight connecting Beijing and Washington D.C. was launched by United Airlines. Connecting two of the world's most important cities for the first time was a historic occasion. The new route was expected to be favored by executives and government officials and was estimated to generate more than $200 million a year (China Daily, 2007). In the freight market, express shipment companies such as FedEx, UPS, and DHL have already built up large-capacity logistics processing centers in Shanghai and Guangzhou. Similar actions have been taken by other foreign competitors for the highly profitable international air transport market in China. As Debbage (1994) suggested, the most competitive air carriers will emerge in countries that most successfully manage the transition from the restrictive bilateral system to “open skies” multilateralism. The regulatory regime will continue to change to reflect these trends. These trends, and the aviation system arising from them, will contribute to bringing China and other nations closer together. China’s airline industry that is currently in the course of this transition has a long way to go.

References

Arfken, G. 1985. Spherical Polar Coordinates. In: Mathematical Methods for Physicists. Academic Press, Orlando, FL.

Bailey, E. E., Graham, D. R., Kaplan, D. P., 1985. Deregulating the Airlines. MIT Press, Cambridge, MA.

Berge, C., 1962. The theory of graphs and its applications. Wiley, New York, NY.

Black, W. R., 1992. Network autocorrelation in transportation network and flow systems. Geographical Analysis 24, 207-222.

Black, W. R., 2003. Transportation: a geographical analysis. Guilford Press, New York, NY.

Bowen, J. T., 2000. Airline hubs in Southeast Asia: national economic development and nodal accessibility. Journal of Transport Geography 8, 25-41.

Bowen, J. T., 2002. Network change, deregulation, and access in the global airline industry. Economic Geography 78 (4), 425-440.

Bowen, J. T., Leinbach, T. R., 1995. The state and liberalization: the airline industry in the East Asian NICs. Annals of the Association of American Geographers 85 (3), 468-491.

Bowen, J. T., Leinbach, T. R., Mabazza, D., 2002. Air cargo services, the state and industrialization strategies in the Philippines: the redevelopment of Subic Bay. Regional Studies 36 (5), 451-67.

Busacker, R., Saaty, T., 1965. Finite graphs and networks. McGraw-Hill, New York, NY.

China Daily, 2007. Beijing-Washington non-stop flights start. Available online at http://www.chinadaily.com.cn.

Chou, Y.-H., 1993. A method for measuring the spatial concentration of airline travel demand. Transportation Research B: Methodological 27(4), 267-273.

Civil Aviation Administration of China, 2005. China's civil airports master plan (in Chinese). Available online at www.caac.gov.cn.

Civil Aviation Administration of China, 2005. China's civil aviation statistics 2004 (in Chinese). Available online at www.caac.gov.cn.

Civil Aviation Resource Net of China, 2005. The history of China's civil aviation industry (in Chinese). Available online at www.carnoc.com.

Coolidge, J., 1952. The unsatisfactory story of curvature. The American Mathematical Monthly,

59 (6), 375-379.

Debbage, K., 1993. U.S. airport market concentration and deconcentration. Transportation Quarterly 47, 115-136.

Debbage, K., 1994. The international airline industry: globalization, regulation and strategic alliances. Journal of Transport Geography 2 (3), 190–203.

Dresner, M., Tretheway, M. W., 1992. Modeling and testing the effect of market structure on price. Journal of Transport Economics and Policy 26 (2), 171-184.

Efendioglu, A. M., Murray, W. L., 2003. Changes and challenges of the airline industry in China. Seventh International Conference on Global Business and Economic Development, 8-11 January, Bangkok, Thailand.

European Commission, 2005. Market integration of internal market. Available online at http://ec.europa.eu.

French, T., 1997. Global trends in airline alliances. Travel and Tourism Analyst 4, 81-101.

Garrison, W., Marble, D., 1962. The structure of transportation networks. U.S. Army Transportation Research Command, Fort Eustis, VA.

Garrison, W., Marble, D., 1965. A prolegomenon to the forecasting of transportation development. Transportation Center at Northwestern University, Evanston, IL.

Goetz, A. R., 1995. Transportation geography specialty group: international air transportation: commemorating the 50th anniversary of the 1944 Chicago Convention, 18 March, the Association of American Geographers Annual Meeting, Chicago, IL. Journal of Transport Geography Volume 3 (3), 229-230.

Goetz, A. R., 2002. Deregulation, competition and antitrust implications in the US airline industry. Journal of Transport Geography 10, 1-18.

Goetz, A. R., 2006. Transport geography: reflecting on a subdiscipline and identifying future research trajectories. The insularity issue in transport geography. Journal of Transport Geography 14, 230–231.

Goetz, A. R., Dempsey, P. S., 1989. Airline deregulation ten years after: something foul in the air. Journal of Air Law and Commerce 54, 927-963.

Goetz, A. R., Graham, B., 2004. Air transport globalization, liberalization and sustainability: post-2001 policy dynamics in the United States and Europe. Journal of Transport Geography 12, 265-276.

Graham, B. J., 1998. Liberalization, regional economic development and the geography of

demand for air transport in the European Union. Journal of Transport Geography 6, 97-104.

Graham, B. J., 1995. Geography and air transport. Wiley, Chichester, UK.

Granitsas, A., 2002. Caught in a down draught. Far Eastern Economic Review 164, 96-98.

Guangzhou Chronicle, 2005. The history of China civil aviation industry (in Chinese). Available online at www.gzsdfz.org.cn.

Haggett, P., 2001. Geography: a modern synthesis, 4th ed. Prentice Hall, New York, NY.

Hitchcock, F. L., 1941. The distribution of a product from several sources to numerous localities. Journal of Mathematical Physics 20, 224-230.

Hooper, P., 1998. Airline competition and deregulation in developed and developing country contexts-Australia and India. Journal of Transport Geography 6, 105-116.

Horan, H., 2002. What is the future of the European flag-carrier? Aviation Strategy, 2-15.

Horner, M. W., O'Kelly, M. E., 2001. Embedding economics of scale concepts for hub network design. Journal of Transport Geography 9, 255-265.

Hoyle, B. S., Knowles, R. D., 1998. Modern transport geography. John Wiley & Sons, Chichester, UK.

Hui, G. W. L., Hui, Y. V., Zhang, A., 2004. Analyzing China's air cargo flows and data. Journal of Air Transport Management 10, 125-135.

International Air Transportation Association (IATA), 2002. World air transport statistics, 46th ed. IATA, Montreal, Canada.

International Civil Aviation Organization (ICAO), 2003. Press release PIO 12/2003. Available online at www.icao.org.

Ivy, R. L., 1993. Variations in hub service in the US domestic air transportation network. Journal of Transport Geography 1, 211-218.

Jiang, H., Ren, L., Hansman, R., 2003. Market and infrastructure analysis of future air cargo demand in China. AIAA 3rd Annual Aviation Technology, Integration, and Operations (ATIO) Technical Forum, 17-19 November, Denver, CO.

Jin, F., 2001. A study on network of domestic air passenger flow in China (in Chinese). Geographic Research 20, 31-39.

Jin, F., Sun, W., Shaw, S.-L., 2005. China's airlines reorganization and its effects on network

structure (in Chinese). Progress in Geography 24(2), 59-68.

Jin, F., Wang, F., Liu, Y., 2004. Geographic patterns of air passenger transport in China 1980-1998: imprints of economic growth, regional inequality, and network development. The professional Geographer 56 (4), 471-487.

Kanafani, A., Ghobrial, A. A., 1985. Airline hubbing-some implications for airport economics. Transportation Research A: General 19, 15-27.

Kansky, K., 1963. Structure of transportation networks: relationships between network geometry and regional characteristics. University of Chicago, Chicago, IL

Kern, W., Bland, J., 1948. Solid mensuration with proofs, 2nd ed. Wiley, New York, NY.

Li, M., 1998. Air transport in ASEAN: recent developments and implications. Journal of Air Transport Management 4 (3), 135–144.

Lopuszynski, A., 1986. Perspectives on airline hubbing in the US. Government Printing Office, United States Department of Transportation, Federal Aviation Administration, Washington, DC.

Lu, F., Shaw, S.-L., Chen, J., Zhou, C., 2005. Spatial patterns of domestic passenger transport and competitive situations of Chinese civil airlines (in Chinese). Geo-Information Science 7(4), 43-49.

Marianov V., Serra, D., ReVelle, C., 1999. Theory and methodology: location of hubs in a competitive environment. European Journal of Operational Research 114, 363-371.

Marín, P. L., 1995. Competition in European aviation: pricing policy and market structure. The Journal of Industrial Economics 43 (2), 141-159.

Matthiessen, C. W., 2004. International air traffic in the Baltic Sea area-hub-gateway status and prospects-Copenhagen in focus. Journal of Transport Geography 12, 197-206.

Miller, H. J., Shaw, S.-L., 2001. Geographic information systems for transportation: principles and applications. Oxford University Press, New York, NY.

National Bureau of Statistics of China, 2005. Statistics of national economic and social development 1990-2004 (in Chinese). Available online at http://www.stats.gov.cn.

O'Connor, K., 2003. Global air travel: toward concentration or dispersal? Journal of Transport Geography 11, 83-92.

O'Connor, K., 1995. Airport development in Southeast Asia. Journal of Transport Geography 3, 269-279.

O'Connor, K., Scott, A., 1992. Airline services and metropolitan areas in the Asia-Pacific region 1970-1990. Review of Urban and Regional Development Studies 4, 240-253.

O'Kelly, M. E., Miller, H. J., 1994. The hub network design problem: a review and synthesis. Journal of Transport Geography 2, 31-40.

O'Sullivan, P., 1980. Transport policy: geographic, economic and planning aspects. Barnes & Noble Books, Totowa, NJ.

Oum, T. H., 1998. Overview of regulatory changes in international air transport and Asian strategies towards the US open skies initiatives. Journal of Air Transport Management 4 (3), 127–134.

Pearson, A., 1997. North Atlantic shifting sands. Airline Business 13(8), 46–51.

Pinkham, R., 2001. Playing for position. Airline Business 17 (7), 40–41.

Pirie, G., 2006. 'Africanisation' of South Africa's international air links, 1994-2003. Journal of Transport Geography 14, 3-14.

Pustay, M. W., 1993. Towards a global airline industry: prospects and impediments. Logistics and Transportation Review 23, 103-128.

Rimmer, P. J., 2000. Effects of the Asian Crisis on the geography of Southeast Asia's air traffic. Journal of Transport Geography 8(2), 83-97.

Robert, R., 2000. The 1995-1996 Taiwan Strait Confrontation: coercion, credibility, and use of force. International Security 25 (2), 87-123.

Rodrigue, J.-P., Comtois, C., Slack, B., 2006. The geography of transport system. Routledge, New York, NY

Scott, D. M., 2006. Embracing activity analysis in transport geography: merits, challenges and research frontiers. Journal of Transport Geography 14 (5), 389-392.

Shaw, S.-L., 1993. Hub structures of major US passenger airlines. Journal of Transport Geography 1 (1), 47-58.

Shimbel, A., 1953. Structural parameters of communication networks. Bulletin of Mathematical Biophysics 15, 501-507.

Shipping Times (Singapore), 1999. Philippines seeks more flights to Thailand for PAL, 15 June, p. 14.

Sinnott, R., 1984. Virtues of the Haversine. Sky and Telescope 68 (2), 159.

Taaffe, E. J., Gauthier, H. L., O'Kelly, M. E., 1996. Geography of transportation. Prentice-Hall, Englewood Cliffs, NJ.

Tasker, R., 1977. Tax clouds in open sky. Far Eastern Economic Review 16, 55.

Tretheway, M. W., 1991. European air transport in the 1990s: deregulating the internal market and changing relationships with the rest of the world. Working paper 91-TRA-003, UBC Transportation and Logistics, Faculty of Commerce and Business Administration, University of British Columbia, Vancouver, Canada.

United Nations, 2005. World Macro regions and components. Available online at www.un.org/depts/dhl/maplib/worldregions.htm.

US Government Printing Office, 1980. Airline Deregulation Act 1978, Public Law 95-504. United States statutes at large 92, 1705-1754.

Ullman, E. L., 1954b. Transportation geography. In: James, P., Jones, C. (Eds.), American geography: inventory and prospect. Syracuse University Press, Syracuse, NY.

Voorhees, A. M., 1955. A general theory of traffic movement. Proceedings of the Institute of Traffic Engineers, 46-56.

Vowles, T. M., 2000. The geographic effects of US airline alliances. Journal of Transport Geography 8, 277-285.

Wang, Y., 1989. Civil aviation in modern China (in Chinese). China Social Science Press, Beijing, China.

Wheatcroft, S., 1990. Towards transnational airlines. Tourism Management 11, 353-358.

Wilson, A. G., 1967. Statistical theory of spatial distribution models. Transportation Research 1, 253-269.

Wilson, A. G., 1974. Urban and regional models in geography and planning. Wiley, London.

Yearbook House of China Transportation and Communication, 1990-2004. China transportation and communication yearbook 1990-2004. Yearbook House of China Transportation and Communication Publications, Beijing, China.

Youssef, W., Hansen, M., 1994. Consequences of strategic alliances between international airlines: the case of Swissair and SAS. Transportation Research A 28A, 415-431.

Zhang, A., 1997. Industrial reform and air transport development in China. Journal of Air Transport Management 4, 155-164.

Appendix

Visual Basic codes for Great circle path

```
Const Pi = 3.1415926535
Const NUM = 100
Private Type myPOINT
        x As Double
        y As Double
End Type
Private pList() As myPOINT
Private plLists() As myPOINT
Private nLines As Integer

Private Function Asin(ByVal x As Double) As Double
If x = 1 Then
    Asin = Pi / 2
ElseIf x = -1 Then
    Asin = -Pi / 2
Else
    Asin = Atn(x / Sqr(-x * x + 1))
End If
End Function

Private Function DegToRad(ByVal x As Double) As Double
DegToRad = x * Pi / 180
End Function

Private Function RadToDeg(ByVal x As Double) As Double
RadToDeg = x * 180 / Pi
End Function

Private Function GreatCircleDistance(p1 As myPOINT, p2 As myPOINT) As Double
lambda1 = DegToRad(p1.x)
phi1 = DegToRad(p1.y)
lambda2 = DegToRad(p2.x)
phi2 = DegToRad(p2.y)
xdiff2 = Sin((lambda2 - lambda1) / 2#)
ydiff2 = Sin((phi2 - phi1) / 2#)
tmp = Sqr(ydiff2 * ydiff2 + Cos(phi1) * Cos(phi2) * xdiff2 * xdiff2)
gcd = Asin(tmp) * 2
GreatCircleDistance = RadToDeg(gcd)
End Function

Private Function GreatCirclePath(ByVal i As Integer) As Double
```

```
Dim nCount As Integer
nCount = UBound(pList) - LBound(pList) + 1
numLines = nCount / 2
ReDim plLists(0 To NUM - 1) As myPOINT
Dim p1 As myPOINT
Dim p2 As myPOINT
  ReDim lineList(0 To NUM - 1) As myPOINT
  p1 = pList(2 * i)
  p2 = pList(2 * i + 1)
  lon1 = p1.x
  lon0 = lon1
  lat1 = p1.y
  lon2 = p2.x
  lat2 = p2.y
  c = GreatCircleDistance(p1, p2)   'c is the number of degrees between points p1 and p2
  If (lon1 < 0#) Then lon1 = lon1 + 360
  If (lon2 < 0#) Then lon2 = lon2 + 360
  xdiff = Abs(lon2 - lon1)
  If (xdiff > 180) Then
    xdiff = 360 - xdiff
    If (lon1 < lon2) Then
      reverse = 1
      Start = lon2
      lon1 = 0
      lon2 = xdiff
      tmp = lat1
      lat1 = lat2
      lat2 = tmp
    Else
      reverse = 0
      Start = lon1
      lon1 = 0
      lon2 = xdiff
    End If
  Else
    If (lon1 > lon2) Then
      reverse = 1
      Start = lon2
      lon1 = 0
      lon2 = xdiff
      tmp = lat1
      lat1 = lat2
      lat2 = tmp
    Else
      reverse = 0
      Start = lon1
```

```
        lon1 = 0
        lon2 = xdiff
      End If
    End If
    delC = DegToRad(c) / (NUM - 1)
    lambda1 = DegToRad(lon1)
    phi1 = DegToRad(lat1)
    lambda2 = DegToRad(lon2)
    phi2 = DegToRad(lat2)
    xdiff = lambda2 - lambda1
    azTmp = (Cos(phi2) * Sin(xdiff)) / ((Cos(phi1) * Sin(phi2)) - (Sin(phi1) * Cos(phi2) *
Cos(xdiff)))
    az = Asin(azTmp / Sqr(1 + (azTmp * azTmp)))
    If (azTmp < 0#) Then az = az + Pi
    For j = 0 To NUM - 1
      delCj = delC * j
      phiTmp = ((Sin(phi1) * Cos(delCj)) + (Cos(phi1) * Sin(delCj) * Cos(az)))
      phi = Asin(phiTmp)
      lambdaTmp = ((Sin(delCj) * Sin(az)) / ((Cos(phi1) * Cos(delCj)) - (Sin(phi1) * Sin(delCj) *
Cos(az))))
      lambda = Asin(lambdaTmp / Sqr(1 + (lambdaTmp * lambdaTmp)))
      If (lambdaTmp < 0#) Then lambda = lambda + Pi
      lon = RadToDeg(lambda)
      lat = RadToDeg(phi)
      lon = lon + Start
      If (lon > 360) Then lon = lon - 360
      If (lon > 180) Then lon = lon - 360
      Dim p As myPOINT
      p.x = lon
      p.y = lat
      lineList(j) = p
    Next j

    If (reverse = 1) Then
      ReDim rList(0 To NUM - 1) As myPOINT
      For k = 0 To NUM - 1
        rList(k) = lineList(NUM - 1 - k)
      Next k
      For k = 0 To NUM - 1
        lineList(k) = rList(k)
      Next k
    End If

    nSplit = 0
    lon0 = lineList(0).x
    For k = 1 To NUM - 1
```

```
    lon = lineList(k).x
    If (((lon * lon0) > 0) Or ((lon * lon0 < 0) And (Abs(lon - lon0) < 180))) Then
    Else
      nSplit = nSplit + 1
    End If
    lon0 = lon
  Next k

  If (nSplit > 1) Then
   ' MsgBox ("Split = " + Split.AsString)
  End If
  If (nSplit = 1) Then
    ReDim pList1(0 To NUM - 1) As myPOINT
    ReDim pList2(0 To NUM - 1) As myPOINT
    p = lineList(0)
    lon0 = p.x
    pList1(0) = p
    Change = 0
    M = 1
    n = 0
    For k = 1 To NUM - 1
      p = lineList(k)
      lon = p.x
      If ((Change = 0) And (((lon * lon0) > 0) Or ((lon * lon0 < 0) And (Abs(lon - lon0) < 180))))
Then
        pList1(M) = p
        M = M + 1
      Else
        Change = 1
        pList2(n) = p
        n = n + 1
      End If
      lon0 = lon
    Next k
    For k = 0 To M - 1
     plLists(k) = pList1(k)
    Next k
    For k = 0 To n - 1
     plLists(M + k) = pList2(k)
    Next k
  Else
    For k = 0 To NUM - 1
     plLists(k) = lineList(k)
    Next k
  End If
GreatCirclePath = 0
```

```
End Function

Private Sub LoadFile_Click()
Dim newline As String
Dim org_x(0 To 500) As Double
Dim org_y(0 To 500) As Double
Dim dest_x(0 To 500) As Double
Dim dest_y(0 To 500) As Double
nLines = 0
Open "C:\Documents and Settings\Xumei\Desktop\Airline Networks\Shape File\1990.txt" For
Input As #1
Line Input #1, newline
Do While Not EOF(1)
    Line Input #1, newline
    lineArray = Split(newline, vbTab)
    org_x(nLines) = lineArray(1)
    org_y(nLines) = lineArray(2)
    dest_x(nLines) = lineArray(4)
    dest_y(nLines) = lineArray(5)
    nLines = nLines + 1
Loop
Close #1
ReDim pList(0 To 2 * nLines - 1) As myPOINT
For i = 0 To nLines - 1
    pList(2 * i).x = org_x(i)
    pList(2 * i).y = org_y(i)
    pList(2 * i + 1).x = dest_x(i)
    pList(2 * i + 1).y = dest_y(i)
Next i
End Sub

Private Sub Solve_Click()
Dim pmap As IMap
Dim pmxdoc As IMxDocument
Set pmxdoc = ThisDocument
Set pmap = pmxdoc.FocusMap
Dim plinelayer As IGeoFeatureLayer
Set plinelayer = pmap.Layer(0)

Dim pline(0 To 100 - 1) As ILine
Dim pP(0 To 100) As IPoint
For j = 0 To nLines - 1
   GreatCirclePath j
For i = 0 To 100 - 1
Set pP(i) = New Point
 pP(i).PutCoords plLists(i).x, plLists(i).y
```

```
Next i

Dim pSegCollection0 As ISegmentCollection
Dim pSegCollection1 As ISegmentCollection
Set pSegCollection0 = New esriGeometry.Path
Set pSegCollection1 = New esriGeometry.Path

Dim found As Boolean
found = False
For i = 0 To 100 - 2
If Not found Then
   If pP(i).x * pP(i + 1).x >= 0 Then
      Set pline(i) = New Line
      pline(i).PutCoords pP(i), pP(i + 1)
      pSegCollection0.AddSegment pline(i)
   Else
      found = True
   End If
Else
   Set pline(i) = New Line
   pline(i).PutCoords pP(i), pP(i + 1)
   pSegCollection1.AddSegment pline(i)
End If
Next i

Dim pPolyline As IPolyline 'IGeometryCollection
Set pPolyline = New Polyline
Dim pGeoColl As IGeometryCollection
Set pGeoColl = pPolyline
pGeoColl.AddGeometry pSegCollection0
If found Then
   pGeoColl.AddGeometry pSegCollection1
End If

Dim plclass As IFeatureClass
Set plclass = plinelayer.FeatureClass
Dim pyline As IFeature
Set pyline = plclass.CreateFeature
Set pyline.Shape = pPolyline
pyline.Store
Next
MsgBox ("Finished")
End Sub
```

Vita

Xumei Liu was born on January 20, 1982, in a little town of Tianmen, in the province of Hubei, China. She went to college when she was 17. She spent four years in college and obtained her bachelor of engineering degree in June 2003. She loves traveling and exotic food. She, then, decided to pursue graduate study in the United States. Luckily, she passed the hideous GRE and TOEFL tests and got admitted into the Department of Geography at the University of Tennessee, Knoxville.

She arrived in Knoxville on August 10, 2005. There, she enjoyed a nice and quiet southern style of living, made many good friends, and learned the joys and pains of higher education. As she now leaves with the graduating class of August 2008, she hopes her work here has been outstanding, and that her 3 years of higher education serves to be well worth the effort.